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1 Introduction

The international transmission of monetary policy is a central topic in international economics, forming the basis for policy design and potential policy coordination. These spillovers take on increasing importance with freer movement of goods and capital, including to and from developing countries. When advanced-economy central banks flooded markets with liquidity following the 2007-8 global financial crisis, debates intensified on how these policies affected countries beyond their jurisdiction. Guido Mantega, the Brazilian Finance Minister, dubbed these low interest rates policies a "currency war".[1] When the loosening cycle reversed, the fallout from the expected tightening of monetary policy in 2013, the proverbial "taper tantrum", were of sufficient concern to have been raised in US Federal Open Committee meetings.[2]

A previous literature, discussed below, has studied spillovers from US monetary policy to the rest of the world. In updating and expanding this earlier analysis, we find that spillovers from US monetary policy have seen dramatic shifts over time. Consistent with earlier findings, we show that in the period following the end of the Bretton-Woods system of fixed exchange rates, a contractionary monetary shock in the US appreciated the US dollar in both real and nominal terms on impact and caused a (delayed) decline in output in the rest of the world. This accords with conventional wisdom and textbook macroeconomic models. In contrast, we find that after 1990, a US monetary tightening has a far more muted response on the dollar on impact and now *depreciates* the US dollar and *stimulates* output overseas, in the first year following the shock.

The analysis is based on data at monthly frequency for the 12 high income countries and areas and 9 emerging markets for which data are available at this frequency. Our baseline specification shows these results using monetary policy shocks identified using the historical methods of Romer & Romer 2004. Results are similar using other common identification methods including high frequency shocks (Gürkaynak *et al.* 2005, Gertler & Karadi 2015) and recursive identification (as in Sims 1992, Eichenbaum & Evans 1995, Christiano *et al.* 1999). The results hold both in the high income and emerging market samples (the latter including data primarily from the later period). In a difference in differences specification, we show that a tightening of US monetary policy appreciated the dollar by less (or depreciated by more) in the period 1990-2007 than it did in 1973-1989 on impact and at all subsequent horizons.[3]

[1] Financial Times, September 10, 2010

[2] New York Times, January 11, 2019

[3] High frequency identification allows us to study the effect of US monetary policy tightening after 2007, when the policy interest rate was at the zero lower bound. Results are similar when including the more recent period, but there

Standard macroeconomic theories of the open economy including the textbook Mundell-Flemming-Dornbusch model and its modern new-Keynesian variants (Svensson & van Wijnbergen 1989, Obstfeld & Rogoff 1995, Betts & Devereux 2000, Devereux & Engel 2003, Corsetti & Pesenti 2005) predict a US dollar appreciation in response to a Fed interest rate hike. In such models, exchange rate reactions to monetary policy shocks are governed by an uncovered interest parity (UIP) condition, a no-arbitrage condition that requires expected exchange rate movements to compensate investors for differential interest rates of assets denominated in different currencies. Under UIP, a monetary tightening is associated with an immediate appreciation, followed by a gradual depreciation. Recent theoretical advances in exchange rate determination (cf. Gabaix & Maggiori 2015) allow for UIP deviations. A key departure of the Gabaix & Maggiori (2015) framework (GAMA model) is to give prominence to financial flows in determining exchange rate dynamics. But this and other existing models would still predict an exchange rate appreciation following a tightening of monetary policy.

Given our empirical findings, a countervailing force is required that would lead to a depreciation (or at least a lesser appreciation) following a tightening of US monetary policy. We discuss a number of potential theories in an expanded version of the GAMA model. In the GAMA model, financial intermediaries absorb imbalances in the supply and demand for currencies, while taking on currency risk exposure. Limited risk-taking capacities stemming from financial frictions imply that currencies will provide excess returns to compensate the financiers for their risk exposure. Although a core result of the GAMA model is that UIP no longer holds, the reaction of exchange rates to an interest rate change is still in the same direction as in the standard model. We introduce a new force to the GAMA model: financiers' risk capacity depends risk appetite in the financial sector and we allow risk appetite to vary with US interest rates.[4]

When US interest rates rise, risk appetite decreases, and financiers' risk-bearing capacity declines. This limits their demand for FX exposure. If the financial sector is long on US dollars–a plausible assumption since the 1990s–this decreases their demand for US dollars and causes a dollar depreciation. The US dollar will then depreciate in response to a tightening of monetary policy if the risk-taking channel dominates the standard forces implied by UIP.[5] The assumption of inter-

are some signs of a reversal of the effect studied here.

[4]For simplicity, we make the constraint dependent on the US interest rate, but results would go through if it depended on the world average interest rate or the difference between the US and foreign interest rate.

[5]This is a different channel than the "flight to safety" channel, whereby heightened risk aversion would lead to a dollar *appreciation*, as risk averse investors flock to the safety of the US dollar. Stavrakeva & Tang (2018) augment hedge-currency theories with a signaling effect of monetary policy. This does indeed lead to an deprecation of the dollar following a Fed tightening because a Fed tightening signals good news in the Fed's information set, thus lowering

est rate dependent risk-taking behavior is plausible and supported by existing evidence (Borio & Zhu 2012, Bekaert *et al.* 2013, Bruno & Shin 2015, Lian *et al.* 2018, Miranda-Agrippino & Rey 2020). We use our framework to explore other possible explanations, such as the role of the US dollar as a hedge currency, as in Stavrakeva & Tang (2018).

The shifting response of non-US output to monetary policy shocks is equally puzzling. International spillovers in standard open economy models come from two main channels: demand and expenditure switching. In the standard model, a US monetary policy tightening could be expansionary or contractionary for the rest of the world. On one hand, tighter monetary policy reduces US import demand; on the other hand, it leads to an appreciation of the US dollar, leading consumers to substitute away from US goods. However, given our finding that the US dollar *depreciates* in the year following US interest rate hikes, the expenditure switching effect is now unfavorable for the rest of the world. Both forces would now tend to depress output outside the US. In stark contrast, we find that non-US output increases following a Fed tightening. While our model doesn't contain a productive sector, we describe a growing literature that focuses on balance sheet effects that allow for output expansions in face of an appreciating local currency.

It is difficult to date the change in the international transmission of US macroeconomic policy with any precision. Panel data poses challenges for breakpoint analysis and ideally one would want to test for a break in the entire impulse response to monetary policy shocks. We provide an informal test for the optimal breakpoint and show a statistically significant break the last months of the 1980s and first months of the 1990s.

