

# On the Empirical Determinants of Nominal Exchange Rates

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## Abstract

This paper documents two facts about the behavior of floating exchange rates in countries where monetary policy follows a Taylor-type rule. First, the current real exchange rate is highly correlated with future changes in the nominal exchange rate at horizons greater than two years. This correlation is stronger the longer is the horizon. Second, for most countries, the real exchange rate is virtually uncorrelated with future inflation rates both in the short and in the long run. We develop a class of models that can account for these observations. Our preferred model is also consistent with other key observations about the volatility and persistence of real exchange rates, as well as the fact that standard tests of uncovered interest rate parity reject that hypothesis.

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\*The views expressed here are those of the authors and do not necessarily reflect the view of the Board of Governors, the FOMC, or anyone else associated with the Federal Reserve System. We thank Oreste Tristani for his comments and Martin Bodenstein for helpful discussions.

# 1 Introduction

This paper examines the behavior of floating exchange rates in countries where monetary policy follows a Taylor-type rule. We document two facts. First, the current real exchange rate ( $REER$ ) is highly correlated with future changes in the nominal exchange rate ( $NER$ ) at horizons greater than two years. This correlation is stronger the longer is the horizon. For most of the countries in our sample, the current  $REER$  alone explains more than 50 percent of the variance of changes in nominal exchange rates at horizons greater than four years. Second, for most countries, the  $REER$  is virtually uncorrelated with future inflation rates at all horizons. Taken together, these facts imply that the  $REER$  adjusts in the medium and long-run overwhelmingly through changes in *nominal* exchange rates, not through differential inflation rates. When a country's consumption basket is relatively expensive, its  $NER$  eventually depreciates by enough to move the  $REER$  back to its long-run level.

We redo our analysis for China which is on a quasi-fixed exchange rate regime versus the U.S. dollar, Hong Kong which has a fixed exchange rate versus the U.S. dollar, and the Euro area countries which have fixed exchange rates with each other. In all these cases, the current  $REER$  is highly correlated with future relative inflation rates. In contrast to the flexible exchange rate countries, the  $REER$  adjusts overwhelmingly through predictable inflation differentials.

We show that our first fact about the relationship between the current  $REER$  and future changes in the  $NER$  emerges naturally in a wide class of models that have two features: home bias in consumption and a Taylor rule guiding monetary policy. This result holds regardless of whether or not we allow for nominal rigidities. We make these arguments using a sequence of models to develop intuition about the key mechanisms underlying our explanations of the facts. We then study a medium-size DSGE model to assess the quantitative plausibility of the proposed mechanisms. We argue that this model can account for the relationship between the current  $REER$  and future changes in inflation and the  $NER$ .

A key question is whether the model is consistent with other features of the data that have been stressed in the open-economy literature. It is well known that, under flexible exchange rates, real and nominal exchange rates commove closely in the short run (Mussa (1986)). This property, along with the fact that real exchange rates ( $REER$ ) are highly inertial (Rogoff (1996)), constitute bedrock observations which any plausible open-economy model must be consistent with. We show that our medium-size DSGE model is in fact consistent with these observations.

We begin our theoretical analysis with a simple flexible-price model where labor is the only factor in the production of intermediate goods. The intuition for why this simple model accounts for our empirical findings is as follows. Consider a persistent fall in domestic productivity or an increase in domestic government spending. Both shocks lead to a rise in the real cost of producing home goods that dissipates smoothly over time. Home bias means that there is a high weight of domestically-produced goods on the domestic consumer basket. So, after the shock, the price of the foreign consumption basket in units of the home consumption

basket falls, i.e. the *RER* falls. The Taylor rules followed by the central banks keep inflation relatively stable in the two countries. As a consequence, most of the adjustment in the *RER* occurs through changes in the *NER*. In the model, the foreign currency depreciates on impact and then slowly appreciates to a level consistent with the return of the *RER* to its steady state value. These predictable movements in the *NER* can occur in equilibrium because they are offset by the interest rate differential, i.e. uncovered interest parity (UIP) holds.

Under the scenario just described, the foreign currency depreciates on impact and then appreciates, in a way that is reminiscent of the overshooting phenomenon emphasized by Dornbusch (1976). The longer the horizon, the higher is the cumulative appreciation of the foreign currency. So in this simple model the current *RER* is highly correlated with the value of the *NER* at future horizons and this correlation is stronger the longer is the horizon.

Risk premia aside, UIP holds conditional on the realization of many types of shocks to the economy. After the realization of one of these shocks, the nominal interest differential between two countries is equal to the expected change in the nominal exchange rate. But there is another class of shocks, namely shocks to the demand for bonds, for which UIP does not hold. So, when the variance of these shocks is sufficiently large, traditional tests of UIP applied to data from our model would reject that hypothesis.

An obvious shortcoming of the flexible-price model is that purchasing power parity (PPP) holds at every point in time. To remedy this shortcoming, we modify the model so that monopolist producers set the nominal prices of domestic and exported goods in local currency. They do so subject to Calvo-style pricing frictions. For simplicity, suppose for now that there is a complete set of domestic and international asset markets. Consider a persistent fall in domestic productivity or an increase in domestic government spending. Both shocks lead to a rise in domestic marginal cost. So, when they are able to, domestic firms increase their prices at home and abroad. As a result, inflation rises at home and abroad. Because of home bias, domestic inflation rises by more than foreign inflation. The Taylor principle implies that the domestic real interest rate rises by more than the foreign real interest rate. So, domestic consumption falls by more than foreign consumption.

With complete asset markets, the *RER* is proportional to the ratio of foreign and domestic marginal utilities of consumption. So, the fall in the ratio of domestic to foreign consumption implies a fall in the *RER*. As in the flexible price model, the Taylor rule keeps inflation relatively low in both countries so that most of the adjustment in the *RER* is accounted for by movements in the *NER*. Again, the implied predictable movements in the *NER* can occur in equilibrium because they are offset by the interest rate differential, i.e. UIP holds.

While the intuition is less straightforward, our results are not substantively affected if we replace complete markets with incomplete markets or assume local currency pricing instead of producer currency pricing.

An important question is whether empirically plausible versions of our model can account for the facts that we document. The key tension is as follows. We require that UIP holds

for the key shocks that generate the correlation between the current *RER* and future *NERs*. But we also require that shocks to the demand for assets be sufficiently important so that traditional tests of UIP are rejected. In addition, we want the shocks in our model to be sufficiently persistent so that, for the reasons emphasized in Engel, Mark and West (2007), *RERs* exhibit properties that are hard to distinguish from a random walk. Finally, to be plausible our model must be consistent with the bedrock observations associated with Mussa (1986) and Rogoff (1996). To this end we study an estimated open-economy medium-size DSGE model. Amongst other features, the model allows for Calvo-style nominal wage and price frictions and habit formation in consumption of the type considered in the Christiano, Eichenbaum and Evans (2005). Our key finding is that the model can simultaneously account for our two empirical facts even though exchange rates behave like random walks at short horizons, unconditional UIP fails, nominal and real exchange commove closely, and the *RER* is inertial.

Our work is related to three important strands of literature. The first strand demonstrates the existence of long-run predictability in nominal exchange rates (e.g. Mark (1995) and Engel, Mark, and West (2007)). Rossi (2013) provides a thorough review of this literature. Our contribution here is to show the importance of the *RER* in predicting the *NER* at medium and long-run horizons.<sup>1</sup> The second strand of literature seeks to explain the persistence of real exchange rates. See, for example, Rogoff (1996), Kollmann (2001), Chari, Kehoe and McGrattan (2002), Benigno (2004), and Engel, Mark, and West (2007), Steinsson (2008). Our contribution relative to that literature is to show that we can account for the relationship between the *RER* and future changes in inflation and the *NER* in a way that is consistent with the observed inertia in *RER*. The third strand of the literature emphasizes the importance of the monetary regime for the behavior of *RER*. See, for example Baxter and Stockman (1989), Engel, Mark, and West (2007), and Engel (2012). Our contribution relative to that literature is to document the critical role that Taylor-rule regimes play in determining the relative roles of inflation and the *NER* in the adjustment of the *RER* to its long-run levels.

Our paper is organized as follows. Section 2 contains our empirical results. Section 3 describes a sequence of models consistent with these results. We start with a model that has flexible prices, complete asset markets, and where labor is the only factor in the production of intermediate goods. We then replace complete markets with a version of incomplete markets where only one-period bonds can be traded. Next, we introduce Calvo-style frictions in price setting. In Section 4 we consider an estimated medium-scale DSGE model. Section 5 concludes.

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<sup>1</sup>Authors like Engel and West (2004, 2005) Molodtsova and Papell (2009) have proposed using variables that might enter into a Taylor rule to improve out of sample forecasting. Such variables includes output gaps, inflation, and possibly real exchange rates. Our focus is not on out-of-sample forecasting.

## 2 Some empirical properties of nominal and real exchange rates

In this section we present our empirical results regarding nominal exchange rates, real exchange rates, and relative inflation rates. Our analysis is based on quarterly data for Australia, Canada, the euro area, Germany, Japan, New Zealand, Norway, Sweden, China, and Hong Kong. We use consumer price indexes for all items and average quarterly nominal exchange rates versus the U.S. dollar.<sup>2</sup>

We begin by describing the results obtained for countries under flexible exchange rates and in which monetary policy is reasonably well characterized by a Taylor rule. We choose the sample period for each country using the following two criteria. First, the exchange rate must be floating. Second, following Clarida, Gali and Gertler (1998), we consider periods when monetary policies are reasonably characterized by Taylor rules. Our sample periods are as follows: Australia: 1973-2007, Canada: 1973-2007, Germany: 1979.Q2-1993, Japan: 1979.Q2-1994, New Zealand: 1989-2007, Norway: 1973-2007, Sweden: 1973-2007, United Kingdom: 1992.Q4-2007.<sup>3</sup> Unless indicated otherwise, a year means that the entire year's worth of data was used.

The  $RER$  is given by:

$$RER_t = \frac{S_t P_t^*}{P_t}, \quad (1)$$

where  $S_t$  is the nominal exchange rate, defined as U.S. dollars per unit of foreign currency. The variables  $P_t$  and  $P_t^*$  denote the domestic and foreign price levels, respectively.

Figures 1 through 9 show, for each country, scatter plots of the  $\log(RER_t)$  against  $\log(S_{t+j}/S_t)$  for different horizons,  $j$ . The maximal horizon ( $J$ ) is country specific, equaling 5 or 10 years. Our rule for setting  $J$  is that  $J$  is either 5 or 10, and we have at least one non-overlapping data point that exceeds that horizon. So, for example, for Canada  $J = 10$ , but for the U.K.,  $J = 5$ . For countries where  $J = 10$ , we display the scatter plots at one, three, seven and ten year horizons. For countries where  $J = 5$ , we display the scatter plots at one, two, three and five year horizons.

Two features of these figures are worth noting. First, consistent with the notion that exchange rates behave like random walks at high frequencies, there is no obvious relationship between the  $\log(RER_t)$  and  $\log(S_{t+j}/S_t)$  at a one-year horizon. However, as the horizon expands, the correlation between  $\log(RER_t)$  and  $\log(S_{t+j}/S_t)$  rises. For the countries for

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<sup>2</sup>The data comes from the International Monetary Fund's International Financial Statistics database, with the exception of consumer prices for China, the euro/U.S. dollar exchange rate, and consumer prices in the euro area. For consumer prices in China, we use data from the St. Louis Fed's FRED database with the series name CHNCPIALLQINMEI. For the nominal exchange rate and consumer prices in the euro area we use data from the St. Louis Fed's FRED database with the series names DEXUSEU and CP0000EZ19M086NEST, respectively.

<sup>3</sup>We exclude France and Italy because the Clarida, Gali and Gertler (1998) dates would give us only 6 years of data for France and 8 years of data for Italy. These years include steep declines from very high initial inflation rates that are hard to reconcile with a stable Taylor-rule regime. Our data for the U.K. starts in 1992 to exclude the period in which the British pound was part of the Exchange Rate Mechanism of the European Monetary System.

which we have the most data, so that  $J = 10$ , the negative relationship is very pronounced at longer horizons.

We now discuss results obtained from running the following *NER* regression:

$$\log\left(\frac{S_{t+j}}{S_t}\right) = \beta_0 + \beta_1 \log(RER_t) + \epsilon_{t,t+j}, \quad (2)$$

for  $j = 1, 2, \dots, J$ . Panel A of Table 1 reports estimates and standard errors for the slope coefficient,  $\beta_1$  obtained using data from flexible exchange rate countries.<sup>4</sup> A number of features are worth noting. First, for every country and every horizon, the estimated value of  $\beta_1$  is negative. Second, for almost all countries, the estimated value of  $\beta_1$  is statistically significant at three-year horizons or longer. Third, in most cases the estimated value of  $\beta_1$  increases in absolute value with the horizon. Moreover,  $\beta_1$  is more precisely estimated for longer horizons.

Panel A of Table 2 reports the  $R^2$ s from the fitted regressions. Consistent with the visual impression from the scatter plots, the  $R^2$ s are relatively low at horizons of one year but rise with the horizon. Strikingly, for the longest horizons the  $R^2$  exceeds 50 percent for all countries except for Japan (where it is 40 percent) and it is almost 88 percent for Canada.

Taken together, the results in Figures 1 – 9 and Table 1 strongly support the notion that, for flexible exchange rate countries where monetary policy is reasonably well characterized by a Taylor rule, the current *RER* is strongly correlated with changes in future nominal exchange rates, at horizons greater than roughly two years.

We now consider the relative-price regression:

$$\log\left(\frac{P_{t+j}^*/P_{t+j}}{P_t^*/P_t}\right) = \beta_0 + \beta_1 \log(RER_t) + \epsilon_{t,t+j}. \quad (3)$$

This regression quantifies how much of the adjustment in the *RER* occurs via changes in relative rates of inflation across countries. Panel A of Table 3 reports our estimates and standard errors for the slope coefficient,  $\beta_1$ . In most cases, the coefficient is statistically insignificant and in some cases it is negative instead of positive. Interestingly, for Australia, the 7 and 10-year horizon estimates of  $\beta_1$  are positive and statistically significant. Panel A of Table 4 reports the  $R^2$ s of the fitted regressions. Notice that the regression  $R^2$ s are all much lower than the corresponding  $R^2$ s from regression (2). As a whole, these results are consistent with the view that, for these countries, very little of the adjustment in the *RER* occurs via differential inflation rates.

We now redo our analysis for China, which is on a quasi-fixed exchange rate versus the U.S. dollar, and Hong Kong, which has a fixed exchange rate versus the U.S. dollar. The sample period is from 1985 to 2007 for Hong Kong and 1994 to 2007 for China. We also use data over the period 1999 to 2007 for France, Ireland, Italy, Portugal, and Spain where the *RER* and relative inflation rates are defined relative to Germany. Two features of Panel C

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<sup>4</sup>We compute standard errors for a generalized method of moments estimator of  $\beta_1$  using a Newey-West estimator of the optimal weighting matrix with the number of lags equal to two quarters more than the forecasting horizon.

of Table 3 are worth noting. First, the estimated values of  $\beta_1$  in equation (3) are statistically significant for every country at every horizon. Second, the estimated value of  $\beta_1$  rises with the horizon. Panel C of Table 4 shows that the regression  $R^2$ s increase with the horizon. Interestingly, the 5 year  $R^2$ s are very high, exceeding 79 percent for all countries with a peak value of 93 percent for Portugal.

We conclude that, for countries on a flexible exchange rate regime and monetary policy well characterized by a stable Taylor rule, adjustments in the  $RER$ , occur slowly via predictable changes in the  $NER$ . In sharp contrast, for countries in fixed exchange rate regimes, adjustments in the  $RER$  occur slowly via predictable changes in inflation rates.

### 3 Benchmark models

In this section we use a sequence of simple models to explain the empirical findings documented above. We begin with a flexible price, two-country, complete-markets model, allowing for two different specifications of monetary policy. We then consider an incomplete markets model, allowing for ‘spread-shocks.’ These shocks imply that traditional tests applied to data from the model economy would reject UIP. We first assume that prices are flexible and then move on to a specification that allows for sticky prices.

#### 3.1 Flexible-price, complete-markets model

Our model consists of two completely symmetric countries. We first describe the households’ problems and then discuss the firms’ problems.

##### 3.1.1 Households

The domestic economy is populated by a representative household whose preferences are given by:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[ \log(C_{t+j}) - \frac{\chi}{1+\phi} L_{t+j}^{1+\phi} + \mu \frac{(M_{t+j}/P_{t+j})^{1-\sigma_M}}{1-\sigma_M} \right]. \quad (4)$$

Here,  $C_t$  denotes consumption,  $L_t$  hours worked,  $M_t$  end-of-period nominal money balances,  $P_t$  the time- $t$  aggregate price level, and  $E_t$  the expectations operator conditional on time- $t$  information. In addition,  $0 < \beta < 1$ ,  $\sigma_M > 1$ , and  $\chi$  and  $\mu$  are positive scalars.

Households can trade in a complete set of domestic and international contingent claims. The domestic household’s flow budget constraint is given by:

$$B_{H,t} + S_t B_{F,t} + P_t C_t + M_t = R_{t-1} B_{H,t-1} + S_t R_{t-1}^* B_{F,t-1} + W_t L_t + T_t + M_{t-1}. \quad (5)$$

Here,  $B_{H,t}$  and  $B_{F,t}$  are nominal balances of home and foreign bonds,  $S_t$  is the nominal exchange rate, defined as the price of the foreign currency unit (units of home currency per unit of foreign currency),  $R_t$  is the nominal interest rate on the home bond and  $R_t^*$  is the

nominal interest rate on the foreign bond,  $W_t$  is the wage rate, and  $T_t$  are lump-sum profits and taxes. For notational ease, we have suppressed the household's purchases and payoffs of contingent claims. With complete markets, the presence of one-period nominal bonds is redundant since these bonds can be synthesized using state-contingent claims.

The first-order conditions are:

$$\chi L_t^\phi C_t = \frac{W_t}{P_t}, \quad (6)$$

$$1 = \beta R_t E_t \frac{C_t}{C_{t+1} \pi_{t+1}}, \quad (7)$$

where,  $\pi_t = P_t/P_{t-1}$ , denotes the inflation rate.

$$\mu \left( \frac{M_t}{P_t} \right)^{-\sigma_M} = \left( \frac{R_t - 1}{R_t} \right) \frac{1}{C_t}. \quad (8)$$

Equation (8) characterizes money demand by domestic agents. Since households only derive utility from their country's money, domestic agents do not hold foreign money balances.

We use stars to denote the prices and quantities in the foreign country. The preferences of the foreign household are given by:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[ \log(C_{t+j}^*) - \frac{\chi}{1+\phi} (L_{t+j}^*)^{1+\phi} + \mu \frac{(M_{t+j}^*/P_{t+j}^*)^{1-\sigma_M}}{1-\sigma_M} \right]. \quad (9)$$

The foreign household's flow budget constraint is given by:

$$B_{F,t}^* + S_t^{-1} B_{H,t}^* + P_t^* C_t^* + M_t^* = R_{t-1}^* B_{F,t-1}^* + S_t^{-1} R_{t-1}^* B_{H,t-1}^* + W_t^* L_t^* + T_t^* + M_{t-1}^*. \quad (10)$$

The first-order conditions for the foreign household are:

$$\chi (L_t^*)^\phi C_t^* = \frac{W_t^*}{P_t^*}, \quad (11)$$

$$1 = \beta R_t^* E_t \frac{C_t^*}{C_{t+1}^* \pi_{t+1}^*}, \quad (12)$$

$$\mu \left( \frac{M_t^*}{P_t^*} \right)^{-\sigma_M} = \left( \frac{R_t^* - 1}{R_t^*} \right) \frac{1}{C_t^*}. \quad (13)$$

We define the real exchange rate,  $RER_t$ , as units of the home good per unit of the foreign good:

$$RER_t = \frac{S_t P_t^*}{P_t}. \quad (14)$$

With this definition, an increase in  $RER_t$  corresponds to a lower real relative price of the home good, i.e. a real depreciation of the home good.



Complete markets and symmetry of initial conditions implies

$$\frac{C_t}{C_t^*} = RER_t. \quad (15)$$

Combining equations (12) and (15) implies

$$1 = \beta R_t^* E_t \frac{C_t}{C_{t+1} \pi_{t+1}} \frac{S_{t+1}}{S_t}. \quad (16)$$

Similarly, combining equations (7) and (15) implies:

$$1 = \beta R_t E_t \frac{C_t^*}{C_{t+1}^* \pi_{t+1}^*} \frac{S_t}{S_{t+1}}. \quad (17)$$

### 3.1.2 Firms

The domestic final good,  $Y_t$ , is produced by combining domestic and foreign goods ( $X_{H,t}$  and  $X_{F,t}$ , respectively) according to the technology

$$Y_t = \left[ \omega^{1-\rho} (X_{H,t})^\rho + (1-\omega)^{1-\rho} (X_{F,t})^\rho \right]^{\frac{1}{\rho}}. \quad (18)$$

Here,  $\omega > 0$  controls the importance of home bias in consumption. The parameter  $\rho \leq 1$  controls the elasticity of substitution between home and foreign goods.

The foreign final good,  $Y_t^*$ , is produced according to:

$$Y_t^* = \left[ \omega^{1-\rho} (X_{F,t}^*)^\rho + (1-\omega)^{1-\rho} (X_{H,t}^*)^\rho \right]^{\frac{1}{\rho}}. \quad (19)$$

The quantity  $X_{H,t}$  denotes domestic goods used in domestic final production and produced according to the technology:

$$X_{H,t} = \left( \int_0^1 X_{H,t}(j)^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}}. \quad (20)$$

The quantity  $X_{H,t}^*$  denotes domestic goods used in foreign final production and produced according to the technology:

$$X_{H,t}^* = \left( \int_0^1 X_{H,t}^*(j)^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}}. \quad (21)$$

Here,  $X_{H,t}(j)$  and  $X_{H,t}^*(j)$  are domestic intermediate goods produced by monopolist  $j$  using the linear technology:

$$X_{H,t}(j) + X_{H,t}^*(j) = A_t L_t(j). \quad (22)$$

The variable  $L_t(j)$  denotes the quantity of labor employed by monopolist  $j$  and  $A_t$  denotes the state of time- $t$  technology. The parameter  $\nu > 1$  controls the degree of substitutability between different intermediate inputs. The quantity  $X_{F,t}$  denotes foreign goods used in

domestic final production and produced according to the technology:

$$X_{F,t} = \left( \int_0^1 X_{F,t}(j)^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}}. \quad (23)$$

The quantity  $X_{F,t}^*$  denotes foreign goods used in foreign final production and produced according to the technology:

$$X_{F,t}^* = \left( \int_0^1 X_{F,t}^*(j)^{\frac{\nu-1}{\nu}} dj \right)^{\frac{\nu}{\nu-1}}. \quad (24)$$

Here,  $X_{F,t}(j)$  and  $X_{F,t}^*(j)$  are foreign intermediate goods produced by monopolist  $j$  using the linear technology:

$$X_{F,t}(j) + X_{F,t}^*(j) = A_t^* L_t^*(j), \quad (25)$$

where  $L_t^*(j)$  is the labor employed by monopolist  $j$  in the foreign country and  $A_t^*$  denotes the state of technology in the foreign country at time  $t$ . In each period, monopolists in the home country choose  $\tilde{P}_{H,t}(j)$  and  $\tilde{P}_{H,t}^*(j)$  to maximize per-period profits, which are given by

$$\left( \tilde{P}_{H,t}(j) (1 + \tau_X) - W_t/A_t \right) X_{H,t}(j) + \left( S_t \tilde{P}_{H,t}^*(j) (1 + \tau_X) - W_t/A_t \right) X_{H,t}^*(j), \quad (26)$$

subject to the demand curves of final good producers:

$$X_{H,t}(j) = \left( \frac{\tilde{P}_{H,t}(j)}{P_{H,t}} \right)^{-\nu} X_{H,t}, \quad (27)$$

and

$$X_{H,t}^*(j) = \left( \frac{\tilde{P}_{H,t}^*(j)}{P_{H,t}^*} \right)^{-\nu} X_{H,t}^*. \quad (28)$$

Here,  $\tau_X$  is a subsidy that corrects the steady state level of monopoly distortion.<sup>5</sup> The aggregate price indexes for  $X_{H,t}$  and  $X_{H,t}^*$ , denoted by  $P_{H,t}$  and  $P_{H,t}^*$ , can be expressed as

$$P_{H,t} \equiv \left( \int_0^1 [P_{H,t}(j)]^{1-\nu} dj \right)^{\frac{1}{1-\nu}}, \quad (29)$$

and

$$P_{H,t}^* \equiv \left( \int_0^1 [P_{H,t}^*(j)]^{1-\nu} dj \right)^{\frac{1}{1-\nu}}. \quad (30)$$

Monopolists in the foreign country choose  $\tilde{P}_{F,t}(j)$  and  $\tilde{P}_{F,t}^*(j)$  to maximize profits

$$\left( \tilde{P}_{F,t}^*(j) (1 + \tau_X) - W_t^*/A_t^* \right) X_{F,t}^*(j) + \left( S_t^{-1} \tilde{P}_{F,t}(j) (1 + \tau_X) - W_t^*/A_t^* \right) X_{F,t}(j). \quad (31)$$

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<sup>5</sup>Impulse response functions from the model are little changed if we set  $\tau_X = 0$ .

subject to the demand curves of final good producers:

$$X_{F,t}(j) = \left( \frac{\tilde{P}_{F,t}(j)}{P_{F,t}} \right)^{-\nu} X_{F,t}, \quad (32)$$

and

$$X_{F,t}^*(j) = \left( \frac{\tilde{P}_{F,t}^*(j)}{P_{F,t}^*} \right)^{-\nu} X_{F,t}^*. \quad (33)$$

Here, the aggregate price index for  $X_{F,t}$  and  $X_{F,t}^*$ , denoted by  $P_{F,t}$  and  $P_{F,t}^*$ , can be expressed as:

$$P_{F,t} \equiv \left( \int_0^1 [P_{F,t}(j)]^{1-\nu} dj \right)^{\frac{1}{1-\nu}}, \quad (34)$$

and

$$P_{F,t}^* \equiv \left( \int_0^1 [P_{F,t}^*(j)]^{1-\nu} dj \right)^{\frac{1}{1-\nu}}. \quad (35)$$

The first-order conditions for the monopolists imply:

$$P_{H,t}(j) = S_t P_{H,t}^*(j) = \frac{W_t}{A_t}, \quad (36)$$

where  $P_{H,t}(j)$  and  $P_{H,t}^*(j)$  are prices that the home monopolist charges in the home and foreign markets, respectively. Similarly,

$$S_t^{-1} P_{F,t}(j) = P_{F,t}^*(j) = \frac{W_t^*}{A_t^*}. \quad (37)$$

Here  $P_{F,t}(j)$  and  $P_{F,t}^*(j)$  are the prices that the foreign monopolist charges in the home and foreign markets, respectively. Equations (36) and (37) imply that PPP holds.

### 3.1.3 Monetary policy, market clearing and the aggregate resource constraint

In our first specification of monetary policy, the domestic monetary authority sets the interest rate according to the following Taylor rule:

$$R_t = \gamma R_{t-1} + (1 - \gamma) \left( r + \theta_\pi (\pi_t - 1) + \varepsilon_t^R \right). \quad (38)$$

We assume that the Taylor principle holds, so that  $\theta_\pi > 1$ . In addition,  $r = \beta^{-1}$ , and  $\varepsilon_t^R$  is an iid shock to monetary policy. To simplify, we assume that the inflation target is zero in both countries. The foreign monetary authority follows a similar rule so that:

$$R_t^* = \gamma R_{t-1}^* + (1 - \gamma) \left( r + \theta_\pi (\pi_t^* - 1) + \varepsilon_t^{R*} \right). \quad (39)$$

In Appendix A we display our results for a Taylor rule in which the constant  $r$  is replaced by the natural rate of interest, i.e. the real interest rate in the economy replaces the intercept

of the Taylor rule. We show that none of our key results are qualitatively affected by this change. The quantitative impact of switching to the natural rate version of the Taylor rule is similar to the impact of switching to the monetary growth rate rule we discuss below.

In our second specification of monetary policy, the domestic monetary authority sets the growth rate of nominal money balances to be:

$$\log\left(\frac{M_t}{M_{t-1}}\right) = x_t^M, \quad (40)$$

where

$$x_t^M = \rho_{X_M} x_{t-1}^M + \varepsilon_t^M. \quad (41)$$

Here,  $\rho < 1$  and  $\varepsilon_t^M$  is an iid shock to monetary policy. For convenience, we have assumed that the unconditional mean growth rate of nominal money balances is zero. The foreign monetary authority follows a similar rule so that:

$$\log\left(\frac{M_t^*}{M_{t-1}^*}\right) = x_t^{M*}, \quad (42)$$

where

$$x_t^{M*} = \rho_{X_M} x_{t-1}^{M*} + \varepsilon_t^{M*}. \quad (43)$$

We assume that government purchases,  $G_t$ , evolve according to:

$$\log\left(\frac{G_t}{G}\right) = \rho_G \log\left(\frac{G_{t-1}}{G}\right) + \epsilon_t^G, \quad (44)$$

and, without loss of generality, that the government budget is balanced each period using lump-sum taxes. Here,  $\epsilon_t^G$  is an iid shock to government purchases. The composition of government expenditures in terms of domestic and foreign intermediate goods ( $X_{H,t}$  and  $X_{F,t}$ ) is the same as the domestic household's final consumption good.

Similarly, government purchases in the foreign purchases,  $G_t^*$ , evolve according to:

$$\log\left(\frac{G_t^*}{G}\right) = \rho_G \log\left(\frac{G_{t-1}^*}{G}\right) + \epsilon_t^{G*}, \quad (45)$$

where  $\epsilon_t^{G*}$  is an iid shock to government purchases and the government budget is balanced each period using lump-sum taxes. The composition of government expenditures in terms of domestic and foreign intermediate goods ( $X_{F,t}^*$  and  $X_{H,t}^*$ ) is the same as the foreign household's final consumption good. Since bonds are in zero net supply, bond-market clearing implies:

$$B_{H,t} + B_{H,t}^* = 0, \quad (46)$$

and

$$B_{F,t} + B_{F,t}^* = 0. \quad (47)$$

Labor-market clearing requires that:

$$L_t = \int_0^1 L_t(j) dj, \quad (48)$$

and

$$L_t^* = \int_0^1 L_t^*(j) dj. \quad (49)$$

Market clearing in the intermediate inputs market requires that

$$X_{H,t} + X_{H,t}^* = A_t L_t, \quad (50)$$

and

$$X_{F,t} + X_{F,t}^* = A_t^* L_t^*. \quad (51)$$

Finally, the aggregate resource constraints are given by

$$Y_t = C_t + G_t, \quad (52)$$

and

$$Y_t^* = C_t^* + G_t^*. \quad (53)$$

### 3.1.4 Impulse response functions

In the examples below we use the following parameter values. We assume a Frisch elasticity of labor supply equal to one ( $\phi = 1$ ) and, as in Christiano, Eichenbaum and Evans (2005), set  $\sigma_M = 10.62$ . We set the value of  $\beta$  so that the steady state real interest rate is 3 percent. We follow Backus, Kehoe and Kydland (1992) and assume that the elasticity of substitution between domestic and foreign goods in the consumption aggregator is 1.5 ( $\rho = 1/3$ ) and that the import share is 15 percent ( $\omega = 0.85$ ), so that there is home bias in consumption. We assume that  $\nu = 6$ , which implies an average markup of 20 percent. This value falls well within the range considered by Altig, et al. (2011). We normalize the value of  $\chi$ , which affects the marginal disutility of labor, and real balances, so that hours worked in the steady state equal one. We assume that monetary policy is given by the Taylor rules (38) and (39). We set  $\theta_\pi$  to 1.5 so as to satisfy the Taylor principle. For ease of exposition, in this section we set  $\gamma = 0$  so that the monetary authority does not do any interest rate smoothing. We choose 0.95 for the first-order serial correlation of the technology shock, a standard value used in the literature (e.g. Hansen (1985)). In Appendix A we solve for the steady state of the model and display the dynamic system of log-linearized equations that characterize the equilibrium for this economy.

Figure 12 displays the impulse response to a negative technology shock. Home bias in consumption has three implications. First, the *RER* falls since home goods are more costly to produce and the home consumption basket places a higher weight on these goods. Second, domestic consumption falls by more than foreign consumption because domestic agents con-

sume more of the good whose relative cost of production has risen. Third, domestic inflation is higher than foreign inflation because of the higher weight of the home good in the home consumer price index.

Since the Taylor rule keeps prices relatively stable, the fall in the *RER* on impact occurs via an appreciation of the home currency. The Taylor rule, together with the Taylor principle, implies that both the real and the nominal interest rates rise more at home than abroad. The technology shock is persistent, so there is a persistent gap between the domestic and foreign nominal interest rates. Since UIP holds in the log-linear equilibrium, the domestic currency must depreciate over time to compensate for the nominal interest rate gap. So, the home currency appreciates on impact and then depreciates. This pattern is reminiscent of the overshooting phenomenon emphasized by Dornbusch (1976).