It is also difficult to disentangle empirically the exact reasons for the shift. Multiple changes occurred in the global economy in this period and several may have contributed to the changing nature of international macroeconomic spillovers. First, the increased financialization of the world economy may have made macro-finance theories of the sort explored in this paper more central in exchange rate determination. The fact that our results only hold when countries are financially open supports this notion. The increasing role of finance may have also made the financial sector more sensitive to interest changes, a factor that is central to our theory.

Second, the US dollar has become increasingly central in the international monetary system in recent decades (Rey 2013, Ilzetzki *et al.* 2019). This may have increased demand for US dollar liquidity and may have stretched the financial system's currency exposure. We use our theoretical

demand for "safe assets". Empirical evidence (Lilley & Rinaldi 2020) suggests that the hedging role of currencies played only a small role in exchange rate determination prior to the global financial crisis. We see that our effect is strongest in the period 1990-2007, prior to the crisis.

framework to study conditions under which increased dollarization of the world economy leads to a reversal in the exchange rate response to interest rate shocks. Our empirical results only holds when countries have large stocks of dollar-denominated assets, reinforcing this view.

Finally, the regime change in our empirical findings corresponds roughly to the period of persistent US current account deficits (a period beginning in the mid-1980s or early 1990s). As will become apparent in Section 4, our theoretical results hold with greater force when the US is running a current account deficit.

An extant empirical literature studies the the international propagation of US monetary policy shocks. Our findings for monetary shocks in the post-Bretton Woods period are in line with those in Eichenbaum & Evans (1995), Cushman & Zha (1997), and Kim & Roubini (2000), whose sample periods range from the 1970s to about 1990. Our contrasting empirical results for the period beginning in the 1990s are new and robust to alternative identification schemes standard in the literature. We further extend this analysis to the largest emerging market economies and find that they respond no differently to US policy shocks in the later sample, where data is available for both income categories. In this regard, our findings resonate with evidence on Latin American economies, where Canova (2005) finds that the local currency appreciates relative to the US dollar in response to US monetary tightening: Our study shows that this is not a phenomenon peculiar to Latin America. Our analysis synthesizes existing disparate results and we are the first to point to the change in the monetary policy transmission over time.[6]

Before turning to our main empirical results in Section 3, we describe the data, our empirical methodology, and the various identification methods used in this paper in Section 2. Section 4 then presents our theory of exchange rates and monetary policy in face of interest-elastic risk aversion in the financial sector. Finally, Section 5 concludes.

2 Data and Methodology

In this section, we describe the data and methods used to estimate spillovers from US monetary policy to the rest of the world.

[6]Stavrakeva & Tang 2018 show a change in monetary policy transmission as the Fed transitioned to quantitative easing during the 2007-9 global financial crisis. They attribute this change to a greater importance of the signalling effect of monetary policy, whereby a loosening of US monetary policy signals bad news in the Fed's information set, leading to a dollar appreciation through flight to safety. In our larger sample we find that the shift in monetary policy transmission occurred earlier.

2.1 Data

We analyze the transmission of US monetary shocks to the rest of the world in an unbalanced panel of 21 countries and areas outside the US for which exchange rate and industrial production data are available at monthly frequency. This includes 11 high income countries, the euro, 9 emerging markets, and chosen based on data availability. The full list of countries and their sample dates is found in Table A1 in the appendix. While data is available prior to 1973 for some countries, our sample begins at the end of the Breton Woods system of fixed exchange rates at 1973. We show some results for a sample ending in 2007, after which US monetary policy was constrained by the zero lower bound on the nominal interest rate and the international transmission of monetary policy may have changed further (cf. Stavrakeva & Tang 2018). In other specifications, we also include the period up to 2017.

The panel is unbalanced primarily because of limited reliable monthly data for developing countries before 1990 and in some cases before 2000. Our hypothesis that the transmission of macroeconomic shocks changed after this date may be confounded by the sample change and instead reflect differences between high income and developing countries. However, we show that results are nearly identical in a balanced panel of high income countries alone.

The euro replaced a number of the national currencies in our sample (German Deutschemark, French franc, and Italian lira) in 1999. We continue treating these countries as separate entities when considering production and real exchange rate spillovers after 1999. These countries are dropped from the analysis of the nominal exchange rate after 1999 to avoid over-weighting the euro in our sample. The euro is treated as a separate cross-sectional territory from 1999 to 2017 when analyzing nominal exchange rate responses.

We report the response of four main non-US variables to US shocks. These are the nominal and real exchange rates, industrial production, and the nominal policy interest rate in each country in our panel. The main data source is the International Monetary Fund's International Finance Statistics (IFS), which we completed using data from the OECD and national statistical agencies. The nominal exchange rate is taken as the monthly average of the nominal bilateral exchange rate in local currency to US dollars, so that an increase in this variable reflects a US dollar appreciation. The real exchange rate is calculated from the nominal exchange rate and the US and local price level. All variables are seasonally adjusted and in natural logarithms. The policy interest rate is in percentage points.

Our baseline specification uses Romer & Romer's (2004) monetary policy shocks. This choice is motivated by data availability both before and after 1990, when we identify a change in monetary transmission. The disadvantage of this methodology is that it cannot be applied to the period following 2008, when variation in policy interest rates all but ended at the zero lower bound. To investigate the recent deacde, we use high frequency shocks to Federal Funds Futures as instruments for the Federal Funds Rate (FFR) following Gertler & Karadi (2015) and using the data of Gürkaynak *et al.* (2005). We show that our results are robust not only to the different identification scheme but also to extending the sample. Finally, we show in the appendix that our results are robust to recursive identification using Cholesky decomposition following Christiano *et al.* (1999).

Romer & Romer (2004) (RR) shocks to the Federal Funds Rate (FFR) are deviations from the Federal Reserve's historical response function to its information set. The latter is compiled from the Fed's Greenbook forecasts. Specifically, RR regress the change in the FFR–or the intended change, before the FFR was publicly announced as the Federal Reserve's policy instrument–on its previous level; forecasts of the current, last quarters, and following two quarters of inflation and GDP; the change in these forecasts since the previous meeting of the Federal Open Market Committee; and its estimates of current unemployment. Residuals from this regression are treated as monetary policy shocks, reflecting changes in the policy rate beyond the systemic response to economic conditions based on the Fed's real-time information set. Importantly, this identification method already controls for the Fed's superior information set, so should purge the data from the signalling value of monetary policy as emphasized by Nakamura & Steinsson (2018), Ricco (2018), and Jarocinski & Karadi (2020). In this regard, our findings require an explanation that goes beyond the confounding effect of information revelation. We we attempt to provide this explanation theoretically in Section 4.