Domestic inflation is persistently higher than foreign inflation, so the domestic price level rises by more than the foreign price level. This result, along with PPP, implies that the home currency must depreciate over time and asymptote to a lower value (the figure displays the value of the foreign currency which is rising to a higher value).

To understand better the relation between the *RER* and the *NER*, note that the log-linearized equilibrium conditions of our model imply that, in response to a technology shock, the behavior of the *RER* is given by:

$$\widehat{RER}_t = \kappa \hat{A}_t. \quad (54)$$

Here,  $\kappa$  is a positive constant that depends on the parameters of the model. This equation implies that the *RER* inherits the AR(1) nature of the technology shock, so that:

$$E_t \widehat{RER}_{t+1} = \rho_A \widehat{RER}_t. \quad (55)$$

Combining the linearized home- and foreign-country intertemporal Euler equations (7) and (12), the relation between the two country's marginal utilities implied by complete markets (15), and the Taylor rules for the two countries (38) and (39) we obtain:

$$\hat{\pi}_t - \hat{\pi}_t^* = \frac{\rho_A - 1}{\theta_\pi - \rho_A} \widehat{RER}_t. \quad (56)$$

When the Taylor principle holds ( $\theta_\pi > 1$ ), we have  $\left| \frac{\rho_A - 1}{\theta_\pi - \rho_A} \right| < 1$ . Recall that the *RER* is defined as  $S_t P_t^* / P_t$ . Equation (56) implies that, on impact, the  $RER_t$  falls by more than  $P_t^* / P_t$ . It follows that  $S_t$  must fall, i.e. the home currency *appreciates* on impact and then depreciates during the transition back to steady state.

As the previous discussion makes clear, home bias plays a critical role in our analysis. Absent that bias, the consumption basket would be the same in both countries and the *RER* would be equal to one. Equation (56) implies that if the *RER* is constant so is relative inflation and the *NER*.

### 3.1.5 Implied regression coefficients

We now assess the model's ability to account for the relation between the current  $RER$  and future changes in the  $NER$ . Recall the basic regression that motivates our analysis:

$$\log\left(\frac{S_{t+j}}{S_t}\right) = \beta_0 + \beta_1 \log(RER_t) + \epsilon_{t,t+j}.$$

We calculate, for different values of  $j$ , the probability limit for  $\beta_1$  implied by the simple model assuming that only technology shocks drive economic fluctuations. These values are reported in Table (1). The model is consistent with the fact that  $\beta_1$  is negative and grows larger in absolute value with horizon. The reason for this result is as follows. In the model, a low current value of the  $RER$  predicts a future depreciation of the domestic currency, so the slope of the regression is negative. The slope increases with the horizon because the cumulative depreciation of the home currency increases over time.

The ability of the model to rationalize the regression coefficients does not depend on technology shocks per se. For example, suppose that government purchases enter the utility function in a time-separable manner and that they follow an AR(1) with first-order serial correlation 0.95. Figure 14 reports the response functions to a government spending shock. Panel A of Table 9 reports the model's implied values of  $\beta_1$  corresponding to regression (2). The results are very similar to the technology shock case.

The intuition underlying our results is as follows. Consider any shock which changes the  $RER$ , other than a shock for which UIP does not hold. Suppose that monetary policy is conducted so that inflation is relatively stable (e.g. a Taylor rule with a large value of  $\theta_\pi$ ). Then  $P_t^*$  and  $P_t$  are relatively stable. So, the only way for the  $RER$  to move is via changes in the nominal exchange rate. Since movements in the  $RER$  are predictable, so too are movements in the nominal exchange rate. For these predictable movements to be an equilibrium in which UIP holds, nominal interest rates must offset the expected movements in the  $NER$ .

### 3.1.6 Economy with money growth rule

Consistent with the intuition in Engel (2012), we now show that, when monetary policy follows a money growth rule (40), the flexible price model is much less successful at accounting for our regression result.

The impulse response functions to a technology shock are displayed in Figure 13. The following features are worth noting. First, prices in both countries move by much more than they did under the Taylor rule. So, the movements in the  $NER$  required to validate the given equilibrium path of the  $RER$  are much smaller than under a Taylor rule. Second, since the growth rate of money does not increase after the shock, the price level eventually reverts to its pre-shock steady state level. As a result, the nominal exchange rate also reverts to its steady state. Third, not all of the adjustment in the  $RER$  occurs via the price level, so there are still predictable movements in the  $NER$ . But these movements are much smaller than

under a Taylor rule. This property is reflected model-implied regression slopes for our *NER* regression that are much smaller than under a Taylor rule. (see 9).

### 3.2 Flexible-price, incomplete-markets model

In this subsection we assume that the only assets that can be traded internationally are one-period nominal bonds. We continue to assume that there are complete domestic asset markets. As in McCallum (1994), we allow for shocks that break UIP in log-linearized versions of the model. But rather than a shock directly to the UIP condition, we assume that household derive utility from domestic bond holdings whose utility flow varies over time.

We modify the household's utility function to be:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[ \log(C_{t+j}) - \frac{\chi}{1+\phi} L_{t+j}^{1+\phi} + \mu \frac{(M_{t+j}/P_{t+j})^{1-\sigma_M}}{1-\sigma_M} + \eta_t V \left( \frac{B_{H,t+j}}{P_{t+j}} \right) \right]. \quad (57)$$

The function  $V$  that governs the utility flow from the stock of domestic bonds is increasing, strictly concave, and has both positive and negative support.<sup>6</sup> For convenience we assume that  $\eta_t$  is zero in steady state, meaning that the flow utility from bonds is also zero in steady state. In what follows, we refer to  $\eta_t$  as a spread shock.<sup>7</sup> Outside of steady state, there may be shocks that put a premium on one bond or the other, arising from flights to safety or liquidity, for example. This type of spread shock is used in a closed-economy context by Smets and Wouters (2007), Christiano, Eichenbaum, and Trabandt (2014), Fisher (2015) and Gust, et al., (2016). Importantly, we assume that the home and foreign household are impacted by the same shocks to the utility flow from bond holdings. The foreign household's objective function is given by:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[ \log(C_{t+j}^*) - \frac{\chi}{1+\phi} (L_{t+j}^*)^{1+\phi} + \mu \frac{(M_{t+j}^*/P_{t+j}^*)^{1-\sigma_M}}{1-\sigma_M} + \eta_t V \left( \frac{B_{H,t+j}^*}{S_t P_{t+j}^*} \right) \right]. \quad (58)$$

It is well known that with incomplete asset markets, the equilibrium process for the *RER* in models like ours has a unit root. To avoid this implication, authors like Schmitt-Grohe and Uribe (2003) assume that there is a small quadratic cost to holding bonds. We adopt a similar assumption in our model. The domestic household's budget constraint is given by

$$B_{H,t} + S_t B_{F,t} + P_t C_t + M_t + \frac{\phi_B}{2} \left( \frac{S_t B_{F,t}}{P_t} \right)^2 P_t = R_{t-1} B_{H,t-1} + S_t R_{t-1}^* B_{F,t-1} + W_t L_t + T_t + M_{t-1}. \quad (59)$$

As in Erceg, et al., (2005), we assume that the quadratic cost of holding bonds applies to

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<sup>6</sup>It is straightforward to allow for a utility flow from holding foreign bonds of the form  $\eta_t^* V \left( \frac{S_t B_{F,t}}{P_t} \right)$ . Abstracting from this term does not affect any of the results reported in this paper.

<sup>7</sup>In reality, the utility flow from bond holdings could well be positive because some agents in the economy must hold certain types of bonds for regulatory reasons.



bonds from the other country. In steady state,  $B_{F,t}$  is zero, and this term drops from the budget constraint. Symmetrically, the budget constraint of the foreign household is given by

$$B_{F,t}^* + S_t^{-1} B_{H,t}^* + P_t^* C_t^* + M_t^* + \frac{\phi_B}{2} \left( \frac{S_t^{-1} B_{H,t}^*}{P_t^*} \right)^2 P_t^* = R_{t-1}^* B_{F,t-1}^* + S_t^{-1} R_{t-1} B_{H,t-1}^* + W_t^* L_t^* + T_t^* + M_{t-1}^*. \quad (60)$$

The first-order conditions of the households are unchanged, except that equation (7) is replaced by:

$$\frac{1}{C_t} = \eta_t V' \left( \frac{B_{H,t}}{P_t} \right) + \beta R_t E_t \frac{1}{C_{t+1} \pi_{t+1}}, \quad (61)$$

equation (17) is replaced by

$$\frac{1}{C_t^*} \left( 1 + \phi_B \frac{B_{H,t}^*}{P_t R E R_t} \right) = \eta_t V' \left( \frac{B_{H,t}}{S_t P_t^*} \right) + \beta R_t E_t \frac{1}{C_{t+1}^* \pi_{t+1}^*} \frac{S_t}{S_{t+1}}, \quad (62)$$

equation (16) is replaced by

$$\frac{1}{C_t} \left( 1 + \phi_B \frac{B_{F,t}}{P_t^* R E R_t} \right) = \beta R_t^* E_t \frac{1}{C_{t+1} \pi_{t+1}} \frac{S_{t+1}}{S_t}, \quad (63)$$

and the money demand, equation (8), is replaced by

$$\mu \left( \frac{M_t}{P_t} \right)^{-\sigma_M} = \frac{\eta_t}{R_t} V' \left( \frac{B_{H,t}}{P_t} \right) + \left( \frac{R_t - 1}{R_t} \right) \Lambda_t. \quad (64)$$

In the absence of complete markets, equation (15) does not hold. So, the ratio of marginal utilities of consumption in the home and foreign country is not proportional to the real exchange rate.

All remaining elements of the model are the same as those of the flexible-price, complete-markets model. We confine our attention to the specification of monetary policy given by the Taylor rule (38). In Appendix A, we solve for the steady state of the model and display the dynamic system of log-linearized equations whose solution corresponds to the equilibrium for this economy.

Figure 15 displays the dynamic response of the economy to a positive iid spread shock in the home country (a positive shock to  $\eta_t$ ). With flexible prices, only nominal variables are affected. The demand for domestic bonds rises at home and abroad so the domestic interest rate falls. The nominal interest rate declines by the same amount as the spread shock. The Taylor rule then implies that inflation also falls, although by less than the spread shock. Since  $P_t$  falls and  $P_t^*$  is unaffected, in order for PPP to hold  $S_t$  has to decline. That is, the home currency appreciates.

### 3.2.1 Uncovered interest rate parity

In a log-linearized version of the model without shocks to the utility flow from real bond holdings, UIP holds. To show this result, log-linearize equations (61) and (63) to obtain

$$\hat{C}_t = CV'(0) \eta_t + \left( \hat{R}_t + E_t \left[ -\hat{C}_{t+1} - \hat{\pi}_{t+1} \right] \right), \quad (65)$$

$$\hat{C}_t + \phi_B b_{F,t} = \hat{R}_t^* + E_t \left[ -\hat{C}_{t+1} - \hat{\pi}_{t+1} + \hat{\Delta S}_{t+1} \right]. \quad (66)$$

Here, the symbol ‘hat’ denotes log-deviation from the steady state,  $\hat{\Delta S}_{t+1} = \log(S_{t+1}/S_t)$ , and  $C$  is the steady-state level of consumption. It is convenient to normalize  $V'(0)$  to be equal to  $\frac{1}{C}$ . Combining equation (65) and (66), and ignoring the small term in  $\phi_B$ , we obtain

$$\hat{R}_t - \hat{R}_t^* = E_t \left[ \hat{\Delta S}_{t+1} \right] - \eta_t. \quad (67)$$

This equation is identical to the reduced-form equation assumed by McCallum (1994).<sup>8</sup>

Absent the spread shocks  $\eta_t$ , equation (67) corresponds to the classic UIP condition

$$\hat{R}_t - \hat{R}_t^* = E_t \left[ \hat{\Delta S}_{t+1} \right]. \quad (68)$$

All the other shocks in our model induce movements in nominal interest rates and exchange rates that are consistent with equation (68). Conditional on these shocks occurring, UIP holds. However, UIP does not hold unconditionally given the presence of these shock. In the presence of spread shocks, traditional tests would reject the UIP condition. For example, the classic Fama (1984) test involves running the regression

$$\hat{\Delta S}_{t+1} = \alpha_0 + \alpha_1 \left( \hat{R}_t - \hat{R}_t^* \right) + \varepsilon_t, \quad (69)$$

and testing the null hypothesis that  $\alpha_0 = 0$  and  $\alpha_1 = 1$ . Our model implies that this null hypothesis should be rejected because of a negative covariance between the error term and the interest rate differential. To see this result, consider a positive iid shock to  $\eta_t$ . A rise in  $\eta_t$  is equivalent to a rise in  $\varepsilon_t$ . Since domestic bonds are in zero net supply, the yield on domestic bonds must fall leading to a decline in  $\hat{R}_t - \hat{R}_t^*$ . So,  $\varepsilon_t$  covaries negatively with  $\hat{R}_t - \hat{R}_t^*$  which causes the probability limit of an ordinary least squares estimate of  $\alpha_1$  to be negative in an economy driven only by spread shocks.

## 3.3 Sticky-price, incomplete-markets model

In this section, we consider a version of the model with sticky prices. In what follows, we assume that monopolist producers set nominal prices in local currency units. The household’s problem is exactly the same as in the previous incomplete markets model. With the exception

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<sup>8</sup>If we don’t ignore  $\phi_B$ , equation (67) is replaced by  $\hat{R}_t - \hat{R}_t^* = E_t \left[ \hat{\Delta S}_{t+1} \right] - \eta_t - \phi_B b_{F,t}$ .

of spread shocks, the basic structure of this model is similar to Kollmann (2001).

The technology for producing final goods is still given by equation (18). Intermediate-good producing firms set prices according to a variant of the mechanism spelled out in Calvo (1983). In each period, a firm faces a constant probability,  $1 - \xi$ , of being able to re-optimize its nominal price. The ability to re-optimize prices is independent across firms and time. Domestic intermediate goods firms choose  $\tilde{P}_{H,t}(i)$  and  $\tilde{P}_{H,t}^*(i)$  to maximize the objective function:

$$E_t \sum_{j=0}^{\infty} \Lambda_{t+j} \left\{ \begin{aligned} & \left( \frac{\tilde{P}_{H,t}(i)}{P_{t+j}} (1 + \tau_X) - MC_{t+j} \right) X_{H,t+j}(i) \\ & + \left( \frac{S_{t+j} \tilde{P}_{H,t}^*(i)}{P_{t+j}} (1 + \tau_X) - MC_{t+j} \right) X_{H,t+j}^*(i), \end{aligned} \right\} \quad (70)$$

subject to the demand equations (27) and (28). Here,  $MC_{t+j}$  denotes the real marginal cost in period  $t + j$ .

Foreign intermediate goods firms choose  $\tilde{P}_{F,t}(i)$  and  $\tilde{P}_{F,t}^*(i)$  to maximize the objective function:

$$E_t \sum_{j=0}^{\infty} \Lambda_{t+j}^* \left\{ \begin{aligned} & \left( \frac{\tilde{P}_{F,t}^*(i)}{P_{t+j}^*} (1 + \tau_X) - MC_{t+j}^* \right) X_{F,t+j}^*(i) \\ & + \left( \frac{S_{t+j}^{-1} \tilde{P}_{F,t}(i)}{P_{t+j}^*} (1 + \tau_X) - MC_{t+j}^* \right) X_{F,t+j}(i), \end{aligned} \right\} \quad (71)$$

subject to equations (33) and (32).

In all other respects, the model is the same as the flexible-price, incomplete-markets model. Appendix A contains the equations that characterize the equilibrium of the model economy.

**A technology shock** Figure 16 displays the response of the economy to a negative technology shock in the home country. These effects are similar to those in the flexible-price model. The key difference is that in the sticky-price model the response of  $\pi_{H,t}$ ,  $\pi_{F,t}$ ,  $\pi_{H,t}^*$ ,  $\pi_{F,t}^*$  is attenuated relative to the flexible-price model. Interestingly, the effect of sticky prices on overall inflation is ambiguous. When prices are flexible, producers of the foreign good reduce the price they charge in the home market. This effect helps reduce the domestic rate of inflation in the flexible-price model. With sticky prices, this effect is attenuated relative to the flexible-price model. So depending on parameter values, domestic inflation can be higher or lower in the sticky price model than in the flexible price model.<sup>9</sup>

Panel A of Table 9 reports the implied values for  $\beta_1$  in our baseline regression, equation (2). Notice that these values are negative and grow in absolute value with the horizon. The basic intuition is that a negative technology shock drives down the real exchange rate. Over time the nominal exchange rate rises to its new steady state value. So, a low value of the

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<sup>9</sup>In Appendix A we show that we obtain quantitatively similar results if we assume that asset markets are complete (see the introduction for a brief discussion of the intuition in this case).

contemporaneous real exchange rate is associated with increases in the exchange rate over time.

Panel B of Table 9 reports the implied values of  $\beta_1$  in our relative-price regression, equation (3). Notice that these values are positive and grow in absolute value with the horizon. While the sign of the coefficients is consistent with the data, this simple model with only technology shocks overstates the extent to which adjustment in the *RER* occurs via inflation.

**A monetary policy shock** Figure 17 shows the effects of an iid monetary policy shock. We set the interest rate smoothing parameter,  $\gamma$ , to 0.75 so that the impact of this shock is easier to see in the figure. The monetary policy shock causes an increase in  $R_t$ . The resulting contraction leads to decrease in domestic consumption, wages, marginal cost, and inflation. The persistence of these effects arises from the interest rate smoothing parameter of the Taylor rule.

The fall in domestic marginal costs leads domestic producers to lower the price of exported goods, so that  $\pi_{H,t}^*$  falls leading to a lower value of  $\pi_t^*$ . The foreign Taylor rule implies that  $R_t^*$  falls. Since the Taylor principle holds, the foreign real interest rate falls, which generates a rise in foreign consumption. The *RER* returns to its initial steady state level after a few periods. The usual UIP logic implies that the interest rate differential must be offset by an expected depreciation of the home currency. This happens via an instantaneous appreciation of the home currency followed by a persistent depreciation.

Both the *RER* and the *NER* initially fall and then rise, which again produces negative values for  $\beta_1$  in our baseline regression, equation (2). As shown in Panel A of Table 9, these model-implied values grow somewhat with horizon, though quickly reach their maximal value after about 1 year. As compared to the case when the economy is driven by technology shocks, the regression coefficients implied by monetary policy shocks are smaller. A shortcoming of this model driven only by monetary policy shocks is that the adjustment in the *RER* occurs roughly equally through changes in the *NER* and relative inflation rates.

**A spread shock** Figure 18 displays the effect of an iid positive spread shock,  $\eta_t$ . In contrast with the flexible price case, a spread shock now has real effects. The shock increases the demand for the domestic bond, so the domestic interest rate falls to clear that market. In the home country, the Taylor rule implies that domestic inflation must fall. Since prices are sticky, inflation cannot fall as much as with flexible prices and the domestic nominal interest rate cannot fall enough to clear the domestic bond market. As a result, the domestic currency appreciates to make domestic bonds more expensive to foreigners, reducing their demand.

According to Figure 18, the spread shock is larger than the difference between  $R_t$  and  $R_t^*$ . So, the modified UIP equation, equation (46), implies that  $E_t \Delta S_{t+1} < 0$ , which corresponds to an expected appreciation of the home currency. This particular result depends on the degree of price stickiness. When prices are very sticky the nominal and the real exchange rate commove, so the domestic currency appreciates on impact and then slowly depreciates.

Panels A and B of Table 9, show the model-implied regression statistics for our baseline regression, equation (2), and our relative-price regression, equation (3). In this simple example with only spread shocks, the *RER* adjusts very quickly via changes in the nominal exchange rate.

## 4 Medium-scale DSGE, incomplete-markets model

In this section we investigate an empirically plausible version of our model can account for the facts that we document. It is well known that open-economy models face important outstanding empirical challenges (see for example Obstfeld and Rogoff (2000) and Engel (2014)). We will not resolve all those puzzles. But our initial results indicate that the model discussed below does reasonably well at accounting for some key characteristics of the data. In this draft we confine ourselves to allowing for only for two types of shocks. In a future draft, we will accommodate a richer menu of shocks and allow for capital accumulation.

### 4.1 Model structure

The basic structure of the model is the same as the sticky price model described above except that we allow for sticky nominal wages as in Erceg, Henderson and Levin (2000). Intermediate producers purchase a homogeneous labor input from a representative labor aggregator. The latter produces the homogeneous labor input by combining differentiated labor inputs,  $l_{j,t}$ ,  $j \in (0, 1)$ , using the technology

$$L_t = \left[ \int_0^1 l_{j,t}(h)^{\frac{\nu_L-1}{\nu_L}} dj \right]^{\frac{\nu_L}{\nu_L-1}}. \quad (72)$$

Labor contractors are perfectly competitive and take the nominal wage rate,  $W_t$ , which is the cost of hiring units of  $L_t$ , as given. They also take the wage rate,  $W_{j,t}$ , of the  $j^{th}$  labor type as given. Profit maximization on the part of contractors implies:

$$l_{j,t}(h) = \left[ \frac{W_{j,t}}{W_t} \right]^{-\nu_L} L_t. \quad (73)$$

Perfect competition and equation (72) imply:

$$W_t = \left[ \int_0^1 W_{j,t}^{1-\nu_L} dj \right]^{\frac{1}{1-\nu_L}}. \quad (74)$$

There is a continuum of households, indexed by  $j \in (0, 1)$ . Each household is a monopoly supplier of a differentiated labor service, and sets its wage  $W_{j,t}$  subject to (73) and Calvo-style wage frictions. That is, the household optimizes the wage,  $W_{j,t}$  with probability  $1 - \xi_w$ . With probability  $\xi_w$  the wage rate is given by:

$$W_{j,t} = W_{j,t-1}.$$

The preferences of the  $j^{\text{th}}$  household are given by

$$E_t \sum_{i=0}^{\infty} \beta^i \left[ \log (C_{t+i} - h\bar{C}_{t+i-1}) - \frac{\chi}{1+\phi} L_{j,t+i}^{1+\phi} + \mu \frac{(M_{t+i}/P_{t+i})^{1-\sigma_M}}{1-\sigma_M} + \eta_{t+i} V \left( \frac{B_{H,t+i}}{P_t} \right) \right]. \quad (75)$$

Here  $\bar{C}_t$  is aggregate consumption in time  $t$ . The household budget constraint becomes

$$B_{H,t} + S_t B_{F,t} + P_t C_t + M_{t+} \quad \frac{\phi_B}{2} \left( \frac{S_t B_{F,t}}{P_t} \right)^2 P_t = R_{t-1} B_{H,t-1} + S_t R_{t-1}^* B_{F,t-1} \\ + W_{j,t} L_{j,t} (1 + \tau_W) + T_t + M_{t-1} + Q_{j,t}. \quad (76)$$

where  $\tau_W$  is a wage subsidy that corrects the steady state level of monopoly distortions. Here,  $Q_{j,t}$  represents the net proceeds of an asset that provides insurance against the idiosyncratic uncertainty associated with the Calvo wage-setting friction. We have suppressed indexing variables by  $j$  that are the same across households.<sup>10</sup>

The sequence of events in a period for a household is as follows. First, the technology shocks and spread shocks are realized. Second, the household makes its consumption and asset decisions, including securities whose payoffs are contingent upon whether it can re-optimize its wage decision. Third, the household sets its wage rate.

The changes introduced to the foreign economy are symmetric so that the preferences of the  $j^{\text{th}}$  household are given by:

$$E_t \sum_{i=0}^{\infty} \beta^i \left[ \log (C_{t+i}^* - h\bar{C}_{t+i-1}^*) - \frac{\chi}{1+\phi} (L_{j,t+i}^*)^{1+\phi} + \mu \frac{(M_{t+i}^*/P_{t+i}^*)^{1-\sigma_M}}{1-\sigma_M} + \eta_{t+i} V \left( \frac{B_{H,t+i}}{P_t^*} \right) \right], \quad (77)$$

Here  $\bar{C}_t^*$  is aggregate consumption in the foreign country at time  $t$ . The budget constraint of the  $j^{\text{th}}$  foreign household is given by:

$$B_{F,t}^* + S_t^{-1} B_{H,t}^* + P_t^* C_t^* + M_{t+}^* \quad \frac{\phi_B}{2} \left( \frac{S_t^{-1} B_{H,t}^*}{P_t^*} \right)^2 P_t^* = R_{t-1}^* B_{F,t-1}^* + S_t^{-1} R_{t-1} B_{H,t-1}^* \\ + W_{j,t}^* L_{j,t}^* (1 + \tau_W) + T_t^* + M_{t-1}^* + Q_{j,t}^*. \quad (78)$$

In Appendix A we derive the set of equations whose solutions constitute a log-linear equilibrium for the model economy.

## 4.2 Parameter values

We divide the parameters into two categories: those that we calibrate and those that we estimate. We calibrate the parameters whose values are listed in Table 5.

We maintain the parameter values used in the previous sections and set the habit persistence parameter,  $h$ , the probability that firms can't adjust their price,  $\xi$ , and the probability

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<sup>10</sup>Instead of contingent securities we could assume that there's only one household which has a continuum of members each of which supplies a specialized type of labor and each of which is subject to Calvo-type wage rigidities. With separable preferences, it is optimal to equalize consumption for each of its members.

that labor suppliers can't readjust their nominal wage,  $\xi_W$  to the point estimates reported in Christiano, Eichenbaum, and Evans (2005). We set the value of  $\nu_L$  so as to imply a 10 percent steady state markup.<sup>11</sup>

We now turn to  $\rho_\eta$  and  $\sigma_\eta$  which govern the AR(1) process for the spread shock. Equation (67) implies that if the one-quarter ahead nominal exchange rate behaves like a random walk, then

$$\hat{R}_t^* - \hat{R}_t = \eta_t. \quad (79)$$

So for any given country we can identify its spread relative to the U.S. with the corresponding interest rate differential. For each of the flexible exchange rate countries in Table 1 we estimate an AR(1) for the interest rate differential,

$$\eta_t = \rho_\eta \eta_{t-1} + \varepsilon_{\eta,t},$$

where  $\varepsilon_{\eta,t}$  is an iid process and  $E\varepsilon_{\eta,t}^2 = \sigma_{\varepsilon_\eta}^2$ . For each country, we report our results in Table 6 using the same sample period as in Table 1. In terms of our model, there is no reason to focus on any one of these estimates since U.S. financial markets are integrated with all of these markets. In practice we set  $\rho_\eta$  to 0.9, which is well within one standard deviation of the point estimate for all of the countries in our sample except for Canada, where it is within two standard deviations.

We estimate the remaining parameters  $\rho_A$ ,  $\sigma_A$ ,  $\sigma_{\varepsilon_\eta}$  so that the model is consistent with the following moments of the data. First, we require that the standard deviation and first-order autocorrelation of HP-filtered model output be the same as the analog objects in quarterly U.S. data over the sample 1973-2007.<sup>12</sup> In this exercise we assume that the technology process is uncorrelated across countries. Second, we require that the model be consistent with the results of implementing the Fama regression defined by equation (69). In particular, we estimated that regression for each of the flexible exchange rate countries and corresponding sample period used to construct Table 1. Our results are reported in Table 7. In every case the coefficient  $\beta_1$  is estimated very imprecisely so many target values would be very reasonable. In results reported below, we require that the probability limit for  $\beta_1$  implied by our model is equal to 0.5. Table 8 reports our results, reported in the column labeled nominal rigidities. We also re-estimated these parameters for a flexible price and wage version of the model ( $\xi = \xi_W = 0$ ).

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<sup>11</sup>We initially set  $\nu_L$  to 21 value assumed in Christiano, Eichenbaum, and Evans (2005). This value corresponds to a steady state labor markup of 5%. When we did this we encountered a determinacy, so we used a half between the value in Christiano, Eichenbaum, and Evans (2005) and the value assumed in Erceg, Guerrieri and Gust (2005). In practice we found that our results were not very sensitive to changes in the value of  $\nu_L$  from our assumed value. See Altig, et al. (2011) for the discussion of the role markups in the dynamics of models like ours.

<sup>12</sup>We measure output using per-capita real GDP.

### 4.3 Empirical results

We now report and discuss the model’s implication for the key statistics that we emphasized in our empirical analysis. Panel C of Table 1 reports the models’ implications for the coefficients in regression (2).

A number of results are worth noting. First, the model with nominal rigidities does a good job of accounting for the estimated values of  $\beta_1$ , including the fact that they rise in absolute value with the regression horizon. Second, the model without nominal rigidities also does reasonably well on this dimension of the data. But it substantially overstates how quickly the absolute value of  $\beta_1$  rises with the horizon.

Panel C of Table 3 reports the model’s implications for the coefficients in the regression equation (3). Taking sampling uncertainty into account, the model with nominal rigidities does a very good job of accounting for the estimated values of  $\beta_1$ . The model without nominal rigidities does not do quite as well on this dimension of the data. Still, it does capture the fact that the estimated values of  $\beta_1$  in regression (3) are much smaller than those in (2).

To understand this last result it is useful to consider the models’ impulse response functions. Figures 19 and 20 display the response functions of the model with nominal rigidities to a technology and spread shock, respectively. Figures 21 and 22 display the analog response functions for the model without rigidities. Consider the response of inflation in the model without rigidities to a technology shock. Notice that  $\pi_{H,t}$  *rises* by roughly 1.75 percent after a negative technology shock. But  $\pi_{F,t}$ , the price of foreign goods in the domestic currency *falls* by 1.0 percent after the shock. Domestic inflation is a weighted average of  $\pi_{H,t}$  and  $\pi_{F,t}$ . So overall inflation doesn’t rise by as much as it would absent the offsetting behavior of  $\pi_{F,t}$ . This observation helps explain the ability of the model without nominal rigidities to generate relatively low estimated values of  $\beta_1$  in regressions like (3) for low values of  $j$ . The model without nominal rigidities still has a quantitative problem because the offsetting effects on inflation are not present when there is a spread shock. Both  $\pi_{H,t}$  and  $\pi_{F,t}$  fall in response to a positive spread shock. All of the movements in inflation and its constituents are muted in the model with nominal rigidities.

In the introduction we noted two key facts with which any plausible open-economy model ought to be consistent: real and nominal exchange rates commove closely in the short run (Mussa (1986)) and *RERs* are highly inertial (Rogoff (1996)). We conclude with a discussion of how our model fares with respect to these facts. Table 12 reports the standard deviations of  $\Delta RER$  and  $\Delta NER$  for the countries in our sample and our model. In addition, we report estimates for an AR(1) representation for the *RERs*. We report the analog statistics for our model in the same table.

Three features of table Table (12) are worth noting. First, our data is consistent with the well know fact that real and nominal exchange are equally volatile (Mussa (1986), Rogoff (1996), and Burstein and Gopinath (2015)). More interestingly, both versions of our model (with and without nominal rigidities) are consistent with this fact. Second, the model, nominal rigidities magnify the volatility of  $\Delta RER$  and  $\Delta NER$  by about 1/3 relative to the



flexible price model. But even the model with nominal rigidities understates, for most countries, the volatility of  $\Delta RER$  and  $\Delta NER$ . The median estimates of these statistics across countries are 0.049 and 0.041, respectively. The analog values in the model with nominal rigidities are 0.029 for both statistics. In the next draft of the paper we will include capital and other shocks to the model, e.g. shocks to monetary policy, government spending and capital embodied technology shocks. These additional shocks will increase the volatility of  $\Delta RER$  and  $\Delta NER$ . Third, with the exception of Germany, the estimated AR(1) coefficients for the  $RER$ s exceed 0.96 which is consistent with the results in Burstein and Gopinath (2015). Interestingly, taking sampling uncertainty into account, both versions of our model account for the estimated value of the AR(1) coefficient.

A different way to think about persistence of the  $RER$ , is to ask whether our model implies that, in small samples, an analyst would reject the hypothesis that the  $RER$  has a unit root. To this end we simulated 10,000 samples, each of length 120, from our model. On each sample we computed an augmented Dickey-Fuller test. We find that in only 40 percent of the samples could we reject, at the 5 percent significance level, the null hypothesis of a unit root. In the remaining 60 percent of the samples, the  $RER$  is sufficiently persistent (and the augmented Dickey-Fuller test is not sufficiently powerful) that we can't reject the null hypothesis that the  $RER$  has a unit root. Taken as a whole these results indicate that our model is broadly consistent with the properties of the data stressed by Mussa (1986) and Rogoff (1996).

## 5 Conclusion

This paper documents that when exchange rates are floating and monetary policy is characterized by a Taylor rule, real exchange rates adjust overwhelmingly in the medium and long run through changes in *nominal* exchange rates. They do not adjust via cross-country differences in inflation rates. Two facts are the basis of this conclusion: for countries under a Taylor rule, changes in the  $NER$  at horizons of two years or more are highly correlated with the current value of the  $RER$ . But changes in the  $NER$  are uncorrelated with differential inflation rates across countries at all horizons that we consider.

In our theoretical analysis, we show that a wide variety of open-economy models are consistent with these facts: models with and without nominal rigidities as well complete and incomplete market models. But to account for our empirical findings, models must allow for home bias in consumption, monetary policy guided by a Taylor rule, and a conditional form of UIP.