The original RR series ends in 1996. We replicate the RR series up to 1996 and extend it to 2005, using the same methodology. Figure A.1 in the appendix compares the original RR series with our replication and extension of their methodology. The difference between the two is barely discernible for the overlapping period. It is difficult to extend the RR series into the 2008 period and beyond because the Federal Funds rate was at the zero lower bound and monetary policy was conducted primarily using other instruments.

When using high frequency identification methods (HFI), we use changes in one-month FFR futures in a thirty-minute window around Federal Open Market Committee (FOMC) announcements, taken from Gürkaynak *et al.* (2005), updated to 2017 and generously shared by Refet Gurkaynak. We follow Gertler & Karadi (2015), who use (the monthly sum of) high frequency changes in

Fed Funds futures as and instruments for the Fed Funds Rate.[7]

2.2 Empirical Specification

The results reported in the following section are impulse responses estimated directly using local projections (Jorda 2005). This methodology has the advantage of estimating impulse responses non-parametrically, such that the information in the impulse response at every horizon comes from the a projection of the shock variables (either directly or instrumented) on the ex-US variable of interest, rather than from autoregressive coefficients estimated via OLS. Thus the full trajectory of the impulse response is comes from aforementioned identification methods rather than the average (vector) auto-correlation properties of the sample as a whole.

In the case of RR shocks and recursive identification, the common practice (cf Ramey 2016) is to project the shocks directly on the variable of interest, in a regression of the form:

$$y_{c,t+h} = \beta_h x_t + \sum_{i=1}^{I_y} \delta_i^y y_{c,t-i} + \sum_{i=1}^{I_x} \delta_i^x x_{t-i} + \alpha_c + \gamma_{c,t} + \text{controls} + \varepsilon_{c,t}, \tag{1}$$

where $y_{c,t+h}$ is the outcome variable for country c at a horizon of h months from date t. β_h gives the impulse response of outcome variable y at horizon h to the US macroeconomic shock given by x_t. The local projection regression includes I_y lags the dependent variable and I_y lags of the policy variable. We set $I_y = 24$ and $I_x = 6$. The regressions include country fixed effects, represented by the vector α_c, and country-specific quadratic time trends represented by $\gamma_{c,t}$.[8]

In specifications where the identification is via instrumental variables (i.e. HFI), the variable x_t is the policy variable (e.g the FFR), predicted by an instrument (e.g. high frequency movements in Fed Funds futures) in a first stage regression.

3 The International Transmission of US Monetary Shocks

We now describe the response of the international macro-economy to monetary policy shocks. Figure 1 displays the response of a number of variables to a Romer & Romer (2004) shock in horizon

[7] Figure A.2 in the appendix plots the two shock measures and shocks based on recursive identification. The correlation between the RR and CEE series is merely 0.14 and is driven mainly by the Volker shocks in the early 1980, captured in both measures. The HFI correlated with each of the other measures with a coefficient of 0.19. The lack of correlation could, but doesn't necessarily, indicate the superiority of one measure over another. The three are different ways to measure monetary policy shocks and could in principle capture different aspects of monetary surprises.

[8] α and γ coefficients and the residuals $\varepsilon_{c,t}$ take on different estimated values in each regression of horizon h, but we suppress h subscripts for ease of notation.

up to 3 years (36 months). The left-hand column shows responses in the period 1973-1989 and the right-hand column in the period 1990-2007. Shaded areas give 95% Newey-West confidence intervals.

The first row shows the average response of (log) bilateral nominal exchange rates to a one percentage point increase in the FFR. Exchange rates are given in local currency units per US dollar, so that a rising exchange rate represents a US dollar appreciation. In the earlier period, an increase in the US policy rate lead to an immediate 2% appreciation. This coincides with the prediction of standard macroeconomic models. The response generally satisfies uncovered interest parity (UIP), given that the dollar depreciates back to its previous level within a year of shock. The exchange rate response in the 1991-2007 period is in stark contrast. In this period, the US dollar barely responds on impact and sees a large *depreciation* following a Fed tightening, peaking at 5% roughly a year a half after the shock. This depreciation is persistent and lasts for close to three years.

The second row of Figure 1 shows the average response of foreign industrial production to a Fed tightening. In the earlier period, foreign output shows a delayed but steady decline, dropping by as much as 1% in response to the 100 basis point tightening of monetary policy. This response is consistent with earlier findings (Eichenbaum & Evans 1995) and is theoretically coherent. The US tightening has demand effect and expenditure switching effects. Lower US/world demand due to the Fed tightening leads to lower foreign production. On the other hand, consumers may substitute towards now cheaper foreign goods due to the stronger dollar. If the demand effect dominates expenditure switching, the foreign industrial production decline shown in the figure is to be expected.

In contrast, foreign industrial production increases following a Fed tightening in the more recent period. The response peaks at 1% in the year following the monetary policy shock. This response is particularly puzzling because in this case both the demand and expenditure switching effects would call for a decline in foreign output. As before, lower world demand would tend to lower production. But now with the US dollar depreciating, the expenditure switching effect would also lead to lower foreign production as US goods are now relatively cheaper.

Admittedly, there is some sign of a delayed (and statistically significant) decline in industrial production after nearly two years, which may indicate that the industrial production response after 1990 is merely a slight upward shift of the impulse response from the 70s and 80s. However, we shortly see that there is a statistically significant difference between the two sub-samples in a difference in differences specification and that the difference in industrial production production responses is far sharper using other identification methods.

The third row of the figure shows the response of the real exchange rate to US monetary policy shocks. Mussa (1986) highlighted that real exchange rate movements are dominated by nominal exchange rates, not relative prices. It is hardly surprising that the real exchange response is similar to that of the nominal exchange rate in the first row of the figure. Note that in this specification, the real exchange rate depreciates by a statistically significant margin on impact and at all horizons.

The fourth row of Figure 1 shows the average response of the non-US policy rate (in percentage points) to a one pp increase in the FFR. Changes in policy responses to US policy could potentially explain differences in the effect of US shocks on the rest of the world. However, foreign central banks appear to have tightened monetary policy similarly–by around 50 basis points per 100 basis points Fed tightening–both before and after 1990.