We assess the quantitative importance of our proposed explanation of our empirical findings using a medium-scale DSGE model. As it turns out, the version of the model that allows for sticky prices and wages does a very good job of accounting for our results. Significantly, the same model is consistent with other key observations about the volatility and persistence of real exchange rates, as well as the fact that standard tests of UIP reject that hypothesis.

The next draft of this paper will allow for capital accumulation and a richer menu of shocks to the economy.

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Figure 1: Australia: NER and RER data

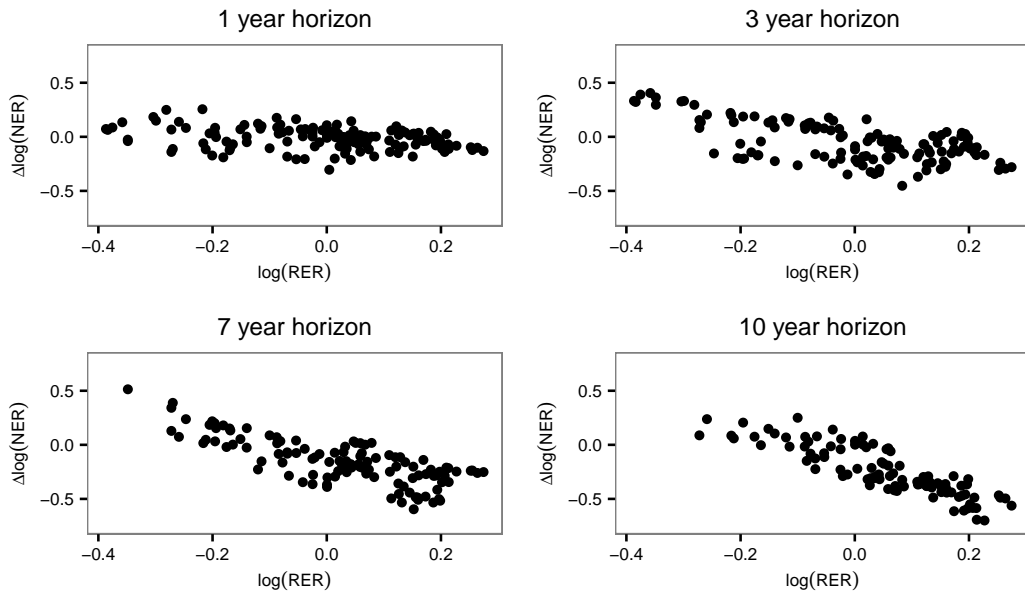


Figure 2: Canada: NER and RER data

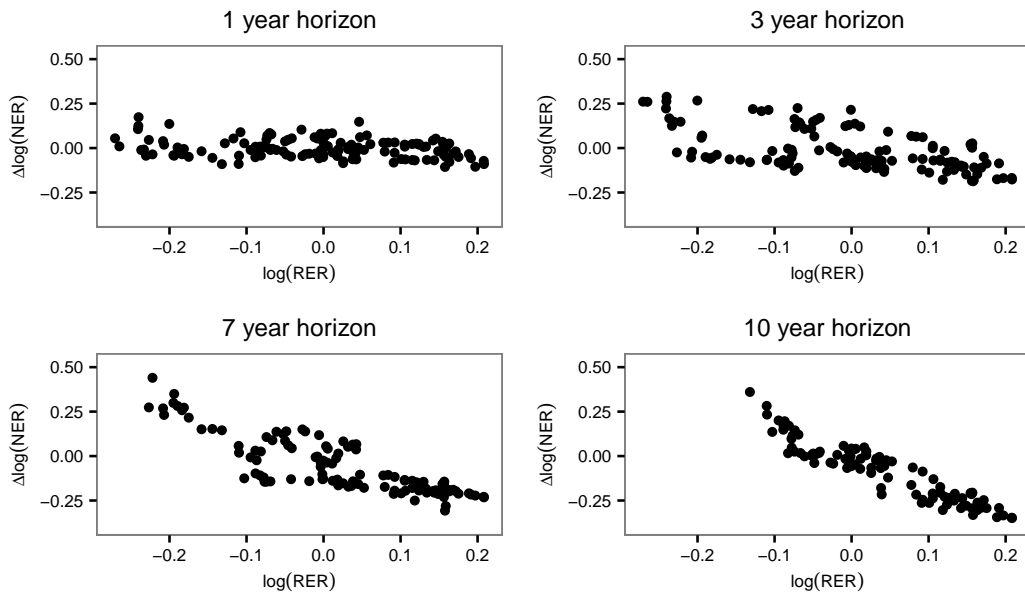


Figure 3: Euro area: NER and RER data

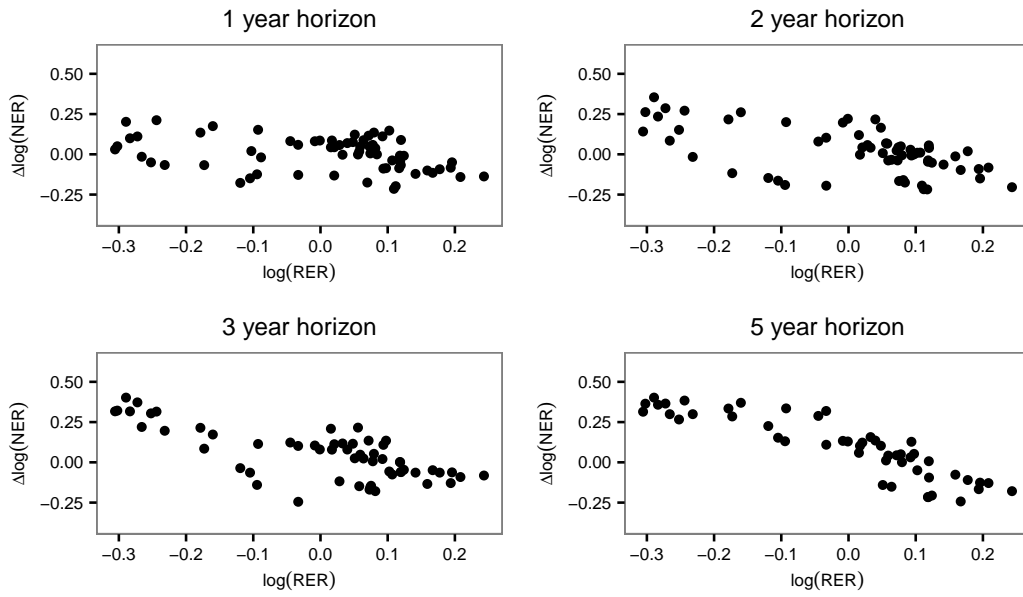


Figure 4: Germany: NER and RER data

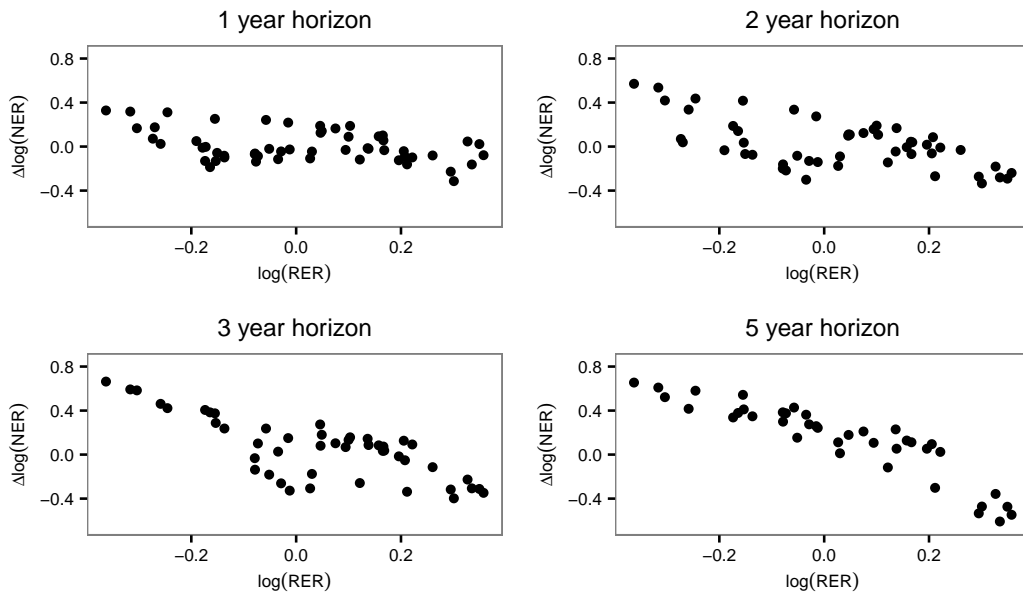


Figure 5: Japan: NER and RER data

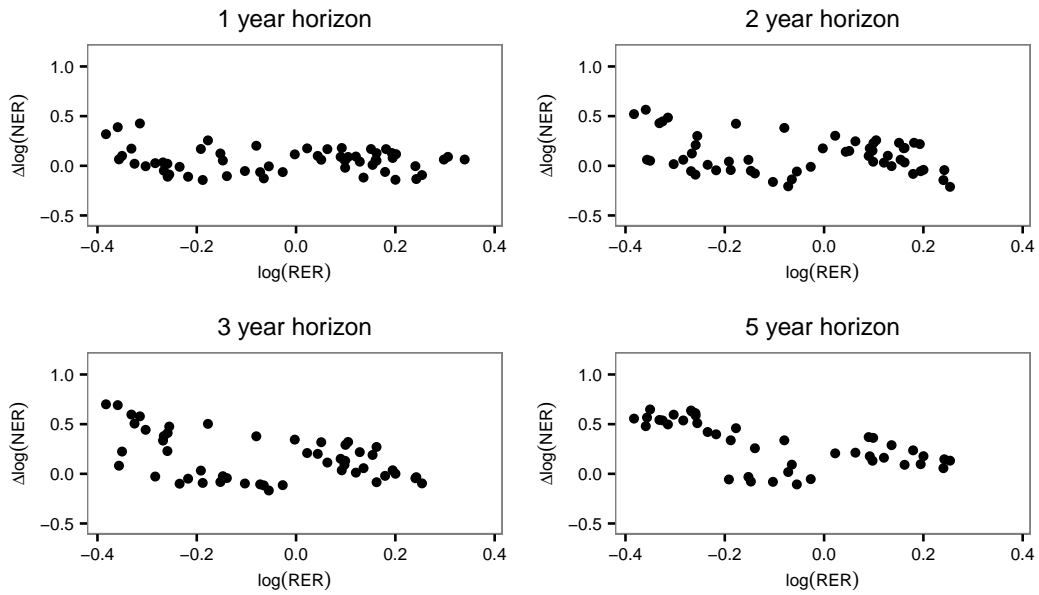


Figure 6: New Zealand: NER and RER data

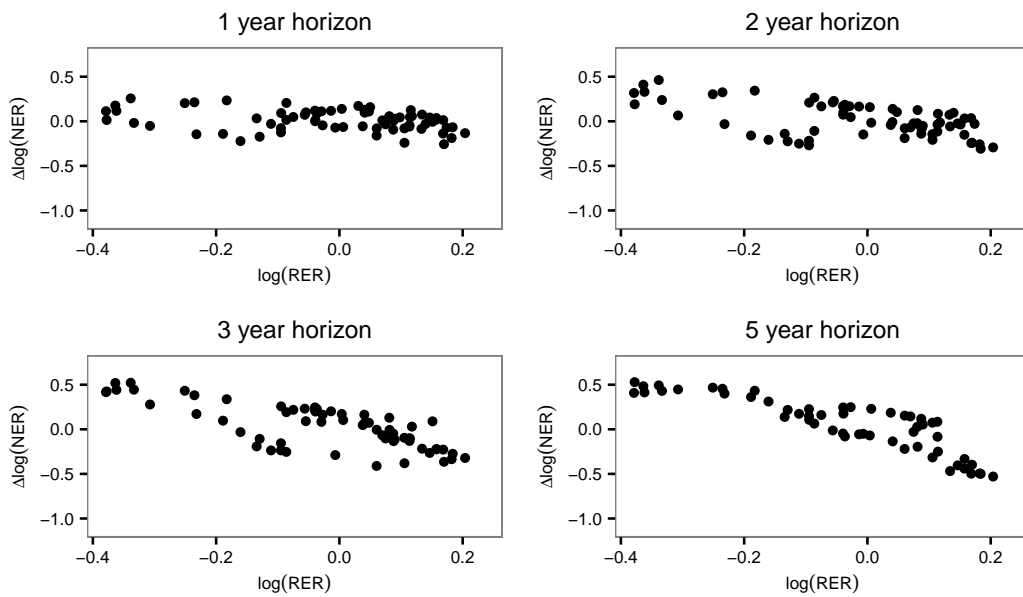




Figure 7: Norway: NER and RER data

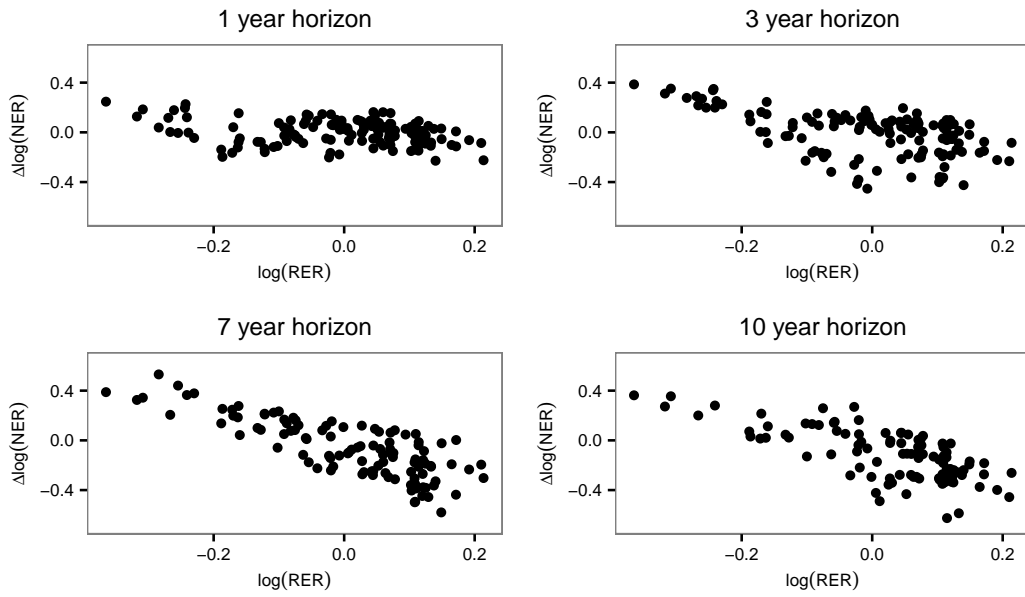


Figure 8: Sweden: NER and RER data

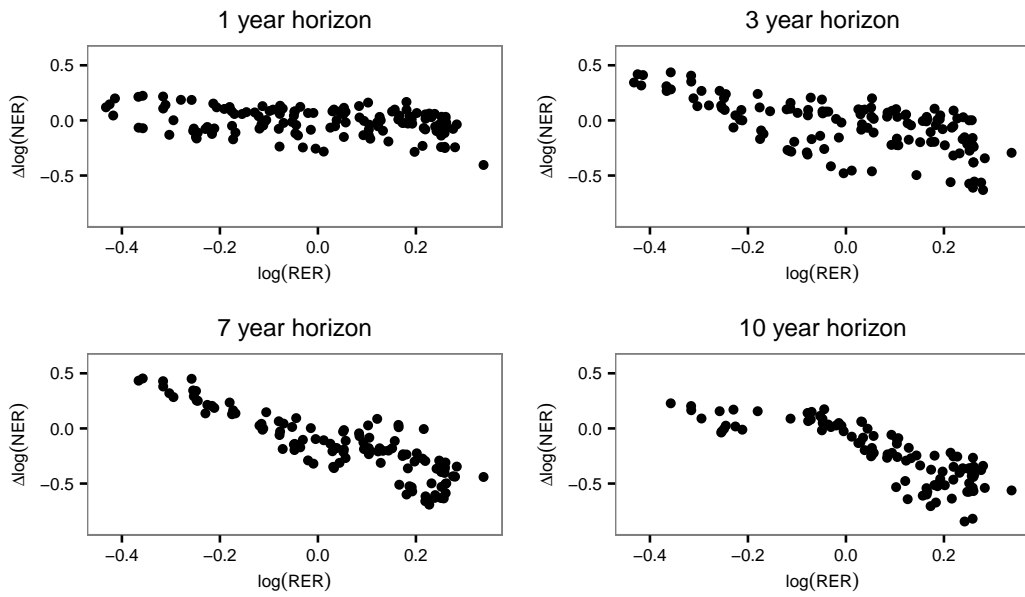


Figure 9: United Kingdom: NER and RER data

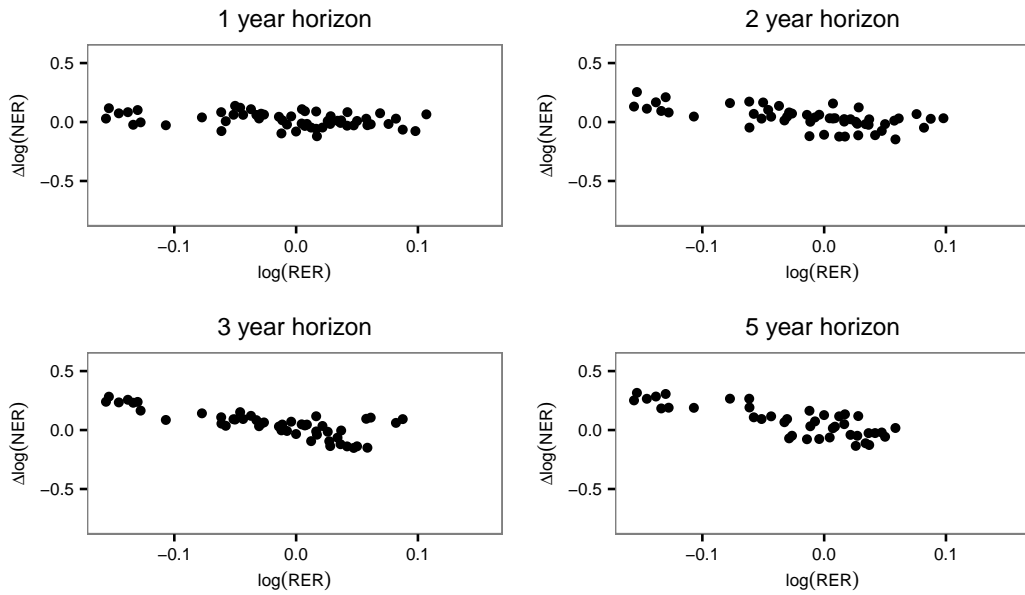


Figure 10: China: NER and RER data

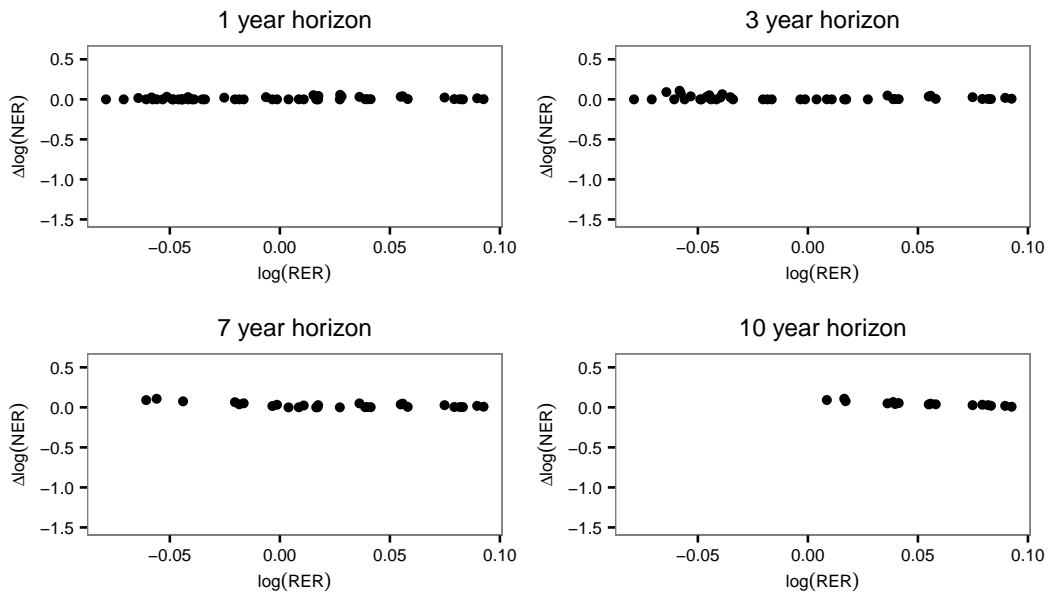


Figure 11: Hong Kong: NER and RER data

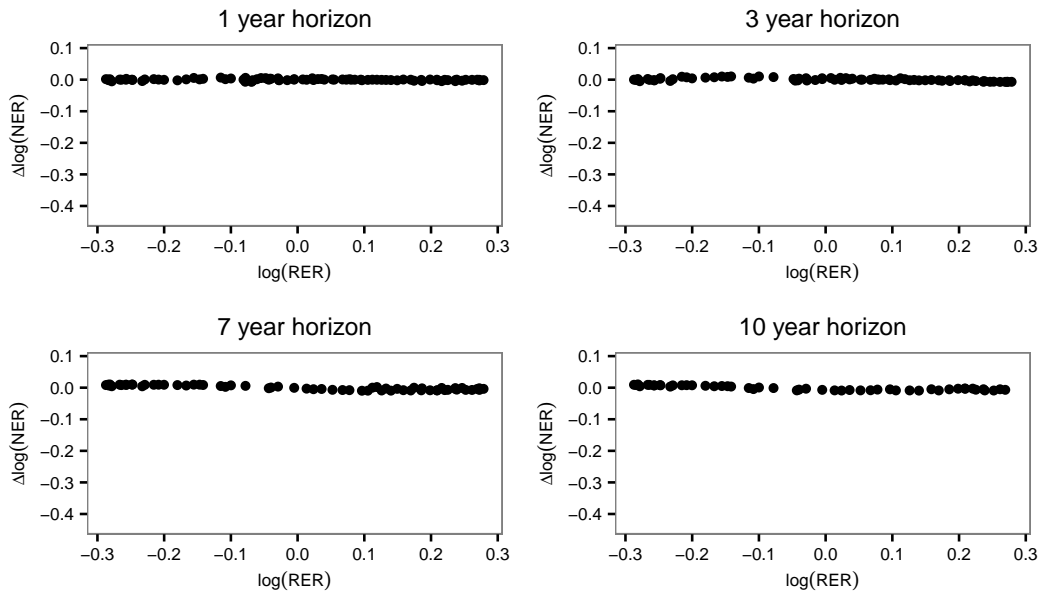
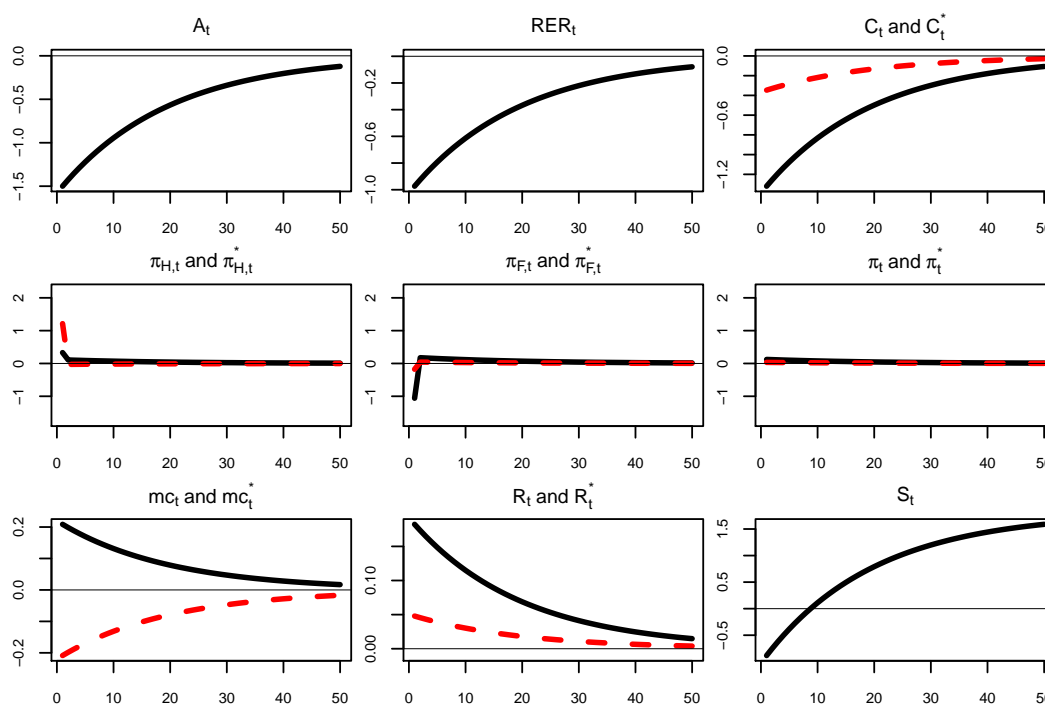
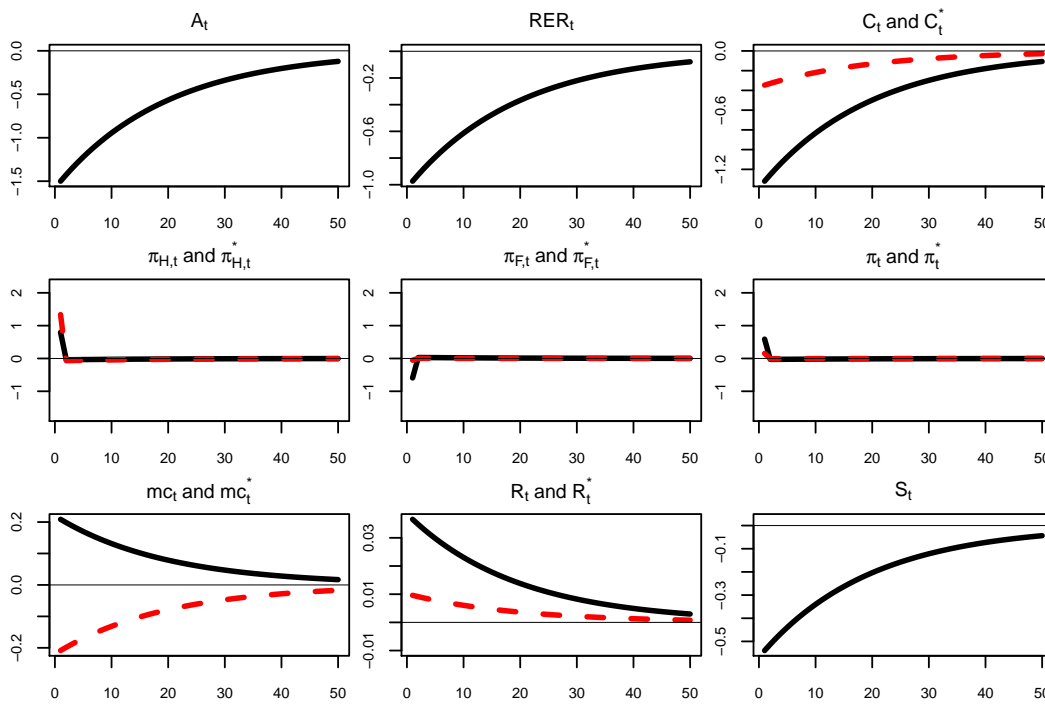


Figure 12: Response to technology shock under Taylor rule



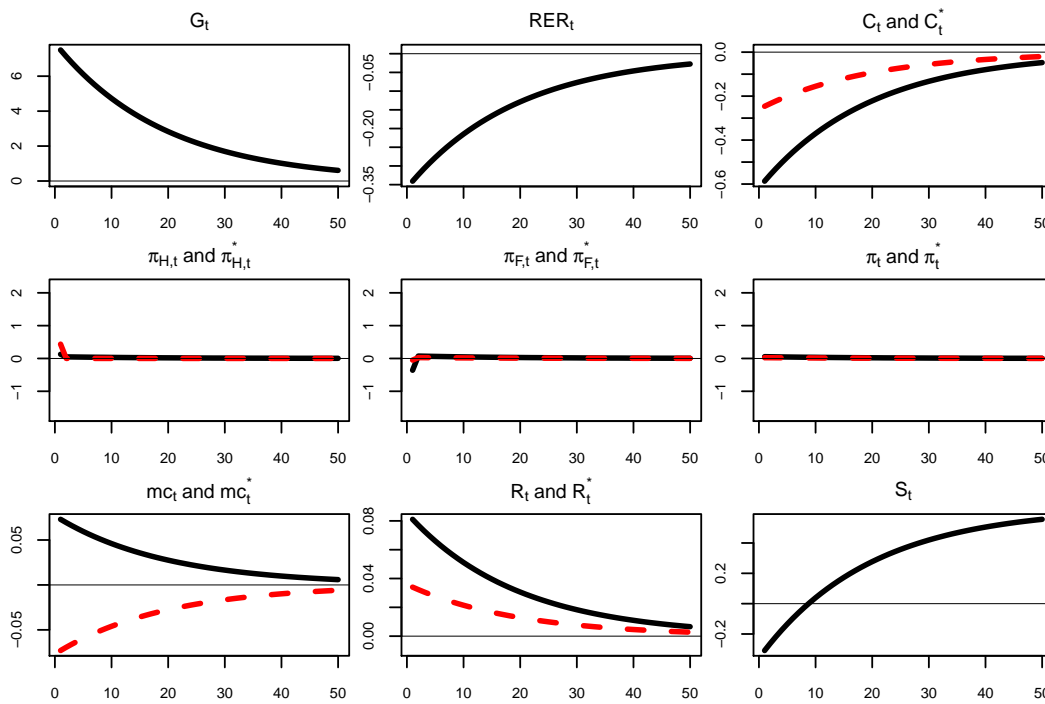
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 13: Response to technology shock under money-growth rule



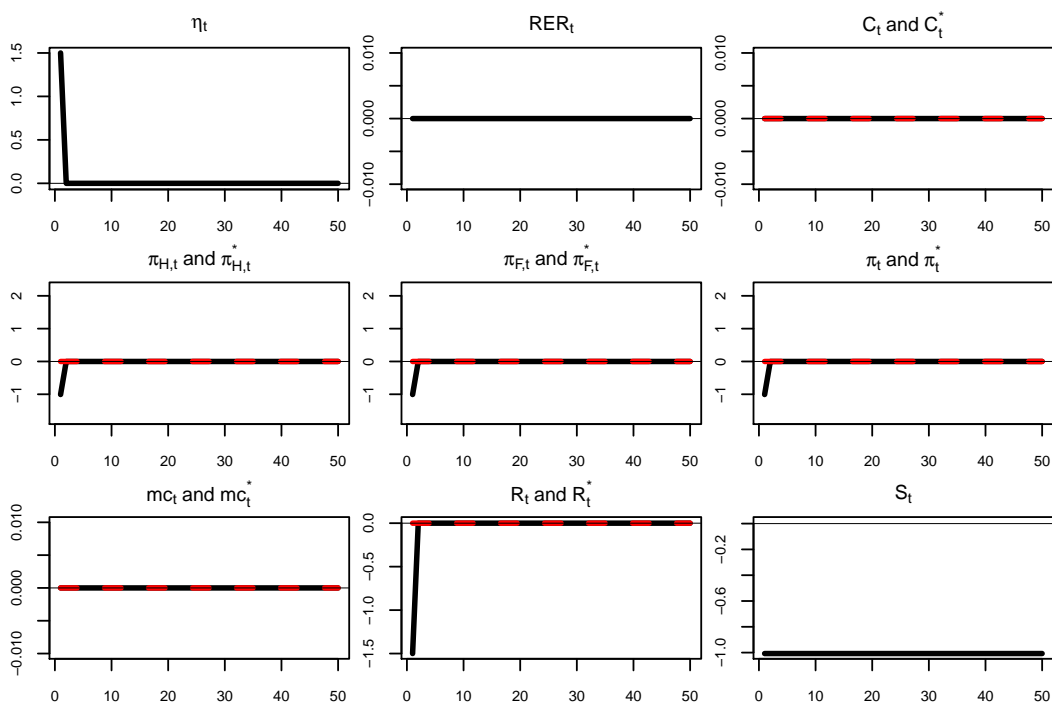
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 14: Response to government spending shock under Taylor rule