Figure 2 reports impulse responses from a different specification that shows the difference between the two periods more formally. The responses are based on a difference in differences specification taking the following form:

$$y_{c,t+h} = \beta_{1,h} x_t + \beta_{2,h} x_t \mathbb{1}(t) + \beta_{3,h} \mathbb{1}(t) \sum_{i=1}^{I_y} \delta_i^y y_{c,t-i} + \sum_{i=1}^{I_x} \delta_i^x x_{t-i} + \alpha_c + \gamma_{c,t} + \text{controls} + \varepsilon_{c,t}, \quad (2)$$

where $\mathbb{1}(t)$ is a dummy variable equaling one for months starting in January 1990. The first term in the regression (the $\beta_{1,h}$ coefficients) gives responses of the variable of interest to monetary policy shocks x_t for the period 1973-1989. The second term (the $\beta_{2,h}$ coefficients) gives the interaction between the period 1990-2007 and the monetary policy shocks and have a difference in differences interpretation. They show how much larger the response to monetary policy shocks were in the more recent period relative to the early period.

Figure 2 plots the impulse response of the interaction (the $\beta_{2,h}$ coefficients) between the shock and the later period for the nominal exchange rate (top panel) and industrial production (bottom panel). The figure illustrates that the exchange rate response is smaller with 95% confidence for all horizons in the first two years. Similarly, the response of industrial production is larger by a statistically significant margin in the later period at most horizons. We note that unlike the split-sample specification of Figure 1, this specification imposes unvarying autoregressive coefficients for the entire 1973-2007 sample. Further, note that because of the local projections methodology, the differences at each horizon are estimated separately and are not due to a particular choice of the auto-regressive process.

We have set the break point between the two sub-samples arbitrarily at 1990. This is around the date at which we find a break point in the data for most countries in the sample, using the Bai & Perron (1998) break point test. However, this procedure cannot be applied to panel data. Further, Bai & Perron (1998) tests jointly for a break point in all the model's parameters, rather than in the specific coefficient of interest (the effect of US monetary policy on foreign variables). We therefore conduct an informal test in Figure A.3 in the appendix to date the break point for the entire panel. Specifically, we run the regression (2), while changing the dummy variable $\mathbb{1}(t)$ to represent a different candidate break point at each date in the sample. The appendix figure shows the T-statistic for a statistically significant break point at the month in question for the panel as a whole. A statistically significant break point (at the 95% confidence level) is found from mid-1988 to mid-1994 for the exchange rate and from 1988 to late 1989 for industrial production.[9]

Robustness: Other Identification Methods and Extended Sample

Figure 3 shows the responses of the same variables to a monetary policy shock identified through high frequency changes in Fed funds futures in narrow windows around Fed announcements since 1990. Unfortunately, data on Fed funds futures is only available starting in 1990, so that we are only able to analyze the period post-1990 and are unable to establish a change in the transmission of US monetary policy. The top-left-hand panel shows the response of the nominal exchange rate. The high-frequency identification shows a small (1%) appreciation on impact, but it is immediately followed by a sharp (3%) depreciation, with an overall response very similar to that seen with other identification methods. Industrial production in the upper right-hand panel shows a 1% and statistically significant response that is far clearer than the one found following a Romer & Romer (2004) shock. Real exchange rate and interest rate responses are shown in the bottom panels.

Data on Federal Funds Futures shocks to monetary policy are available up to 2017 and Figure A.4 in the appendix extends the sample to these later dates. Responses are almost identical to those seen in Figure 3 and are nearly a mirror image of those found using other identification methods in the period 1973-1989. We have attempted to ascertain whether the financial crisis brought another breakpoint in responses to US monetary policy, but found no conclusive results due to the small sample size. Nevertheless, a comparison between Figure 3 and Figure A.4 in

[9]Similar dates are found for the break point in the response of exchange rates for sub-samples of high income and developing countries. Breakpoints for industrial production are statistically significant only at the 90% confidence level when considering these two sub-samples separately.

the appendix suggests that the impulse responses may have shifted slightly upward in the past decade, perhaps suggesting a strengthening of some of the forces that applied pre-1990

Finally, Figure A.5 shows nearly identical impulse responses when using a Cholesky decomposition.

Robustness: Control Variables

We continue our robustness tests by controlling for a number of variables to ensure that our results aren't confounded by other domestic or international shocks. On the US front, we control for (six lags of) the nominal exchange rate, the discount rate, industrial production and inflation.[10] We also control for (six lags of) US industrial production and inflation, the S&P500 stock index, Gilchrist & Zakrajsek's (2012) measure of US credit spreads, and an index of commodity prices (US Bureau of Labor Statistics' producer commodity price index). The responses of the the nominal exchange rate (left hand column) and industrial production (right hand column) in the period beginning in 1990 are shown in Figure A.6 in the appendix. Each row represents a different identification scheme (from top to bottom: Romer & Romer 2004, Cholesky decomposition, and high frequency identification). Standard error bands are wider as could be expected due to the loss of power, but overall the results hold.[11]

Figure A.7 in the appendix shows the responses of domestic US variables to the three shocks, when including the aforementioned control variables. The figure shows (from left to right) the responses of US industrial production, inflation, and the S&P500 stock market index to monetary shocks identified with all methods. All regressions are for the period 1990 to 2007. The figure demonstrates that the puzzling response of foreign variables isn't due to a peculiarity of the domestic transmission of monetary policy. The response to Romer & Romer (2004) shocks are exactly as could be expected. Industrial production shows a delayed response–almost identical to the one in Romer & Romer's (2004) original article, despite the different time sample. Inflation declines by a statistically insignificant amount and doesn't show a "price puzzle" often observed in time series studies of monetary policy.

Jarocinski & Karadi (2020) have pointed to a separate puzzle whereby the stock market often

[10] We cannot control for both the real and the nominal exchange rate as the two are nearly perfectly correlated for most countries, but controlling for the nominal exchange rate and domestic and US inflation effectively controls for the real exchange rate.

[11] The exchange rate puzzle appears robust to the controls. Industrial production increases on impact, although the increase is further weakened and no longer statistically significant in the Romer & Romer 2004 specification, and no longer differs substantially from the one seen in the 1973-1989 period.

increases in high frequency following Fed tightening. They interpret this unexpected response as reflecting a signalling effect, whereby tighter US monetary policy conveys positive information about the Fed's information about the US economy. In Figure A.7, the stock market declines on impact in response to a Romer & Romer (2004) shock by a statistically significant margin. It is reassuring that domestic US responses are theoretically coherent for our baseline identification method.[12] [13]

Heterogeneity

The responses in Figure 1 pool a very heterogeneous set of countries. We now split the sample along several dimensions. We find that our results are robust to various sub-samples of the data and aren't driven by outliers or a particular country. However, our results hold with greater force in certain subsets of the data in ways that help shed light on the theoretical channels at play.