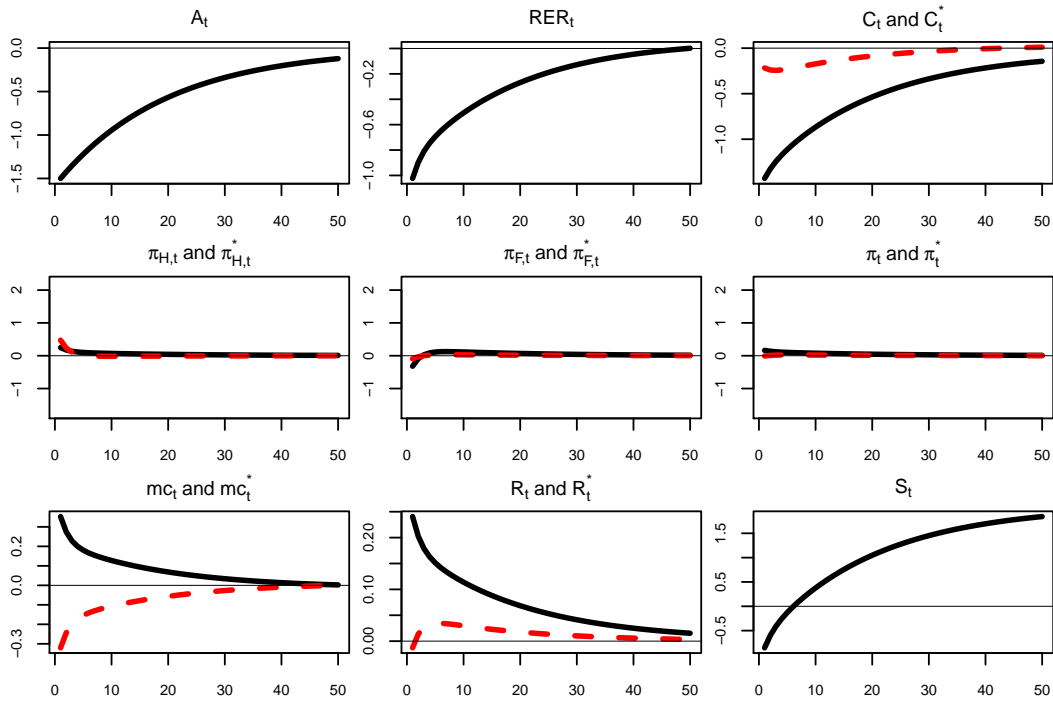
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 15: Response to spread shock under Taylor rule with incomplete markets



Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

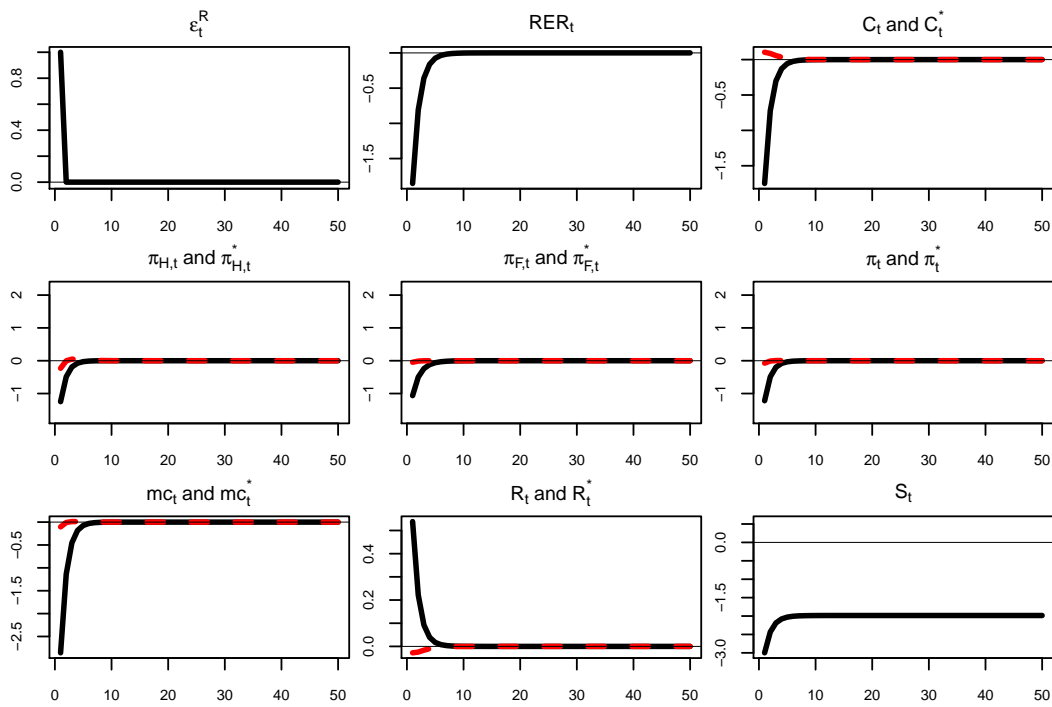
Figure 16: Response to technology shock under Taylor rule with incomplete markets and sticky prices



Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

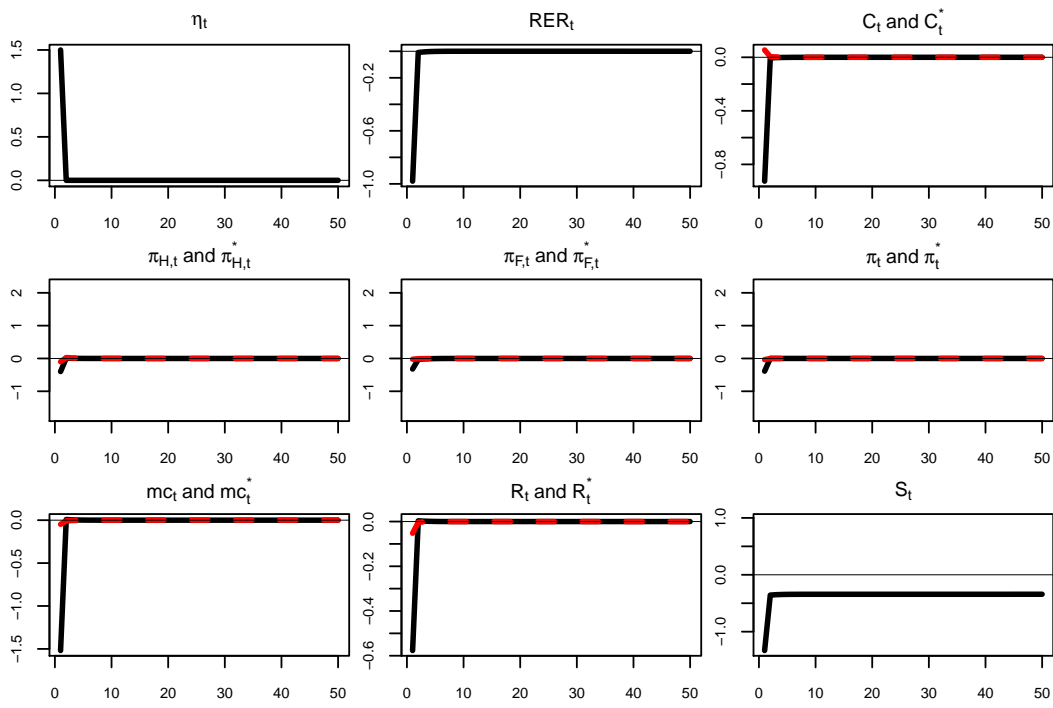


Figure 17: Response to monetary-policy shock under Taylor rule with incomplete markets and sticky prices



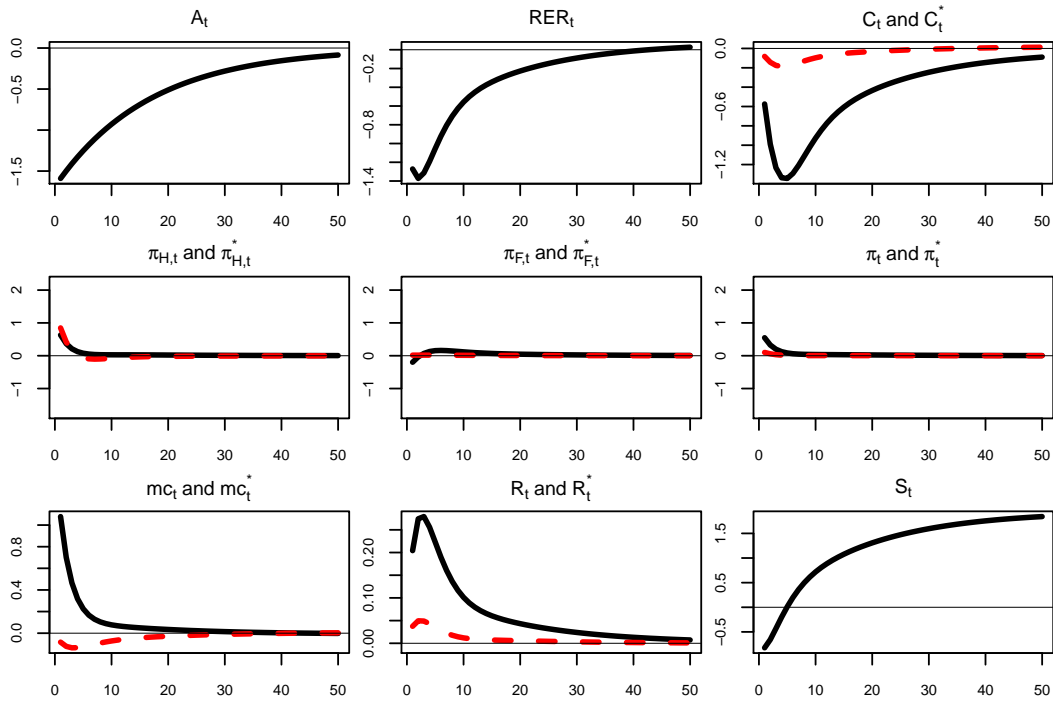
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 18: Response to spread shock under Taylor rule with incomplete markets and sticky prices



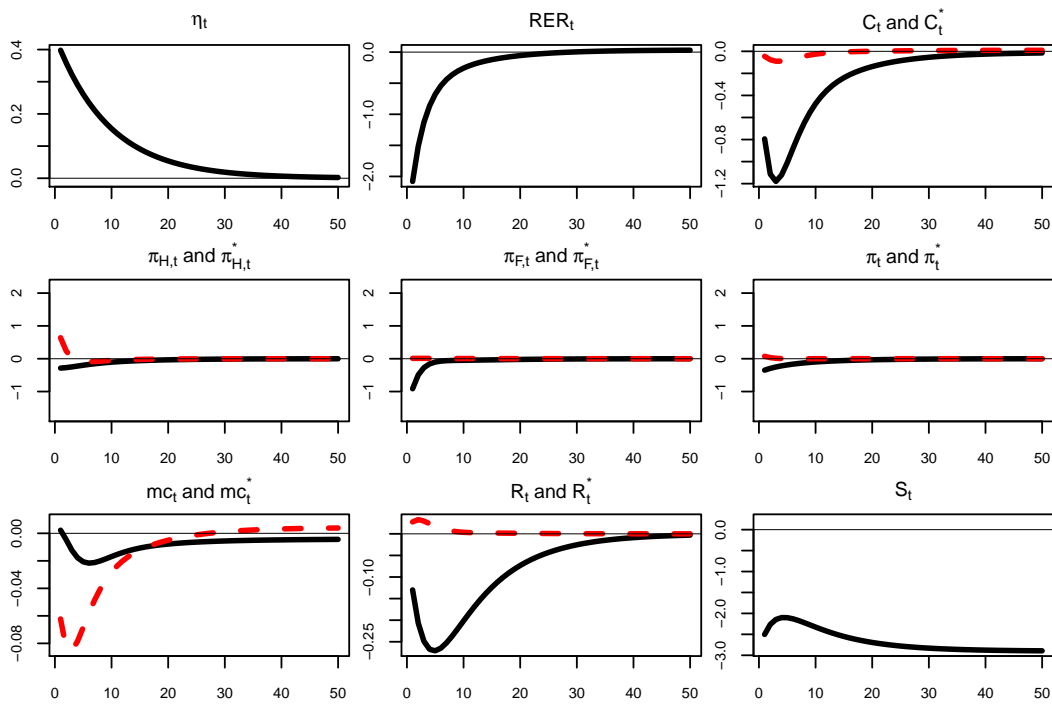
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 19: Response to technology shock under Taylor rule with incomplete markets and nominal rigidities



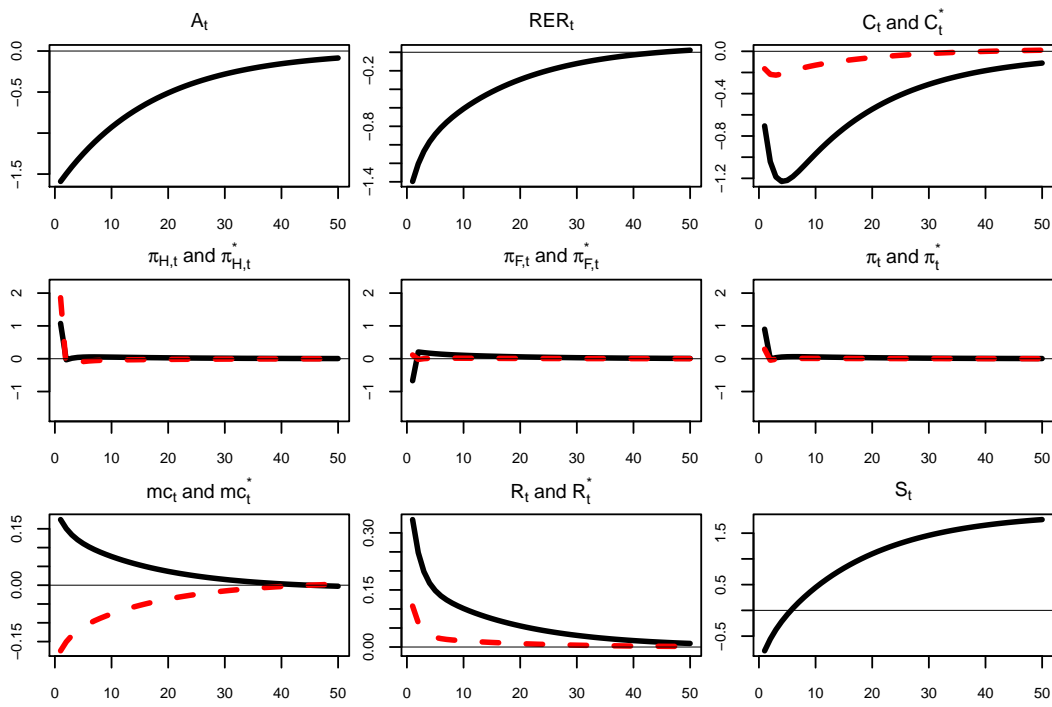
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 20: Response to spread shock under Taylor rule with incomplete markets and nominal rigidities



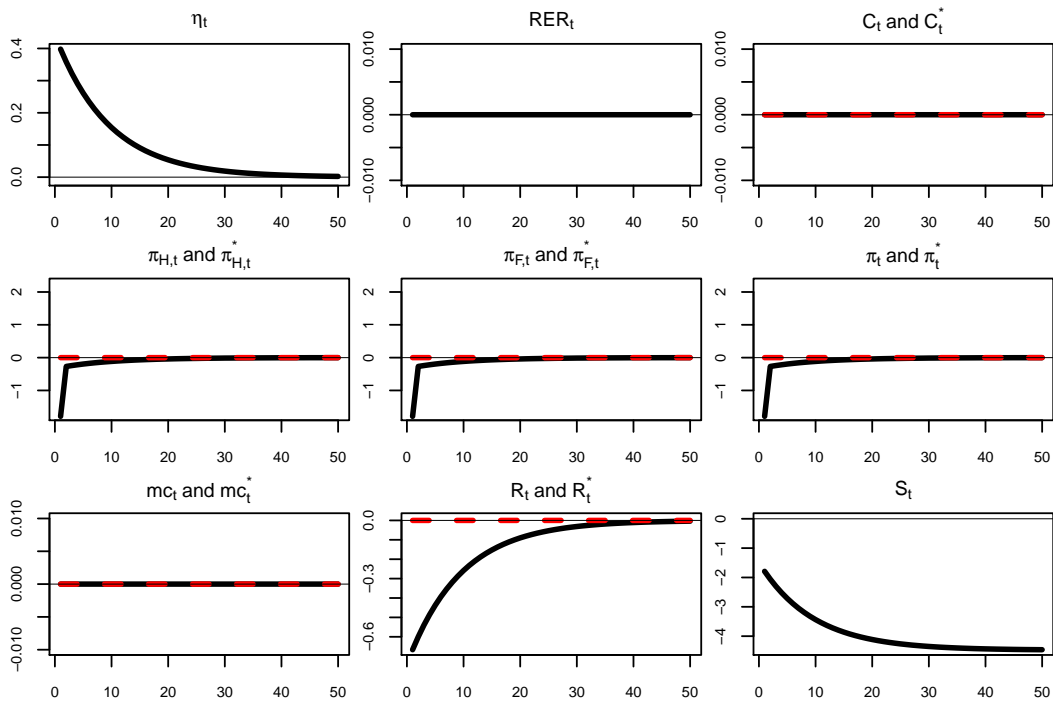
Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 21: Response to technology shock under Taylor rule with incomplete markets and flexible prices, medium-scale model



Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Figure 22: Response to spread shock under Taylor rule with incomplete markets and sticky prices, medium-scale model



Note: The vertical axis is expressed in percent. Inflation and interest rates are in annualized percent. The horizontal axis shows quarters after the shock. Red-dashed lines indicate the variables with a \*.