Most importantly, the figures include countries with incomes per capita ranging from $16,000 (Colombia, in purchasing power parity) to five times larger (Norway). Figure 4 splits the sample into high income countries (left hand column) and emerging markets (right-hand column) based on World Bank classifications. This and subsequent figures restrict attention to the two main variables with the nominal exchange rate in the top row and industrial production on the bottom. The figures are given for the Romer & Romer 2004 specification, but results based on the other shocks show similar patterns.

Figure 4 shows that the exchange rate of both high income countries and emerging economies depreciate by a statistically significant margin following a tightening of US monetary policy. The peak responses for both groups of countries is very similar. In terms of output, the responses for both sets of countries is also remarkably similar, with industrial production increasing by roughly 1% and a statistically significant margin. The results aren't driven by countries in a specific income category. If anything, the results are somewhat sharper in the high income sample and the emerging markets appear to add some noise to our baseline estimates.

Figures A.8 to A.11 in the appendix look at several other cuts of the data. Figure A.8 splits the sample based on capital account openness. Specifically, it compares observations when a country

[12] Responses to high frequency shocks in the bottom row of the figure are somewhat erratic with large standard errors, but their general trajectory is the same as the responses to Romer & Romer (2004) shocks. The recursive identification responses are similar for industrial production, but inflation increases, showing a price puzzle, and the stock market declines only with a delay

[13] It may seem paradoxical that we are able to identify the responses of foreign variables with more statistical accuracy than those of US variables. Instead, this reflects the increased statistical power delivered by panel data. Our panel has roughly 20 times the observations more than the US own responses.

had a value above the sample median according to the Chinn & Ito (2006) index and those below the median. The figure shows that the results hold even more forcefully when countries have an open capital account (left hand column). In contrast, the results disappear and show little exchange rate response to US monetary policy when the capital account is closed. This is to be expected if the transmission of US monetary policy is due to a financial channel, as in the theory discussed in the following section.

Figure A.9 splits the sample based on the degree of domestic financial dollarization. Specifically, the sample is divided into episodes when a country had a ratio of dollar-denominated assets plus liabilities to GDP above and below the sample mean (source: IFS). The figure shows another interesting dimension of heterogeneity. The results hold with greater force when countries are more financially dollarized, where dollar-denominated borrowing and lending play a greater role. The countries in our sample have far more dollar denominated assets (lending) on average than liabilities denominated in dollars.[14] As we will see in the following section, this is consistent with our theory where an increased demand for US dollar assets can lead to a reversal in the effects of US monetary policy on the exchange rate.

Figure A.10 compares country-years that were above median in terms of openness to trade, measured as the ratio of exports plus imports to GDP, to those below. Figure A.11 compares countries with current account surpluses to those with current account deficits. We don't see clear patterns of heterogeneity along these lines. Dividing the sample based on the US current account (being above or below median: it was negative for nearly the entire period) leads to a split of our sample that is nearly identical to the dates we consider here. We cannot differentiate between the change in the US current account balance and other factors that have changed over this time period, as we discuss in the following section.

4 Theory: Exchange Rates and Interest-Elastic Risk Taking

Conventional and most existing theories hold that raising the interest rate in one economy relative to another will appreciate that economy's currency. The currency then depreciates back to its equilibrium long run level. Instead, the evidence in the previous section suggests that since 1990, the dollar has barely moved on impact is shows a prolonged depreciation in response to a US monetary policy shock (Figure 1). Further, the dollar has appreciated by less (depreciated more) than

[14] Further the correlation between these two indicators is 0.94.

it did at any time horizon following an increase in US interest rates (Figure 2. What could have lead to a lesser appreciation or even a depreciation of the dollar following a US monetary tightening? Before delving into any specific theory, let us cast the problem into an intuitive setting where exchange rates is determined by the global demand and supply of assets in different currencies.

Consider a general (relative) supply and demand framework for US dollar denominated assets, as shown in Figure 5. The exchange rate is of the non-US currency, so that a higher value reflects a stronger dollar. A downward-sloping demand curve arises because a higher exchange rate level implies a greater expected depreciation, which lowers the expected relative returns of the dollar, and hence the relative demand for dollar assets. The relative supply of dollar assets is upward sloping, with different interpretations depending on the theoretical model. One common theoretical underpinning for this curve comes from the current account deficit: A stronger dollar is associated with a larger US current account deficit, financed with increased borrowing and a greater supply of dollar-denominated bonds.

In this simple and intuitive configuration, it is clear that in order to generate a depreciation of the dollar in response to an increase in U.S. interest rates, either the demand for domestic currency bonds has to fall, or their supply has to rise. In a basic framework where the UIP condition holds, the demand curve is infinitely elastic, as shown in the horizontal line in the figure. Given the expected long run equilibrium exchange rate, the current exchange rate level is pinned down by the required depreciation, which must exactly equal the (risk-adjusted) interest rate differential between foreign and domestic bonds. Any other level of the exchange rate would lead to arbitrage opportunities whereby bonds of one currency are strictly preferable to the other. A rise in the US interest rate shifts up the demand curve for dollar assets, and induces an appreciation sufficient to lead to an expected depreciation to re-establish parity between the returns on domestic and foreign assets. This effect holds even in models with a less elastic relative demand for dollars, where the UIP condition does not hold or holds imperfectly. In such cases, the demand curve is downward-sloping and an interest rate hike still shifts up the demand curve and leads to an appreciation. Hence the evidence that the dollar fails to appreciate and even depreciates following a US interest rate rise goes against a broad class of theories.

One theory that pushes in the opposite direction and can generate a fall in demand following a Fed tightening relates to the signalling mechanism (or information channel) of monetary policy. Stavrakeva & Tang (2018) build a model where an expansionary U.S. monetary policy shock signals that the central bank foresees an impending worsening of economic conditions. If the central bank has superior information, this downgrades the private sector's growth expectations, leading to heightened risk aversion and induces a flight to safety, which appreciates the dollar, perceived to be a safe asset. A contractionary monetary policy shock has the opposite effect, as the private sector unwinds its safe positions and depreciates the dollar. If the signalling effect is sufficiently strong, it could overwhelm the relative demand for dollars due to UIP to the point that a Fed tightening leads to a decrease in dollar demand and to a dollar depreciation.

This mechanism assumes a special safe-asset status of the dollar (alongside a handful of other hedge currencies). However, as we show in Figures 1 and 4 (which exclude the Great Recession) and in Figure A.3 in the appendix (which finds the breakpoint to be around 1990), the change in the transmission of monetary policy occurred well before the Great Recession of 2008, when Stavrakeva & Tang (2018) and others believe the risk-aversion dollar-hoarding nexus to have become pertinent. Lilley & Rinaldi (2020) show that currencies' equity beta had negligible explanatory power on currency values before 2008, but strong predictive power thereafter. While we find theories based on signalling compelling, our empirical evidence spans two decades before the financial crisis and suggests other possible channels.

An alternative theory, which we present in this paper, builds on the GAMA model. We assume that a rise in interest rates elevates creditor risk aversion and this reduces the financial sector's intermediation capacity. Financiers' demand for dollars declines and the dollar depreciates. Both the mechanisms described so far would lead to a downward shift in dollar demand when interest rates rise. But there is an important distinction. In Stavrakeva & Tang (2018), the interest rate hike itself has no effect on risk aversion, nor does it lead to a dollar depreciation. Instead it is the Fed's information transmission that depreciates the dollar. Our theory describes a channel where the interest rate hike itself leads to greater risk aversion and a depreciation. Romer & Romer (2004) shocks are designed to control for the Fed's information set based on real-time Green Book forecasts. Insofar as they do so successfully, the impulse responses we have presented should have controlled for the signalling effect and reflect a response to the interest rate change itself.

Christiano *et al.* (2020) propose a different mechanism. When risk aversion is heightened, U.S. financiers are more reluctant to lend in foreign currencies. The fall in relative demand for foreign currency then appreciates the dollar. Kalemli-Ozčan (2019) emphasizes the changes in global investors' risk perceptions caused by U.S. monetary policy, which can also lead to a demand toward and away from dollars. Though these effects are not the focal point of the model, and we do not model explicitly the special status of dollar, these channels can be mapped into model as shifts in the demand for dollars due to risk appetite. We discuss this further towards the end of this section.

The GAMA model contains households in two countries (which we call the US and Japan) and a financial sector. The household side of the two-period model is standard and laid out in Appendix B. Household consumption decisions lead to a current account balance, which gives the microfoundations for the upward-sloping relative supply for dollars in Figure 5. Current account deficits are financed by net borrowing, but households cannot borrow directly from abroad. Instead, financiers intermediate the trade in bonds between the two countries. When trade imbalances arise, financiers absorb the excess relative supply of dollars and yen. For instance, if the US runs a trade deficit there is an excess demand for dollar borrowing from American households and financiers fill in this gap by being long in dollars and short in yen. In this model, UIP doesn't hold and financiers are compensated for currency risk by the excess returns on their net dollar position. The expected dollar returns that financiers maximize are

$$V_0 = \mathbb{E}\left[\beta\left(R - R^*\frac{e_0}{e_1}\right)\right]q_0,$$

where q_0 is the financiers' dollar holdings equal to the dollar value of the financiers' short position in yen, $-e_0q_0$; R and R^* are respectively dollar and yen interest rates.

Financiers may divert funds after taking a position but before uncertainty is realized. If financiers divert, creditors recover a share $(1 - \Gamma|e_0q_0|)$ of their claims $|e_0q_0|$. Anticipating the financiers' incentives to divert funds, creditors subject financiers to a constraint

$$e_0V_0 \geq |e_0q_0|\,\Gamma\,|e_0q_0| = \Gamma\,(e_0q_0)^2\,, \tag{3}$$

which requires the financial sector to have sufficient net worth to cover a fraction (or multiple) Γ of the required recovery rate.

Our key departure from the GAMA model is the assumption about Γ, the financiers' risk bearing capacity. In the original model, the risk bearing capacity of financiers is assumed to be limited by the overall size of financial institutions' positions and by their expected riskiness, which is proxied by the variance of future exchange rates. Thus,

$$\Gamma = \gamma\,(\mathrm{var}\,(e_1))^{\varphi}\,, \tag{4}$$

where $\gamma > 0$ is risk aversion, $\varphi \geq 0$ is an elasticity, and e_1 denotes the next-period exchange rate. We make the additional assumption that $\gamma = \psi R^{\eta}$, with $\psi > 0$ and $\eta > 0$.[15] That is, risk aversion γ depends on the level of US interest rates. A rise in US interest rates reduces creditors' risk appetite which subsequently tightens the credit constraint. This assumption conforms with the conventional wisdom of "risk-on, risk-off" cycles that may be affected by monetary policy changes. This view garners empirical support in numerous empirical studies over the past decade (Borio & Zhu 2012, Bekaert *et al.* 2013, Bruno & Shin 2015, Lian *et al.* 2018, Miranda-Agrippino & Rey 2020).

The financiers' demand for dollars is pinned down by the non-diversion constraint (3), which is binding in equilibrium and gives:

$$q_0 = \frac{1}{\Gamma(R)} \mathbb{E}\left[\frac{1}{e_0} - \frac{R^*}{e_1 R}\right]. \tag{5}$$

There are two competing effects of the US interest rate R on q_0. On the one hand, expected excess returns (in the square brackets) rise as R increases, and financiers demand greater net dollar holdings q_0. This is the UIP effect whereby excess dollar returns due to a US interest rate hike increase dollar demand. On the other hand, risk capacity falls ($\Gamma(R)$ increases) when US interest rates rise, forcing financiers to take on smaller positions (q_0 falls). This is a new channel, leading to lower net demand for dollars. Net demand for dollars could increase or decrease depending on which of the two effects dominates. We will argue that several forces may have strengthened the latter in relative terms in recent years, leading to a weaker dollar appreciation or even a depreciation following a US monetary tightening.