Table 1: Baseline regression  $\beta_1$

	Horizon (in years)				
	1	3	5	7	10
A: Flexible exchange rate countries					
Australia	-0.198 (0.093)	-0.703 (0.193)	-1.057 (0.212)	-1.127 (0.223)	-1.590 (0.137)
Canada	-0.122 (0.073)	-0.549 (0.184)	-0.944 (0.186)	-1.158 (0.143)	-1.661 (0.123)
Euro Area	-0.252 (0.144)	-0.768 (0.112)	-1.095 (0.112)	NA	NA
Germany	-0.310 (0.147)	-1.103 (0.169)	-1.557 (0.275)	NA	NA
Japan	-0.091 (0.148)	-0.554 (0.317)	-0.746 (0.206)	NA	NA
New Zealand	-0.231 (0.164)	-1.149 (0.135)	-1.563 (0.289)	NA	NA
Norway	-0.214 (0.120)	-0.765 (0.159)	-1.287 (0.250)	-1.463 (0.293)	-1.239 (0.053)
Sweden	-0.199 (0.095)	-0.745 (0.158)	-1.135 (0.188)	-1.365 (0.133)	-1.281 (0.214)
United Kingdom	-0.295 (0.160)	-1.315 (0.340)	-1.644 (0.163)	NA	NA
B: Fixed exchange rate countries					
China	0.072 (0.065)	-0.119 (0.158)	-0.209 (0.109)	NA	NA
Hong Kong	-0.003 (0.002)	-0.015 (0.006)	-0.025 (0.005)	-0.031 (0.004)	-0.031 (0.005)
C: Model-implied values.					
With nominal rigidities	-0.393	-0.711	-0.868	-0.972	-1.064
Without nominal rigidities	-0.546	-1.130	-1.410	-1.546	-1.631

Table 2: Baseline regression  $R^2$

Horizon (in years)					
1	3	5	7	10	

A: Flexible exchange rate countries

Australia	0.104	0.388	0.586	0.601	0.756
Canada	0.078	0.349	0.590	0.687	0.878
Euro Area	0.122	0.542	0.795	NA	NA
Germany	0.172	0.570	0.834	NA	NA
Japan	0.024	0.214	0.402	NA	NA
New Zealand	0.100	0.559	0.751	NA	NA
Norway	0.076	0.294	0.552	0.646	0.512
Sweden	0.107	0.409	0.654	0.765	0.667
United Kingdom	0.105	0.584	0.648	NA	NA

B: Fixed exchange rate countries vis-à-vis U.S.

China	0.049	0.052	0.139	NA	NA
Hong Kong	0.054	0.334	0.619	0.746	0.732



Table 3: Relative price regression  $\beta_1$ 

	Horizon (in years)				
	1	3	5	7	10
A: Flexible exchange rate countries					
Australia	0.011 (0.034)	0.046 (0.095)	0.098 (0.080)	0.197 (0.083)	0.482 (0.183)
Canada	0.014 (0.015)	0.033 (0.044)	0.040 (0.064)	0.075 (0.106)	0.258 (0.183)
Euro Area	0.002 (0.013)	0.003 (0.021)	0.043 (0.016)	NA	NA
Germany	-0.211 (0.120)	-0.257 (0.181)	-0.190 (0.237)	NA	NA
Japan	-0.003 (0.012)	0.010 (0.029)	0.040 (0.026)	NA	NA
New Zealand	-0.010 (0.011)	-0.066 (0.017)	-0.089 (0.012)	NA	NA
Norway	-0.066 (0.030)	-0.152 (0.111)	-0.113 (0.169)	-0.059 (0.194)	-0.062 (0.204)
Sweden	0.015 (0.021)	0.077 (0.056)	0.108 (0.097)	0.055 (0.187)	-0.023 (0.212)
United Kingdom	-0.018 (0.013)	-0.030 (0.047)	-0.036 (0.037)	NA	NA
B: Fixed exchange rate countries					
China	-0.298 (0.082)	-0.722 (0.064)	-1.141 (0.035)	NA	NA
Hong Kong	-0.093 (0.051)	-0.453 (0.142)	-0.927 (0.165)	-1.323 (0.145)	-1.629 (0.031)
C: Fixed exchange rate countries vis-à-vis Germany					
Ireland	-0.301 (0.089)	-0.830 (0.084)	-1.092 (0.093)	NA	NA
Portugal	-0.222 (0.055)	-0.651 (0.063)	-0.820 (0.036)	NA	NA
Spain	-0.153 (0.031)	-0.422 (0.080)	-0.632 (0.070)	NA	NA
D: Model-implied values					
With nominal rigidities	0.000	0.000	0.035	0.071	0.108
Without nominal rigidities	0.188	0.438	0.560	0.620	0.657

Table 4: Relative price regression  $R^2$

	Horizon (in years)				
	1	3	5	7	10
A: Flexible exchange rate countries					
Australia	0.004	0.013	0.037	0.086	0.236
Canada	0.011	0.016	0.014	0.024	0.102
Euro Area	0.002	0.001	0.264	NA	NA
Germany	0.162	0.101	0.051	NA	NA
Japan	0.003	0.005	0.118	NA	NA
New Zealand	0.020	0.346	0.663	NA	NA
Norway	0.104	0.111	0.037	0.006	0.004
Sweden	0.013	0.063	0.064	0.008	0.001
United Kingdom	0.021	0.021	0.019	NA	NA
B: Fixed exchange rate countries vis-à-vis U.S.					
China	0.368	0.816	0.938	NA	NA
Hong Kong	0.125	0.373	0.659	0.877	0.990
C: Fixed exchange rate countries vis-à-vis Germany					
France	0.149	0.639	0.799	NA	NA
Ireland	0.415	0.724	0.836	NA	NA
Italy	0.394	0.703	0.802	NA	NA
Portugal	0.475	0.851	0.934	NA	NA
Spain	0.487	0.748	0.879	NA	NA

Table 5: Calibrated Parameters

Parameter	Value	Target
$\sigma_M$	10.62	Elasticity of money demand
$\mu$	1	Steady state money stock
$\beta$	$1.03^{-0.25}$	Steady state interest rate
$h$	0.65	Consumption persistence
$\sigma$	1	log utility
$\phi$	1	Disutility of labor
$\gamma$	0.75	Policy rate smoothing
$\theta\pi$	1.5	Taylor principle
$\nu$	6	Intermediate goods firm's markups
$\rho_\eta$	0.9	Persistence of interest rate differential
$\rho$	$\frac{1}{3}$	Substitutability of home and foreign goods
$\xi$	0.6	Frequency of price adjustment
$\phi_B$	0.001	Cost of foreign bond holdings
$\nu_L$	11	Differentiated wage markup
$\xi_W$	0.65	Frequency of wage adjustment

Table 6: Relative interest rate regressions

	$\rho_\eta$	$\sigma$
Australia	0.897 (0.041)	0.352 (0.053)
Canada	0.727 (0.098)	0.301 (0.046)
Euro Area	0.933 (0.042)	0.098 (0.008)
Germany	0.939 (0.041)	0.327 (0.075)
Japan	0.831 (0.100)	0.385 (0.091)
New Zealand	0.904 (0.044)	0.172 (0.018)
Norway	0.843 (0.085)	0.465 (0.065)
Sweden	0.730 (0.181)	0.686 (0.343)
United Kingdom	0.852 (0.060)	0.123 (0.006)

Table 7: Fama regression statistics

	$\beta_0$	$\beta_1$
Australia	-0.004 (0.004)	-0.297 (0.432)
Canada	-0.001 (0.002)	-0.395 (0.367)
Euro Area	0.000 (0.005)	-1.422 (2.046)
Germany	0.004 (0.008)	-0.454 (0.827)
Japan	0.031 (0.008)	-2.771 (0.777)
New Zealand	-0.013 (0.009)	-2.223 (1.115)
Norway	0.001 0.004	-0.008 0.534
Sweden	-0.000 0.004	0.570 0.662
United Kingdom	0.004 0.004	-0.012 1.389

Table 8: Estimated Parameters

Parameter	Value, Flexible Prices	Values, Sticky Prices
$\rho_A$	0.895	0.958
$\sigma_A$	0.018	0.014
$\sigma_\eta$	0.005	0.003

Table 9: Single-shock model-implied regression statistics

Model	Nominal Rigidities	Asset Markets	Mon. Pol.	Shock	Horizon (in years)				
					1	3	5	7	10

A: Baseline regression  $\beta_1$

Small	None	C	Taylor	Tech.	-0.512	-1.270	-1.772	-2.106	-2.408
Small	None	C	Money	Tech.	-0.103	-0.255	-0.355	-0.422	-0.483
Small	None	C	Taylor	Gov.	-0.512	-1.270	-1.772	-2.106	-2.408
Small	Prices	I	Taylor	Tech.	-0.614	-1.438	-1.983	-2.346	-2.678
Small	Prices	I	Taylor	Spread	-1.008	-1.010	-1.010	-1.010	-1.010
Small	Prices	I	Taylor	Mon. Pol.	-0.525	-0.549	-0.549	-0.549	-0.549
Medium	W, P	I	Taylor	Tech.	-0.538	-1.096	-1.377	-1.549	-1.692
Medium	W, P	I	Taylor	Spread	-0.023	0.271	0.431	0.501	0.539
Medium	None	I	Taylor	Tech.	-0.546	-1.130	-1.410	-1.546	-1.631

B: Relative-price regression  $\beta_1$

Small	None	C	Taylor	Tech.	0.327	0.810	1.131	1.343	1.536
Small	None	C	Money	Tech.	-0.083	-0.205	-0.286	-0.340	-0.389
Small	None	C	Taylor	Gov.	0.327	0.810	1.131	1.343	1.536
Small	Prices	I	Taylor	Tech.	0.375	0.903	1.255	1.493	1.714
Small	Prices	I	Taylor	Spread	0.009	0.010	0.010	0.010	0.010
Small	Prices	I	Taylor	Mon. Pol.	-0.434	-0.451	-0.451	-0.451	-0.451
Medium	W, P	I	Taylor	Tech.	0.231	0.452	0.593	0.681	0.755
Medium	W, P	I	Taylor	Spread	-0.590	-1.153	-1.387	-1.487	-1.541
Medium	None	I	Taylor	Tech.	0.188	0.438	0.560	0.620	0.657

Note: The column labeled ‘Model’ gives information about the model used in each row. A ‘Small’ model means that there were no labor monopolies, habit formation, or interest rate smoothing, whereas a ‘Medium’ model includes these features. The column labeled ‘Nominal Rigidities’ gives information about which nominal rigidities are included in the model, if any. A value of ‘P, W’ means that both prices and wages are sticky. The column labeled ‘Asset Markets’ gives information about if asset markets are complete (C) or incomplete (I). The column labeled ‘Mon. Pol.’ gives information about the monetary policy rule assumed in each economy, where ‘Taylor’ means a Taylor rule and ‘Money’ means a money growth rule. The column labeled ‘Shock’ gives information about the only shock in the economy. ‘Tech.’ means technology, ‘Gov.’ means government spending, ‘Mon. Pol.’ means monetary policy, and ‘Spread’ means the spread shock,  $\eta_t$ .

Table 10: Baseline regression  $\beta_0$

	Horizon (in years)				
	1	3	5	7	10
A: Flexible exchange rate countries					
Australia	-0.016 (0.015)	-0.057 (0.038)	-0.092 (0.042)	-0.126 (0.029)	-0.156 (0.031)
Canada	-0.002 (0.009)	-0.015 (0.025)	-0.030 (0.031)	-0.033 (0.027)	-0.014 (0.017)
Euro Area	0.004 (0.022)	0.051 (0.031)	0.085 (0.027)	NA	NA
Germany	0.011 (0.035)	0.104 (0.075)	0.184 (0.046)	NA	NA
Japan	0.053 (0.029)	0.127 (0.068)	0.226 (0.067)	NA	NA
New Zealand	0.009 (0.026)	0.000 (0.060)	0.000 (0.067)	NA	NA
Norway	-0.001 (0.015)	-0.016 (0.041)	-0.037 (0.047)	-0.055 (0.037)	-0.085 (0.049)
Sweden	-0.013 (0.019)	-0.040 (0.046)	-0.066 (0.043)	-0.088 (0.020)	-0.136 (0.040)
United Kingdom	0.016 (0.014)	0.024 (0.032)	0.031 (0.026)	NA	NA
B: Fixed exchange rate countries					
China	0.010 (0.004)	0.017 (0.009)	0.023 (0.008)	NA	NA
Hong Kong	-0.000 (0.000)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	-0.002 (0.001)

Table 11: Relative price regression  $\beta_0$

	Horizon (in years)				
	1	3	5	7	10
A: Flexible exchange rate countries					
Australia	0.013 (0.005)	0.039 (0.018)	0.059 (0.027)	0.076 (0.036)	0.095 (0.044)
Canada	0.000 (0.003)	0.002 (0.009)	0.002 (0.015)	0.001 (0.022)	-0.007 (0.026)
Euro Area	-0.004 (0.001)	-0.009 (0.004)	-0.016 (0.003)	NA	NA
Germany	-0.042 (0.020)	-0.136 (0.050)	-0.203 (0.073)	NA	NA
Japan	-0.024 (0.003)	-0.067 (0.008)	-0.107 (0.005)	NA	NA
New Zealand	-0.006 (0.002)	-0.020 (0.004)	-0.032 (0.003)	NA	NA
Norway	0.004 (0.004)	0.015 (0.015)	0.026 (0.027)	0.042 (0.039)	0.071 (0.051)
Sweden	0.006 (0.005)	0.021 (0.017)	0.035 (0.033)	0.052 (0.055)	0.090 (0.074)
United Kingdom	-0.009 (0.002)	-0.027 (0.006)	-0.047 (0.007)	NA	NA
B: Fixed exchange rate countries					
China	-0.012 (0.005)	-0.034 (0.005)	-0.045 (0.002)	NA	NA
Hong Kong	0.009 (0.010)	0.033 (0.039)	0.063 (0.053)	0.086 (0.037)	0.065 (0.003)
C: Fixed exchange rate countries vis-à-vis Germany					
France	0.000 (0.001)	0.002 (0.002)	0.003 (0.002)	NA	NA
Ireland	0.007 (0.004)	0.017 (0.010)	0.021 (0.010)	NA	NA
Italy	0.004 (0.001)	0.012 (0.003)	0.018 (0.002)	NA	NA
Portugal	0.006 (0.002)	0.016 (0.002)	0.021 (0.001)	NA	NA
Spain	0.008 (0.002)	0.022 (0.004)	0.034 (0.004)	NA	NA

Table 12: Persistence and volatility of exchange rates

	$\rho_{RER}$	$\sigma_{\Delta RER}$	$\sigma_{\Delta S}$
Australia	0.971 (0.846,0.986)	0.049 (0.004)	0.040 (0.003)
Canada	0.986 (0.872,0.997)	0.026 (0.002)	0.022 (0.002)
Euro Area	0.961 (0.719,0.982)	0.048 (0.004)	0.041 (0.003)
Germany	0.905 (0.682,0.954)	0.064 (0.006)	0.076 (0.018)
Japan	0.995 (0.759,1.011)	0.060 (0.004)	0.053 (0.004)
New Zealand	0.979 (0.759,0.992)	0.044 (0.005)	0.041 (0.003)
Norway	0.947 (0.824,0.972)	0.052 (0.003)	0.043 (0.002)
Sweden	0.970 (0.849,0.986)	0.057 (0.005)	0.047 (0.003)
United Kingdom	0.966 (0.701,0.988)	0.031 (0.004)	0.027 (0.003)
China	0.959 (0.674,0.986)	0.004 (0.001)	0.014 (0.001)
Hong Kong	0.982 (0.935,0.999)	0.003 (0.000)	0.013 (0.001)
Nominal rigidities	0.884	0.029	0.029
Without nominal rigidities	0.919	0.020	0.023

Note: confidence intervals for  $\rho_{RER}$  are constructed from a parametric bootstrap for an AR(1) model of  $\log(RER_t)$ . We used 10,000 bootstrap draws and report the 0.025% and 0.975% quantiles of the bootstrap distribution of the statistic of interest. Standard errors for  $\sigma_{\Delta RER}$  and  $\sigma_{\Delta S}$  are GMM standard errors.