The balance of payments equation pins down the supply of dollars Q_0 in each period. Net asset supplies Q_t in periods 0 and 1 are respectively:

$$\frac{\xi_0}{e_0} - \iota_0 + Q_0 = 0 \tag{6}$$

$$\frac{\xi_1}{e_1} - \iota_1 - RQ_0 = 0, \tag{7}$$

The specific functional form for the the current account balance is derived in the household problem in Appendix B. In equilibrium, demand equals supply, so that $q_0 = Q_0$. Henceforward,

[15] Alternatively, one can make the assumption that $\gamma = \psi(\frac{R}{R^*})^{\eta}$—that risk aversion depends on the interest rate differential. The results in this case are qualitatively the same.

we consider the case in which the US runs a trade deficit, by setting preferences such that $\iota_0 > \frac{R^*}{R}\mathbb{E}[\iota_1]$.[16] This implies that excess returns $\left(R - R^*\frac{e_1}{e_0}\right)$ are always positive, and $Q_0 > 0$ in equilibrium.

The balance of payments equation, (6) gives the second equation linking e_0 and q_0. For simplicity assume that $\xi_t = 1$ in both periods $t = 1, 2$. Combining (5), (6), and (7) yields the equilibrium dollar position of the financiers and the exchange rates in both periods:

$$Q_0 = \frac{\iota_0 - \frac{R^*}{R}\mathbb{E}[\iota_1]}{\Gamma + 1 + R^*}, \tag{8}$$

$$e_0 = \frac{\Gamma + 1 + R^*}{(\Gamma + R^*)\,\iota_0 + \frac{R^*}{R}\mathbb{E}[\iota_1]}, \tag{9}$$

$$e_1 = \frac{\Gamma + 1 + R^*}{(\Gamma + 1 + R^*)\,\iota_1 + R\iota_0 - R^*\mathbb{E}[\iota_1]}. \tag{10}$$

The equilibrium response of Q_0 to changes in R is:

$$\frac{\partial Q_0}{\partial R} = \frac{1}{R}\frac{\mathbb{E}[\iota_1]\,\frac{R^*}{R}\,(\Gamma + 1 + R^*) - \eta\Gamma\mathbb{E}\left[\iota_0 - \iota_1\frac{R^*}{R}\right]}{(\Gamma + 1 + R^*)^2}.$$

Thus, $\frac{\partial Q_0}{\partial R} < 0$ if

$$\eta > \frac{\Gamma + 1 + R^*}{\Gamma}\frac{\mathbb{E}[\iota_1 R^*]}{\mathbb{E}[\iota_0 R - \iota_1 R^*]}. \tag{11}$$

This gives the condition under which the risk-bearing capacity effect dominates–that is, Q_0 falls when US rates rise. The parameter η governs the responsiveness of risk aversion to interest rates. The right hand side of the inequality is a decreasing function of η (as Γ is increasing in η), and thus there is a threshold level of η above which financiers' dollar demand falls. Intuitively, the more sensitive risk aversion γ is to interest rates, the more risk capacity falls when interest rates rise, and the smaller the dollar position financiers can take on. It is evident from (6) that a fall in Q_0 is associated with a depreciation of the exchange rate (e_0 falls).

The equilibrium current and future exchange rates e_0 and e_1 arising from (9) and (10) range

[16] This is the empirically relevant case in recent decades. We explore the possibility that this relationship has changed over time in the numerical results below.

between the values that prevail under financial autarky (Γ goes to infinity) and those arising when UIP holds ($\Gamma = 0$). An increase in US interest rates has an ambiguous impact on financiers' demand for dollar bonds and therefore on dollar exchange rates. Figure 6 revisits the graphical representation of the financiers' demand and the households' supply for dollar bonds in period $t = 0$, corresponding to (5) and (6). The financiers' demand for dollar bonds is downward sloping —the stronger is the dollar, the greater is the expected depreciation, and the lower are financiers' returns. The supply curve is upward sloping—the higher the level of exchange rate, the larger the trade deficit, and the greater is the supply of dollars bonds from the households.

When R increases, the demand curve could shift left or right depending on which effect (UIP or risk-bearing capacity) dominates. On one hand, returns on dollar bonds have now increased, shifting the demand for dollars upwards. On the other hand, financiers' risk-bearing capacity has declined, leading to lower dollar demand.[17] The figure illustrates the case where (11) is satisfied so that the risk capacity effect dominates in response to a rise in U.S. interest rates. The equilibrium exchange rate thus depreciates on impact as a result of reduced demand from financiers.

It is worth noting the different frequencies at which these two forces operate. The change in US interest rates causes an immediate change in relative dollar returns (the bracketed term in equation 5) and should lead to an immediate dollar appreciation, followed by a gradual depreciation. In contrast, the effects of interest rates on risk appetite and their subsequent effect on the financial sectors' constraints may require time to unfold and would lead to a persistent downward shift in dollar demand. An increase in the importance of the risk-bearing channel would therefore lead to a generalized downward shift in the exchange rate's impulse response to an increase in US interest rates, as appears to be the case in Figures 1 and 2.

Simulating Changes in the International Monetary System

We now subject the model to a number of comparative statics to investigate changes in the international monetary system that may have increased the importance of the risk-bearing channel. First, we consider the possibility that the global economy has become more financialized, but in a very particular way. Namely, we consider the possibility that risk aversion has become more sensitive to interest rates over time. Second, we investigate how the increased dominance of the US dollar may have affected international monetary transmission. Finally, we consider the possibility that the widening US current account deficit played a role.

[17] Formally, the change in R induces a leftward rotation rather than a downward shift of the demand curve.

Our theory lends itself directly to study the first of these factors. Figure 7 illustrates how the model's predictions change with the elasticity of risk aversion with respect to interest rates, η. It shows how the response (in percent) of several variables to a one percentage point increase in the US interest rate as a function of the elasticity of risk aversion with respect to interest rates η.[18] As noted earlier, an increase in the US interest rate increases financiers' demand for dollars because of the higher returns on dollar bonds, but decreases their demand because increased risk aversion tightens their credit constraint. With $\eta = 0$ risk aversion is unaffected by interest rates, the first channel dominates, and financiers' dollar exposure increases (top, left-hand panel in the figure). As η increases, risk aversion becomes increasingly interest-elastic, depressing financiers' dollar exposure as interest rates increase. With η above the threshold in (11), interest rate increases may even decrease dollar demand.

The top, right-hand panel of the figure shows the exchange rate response to an increase in the US interest rate, on impact. When the elasticity of risk aversion with respect to interest rates is low, the higher demand for dollars leads to a dollar appreciation, as in the conventional model. At higher levels of η, demand for dollars declines in response to an interest rate increase, leading to a dollar depreciation, consistent with our empirical findings. The depreciation is caused by heightened risk aversion following the interest rate increase. Hence, our empirical results can be rationalized if risk aversion in financial markets has become more sensitive to interest rates over time.[19]

We next investigate a second factor that may have affected the international transmission of monetary policy: The role of the dollar as an anchor currency (Rey 2013, Gopinath 2015, Maggiori *et al.* 2018, Ilzetzki *et al.* 2019, Gopinath *et al.* 2020). To capture the fact that there might be additional demand for US dollars due to its international role, we add an exogenous foreign demand for US dollar denominated debt through a parameter f^*, which is positive (negative) when the non-financial sector demands a long (short) position in the dominant currency. The flow equations (6) and (7) are now given by:

[18] Formally, the figure shows the percent difference in the variable in question between a model solved with $R = 1/\beta + 0.01, R^* = 1/\beta$ and one with $R = R^* = 1/\beta$, where $\beta = 0.95$.

[19] It is less clear whether changes in the *level* of risk aversion could explain the puzzle. The figure shows how η affects the exchange rate response to US interest rates for two values of ψ, governing the level of risk aversion, as opposed to its interest rate elasticity. As (4) illustrates, the elasticity of risk aversion and therefore of Γ with respect to interest rates isn't affected by ψ. However, the exchange rate doesn't change one to one with Γ and the experiment is a one percentage point, rather than percent, change in interest rates. If anything, a reduction in risk aversion over time (which would lead to a larger financial sector in the model) makes it more difficult to resolve the puzzle.

$$\frac{\xi_0}{e_0} - \iota_0 + f^* + Q_0 = 0 \tag{12}$$

$$\frac{\xi_1}{e_1} - \iota_1 - f^* R - Q_0 R = 0, \tag{13}$$

Figure 8 shows how this factor affects the international transmission of interest rate policy. Lower (or negative) values of f^* represent an increased demand for borrowing in US dollars, putting additional pressure on the financial system's limited intermediation capacity (it being already long on the dollar). This, in turn, magnifies the importance of interest rates as they tighten the financial system's credit constraint through increased risk aversion. Accordingly, as one moves from right to left in Figure 8, financial intermediation (Q_0) and the exchange rate respond more negatively to increases in the US interest rate, potentially leading to a depreciation following a Fed tightening. The model can therefore explain the sign reversal in the effects of US interest rates on the exchange rate if dollar dominance manifests itself in increased net demand from the non-financial sector for dollar-denominated assets over time.

In principle, the increased prominence of the dollar leads to an increased demand for, but also an increased supply of dollar assets (due to dollar-denominated borrowing). On one hand, Maggiori *et al.* (2018) document that the vast majority of corporate debt is denominated in US dollars, including outside the US. Further, Ilzetzki *et al.* (2020) show that the share of US dollar borrowing by governments in developing countries has increased in recent decades. On the other hand, massive increases in central bank reserves have contributed to demand for long US dollar positions. The value of dollar assets in the countries in our sample is twice the value of dollar liabilities on average, so that that increases in dollarization reflect a higher net demand for US assets. The theoretical effect is therefore consistent with our empirical finding that the reversal in the effects of monetary policy on the exchange rate is greater in countries and years with a greater degree of financial dollarization (Figure A.9).

Another factor that changed between our two empirical sub-samples is the widening US current account deficit. In the model, we alter the value of ι_0 to reflect an increase in US consumer demand for foreign tradable goods. Figure 9 shows that higher values of ι_0, representing a greater US demand for foreign goods and leading to a larger US current account deficit, contribute to a downward pressure on the US dollar when US interest rates rise. The intuition is the same as before: the financial sector finances the net currency positions arising from the US current account deficit. A larger deficit puts greater pressure on the the financial sector to have a long position in the US dollar. This magnifies the effect of changes in risk aversion on dollar demand from the financial sector and therefore on the exchange rate, in turn amplifying the force that allows for a dollar depreciation following an increase in US interest rates.

We have seen how three potential shifts in the international monetary system may have affected the transmission of US interest rate shocks in ways consistent with the empirical findings of the previous section. While the interest elasticity of risk aversion plays a direct role in the first channel studied in Figure 7, note that interest-rate-elastic risk-aversion is a necessary condition in our model for any of the factors studied here to lead to a sign reversal in the response of the exchange rate to interest rate shocks.

In closing our discussion of the the effects of interest rates and risk aversion in our framework, we consider the alternative hypothesis that risk aversion increases during flight-to-safety episodes, e.g. due to a negative signal from the Fed that leads to heightened demand for safe assets such as the dollar. Note that any such theory must break the symmetry of the model and provide a special status for one of the two currencies. Modeling the reason the dollar's special status goes well beyond the scope of this paper. For simplicity, we assume that the demand for dollars f^* is now a function of risk aversion. Specifically, a positive shock to risk aversion $\epsilon_\gamma > 0$ increases the (non-financial sector's) demand for dollar assets f^* through a simple linear relationship: $f^* = \rho\epsilon_\gamma$.

Figure 10 shows the effects of an increase in risk aversion as described here. Risk aversion now has two effects on the exchange rate. First, heightened risk aversion decreases the financial sectors' risk-bearing capacity (Γ) and decreases demand for dollars (when the financial sector is long on dollars). Second, heightened risk aversion induces a flight to safety, *increasing* the demand for dollars (through an increase in f^*). Which of these two channels dominates depends on their (time-varying) responsiveness to risk aversion.

This can be seen in Figure 10, where the effect of a risk aversion shock on the exchange rate depends on the value of ρ (formally relative to η). For a small value of ρ, the dollar depreciates in response to a risk aversion shock, with the size of depreciation increasing in the size of the shock. For a large value of ρ, this is reversed and the dollar appreciates in response to a risk aversion shock, with the size of depreciation increasing in the size of the shock.

It is possible to reconcile our theory with theories based on "flight to safety" if the flight to safety mechanism (ρ) was heightened during the global financial crisis (consistent with the evidence of Lilley & Rinaldi 2020). According to this theory, before the crisis, increased risk aversion would have depreciated the dollar, while risk aversion may have strengthened the dollar during the crisis. We leave this question for future research.

The Reversal in the Output Response

Our theory has the potential to elucidate one puzzling aspect of our empirical findings: the depreciation of the dollar following US interest rate increases. Our findings posed a second puzzle: US contractionary monetary shocks lead to an output expansion in the rest of the world, while depreciating the dollar. This is puzzling because both the decline in US demand and the relative decrease in the price of US goods would tend to contract foreign output. Our theory is a model of the financial sector, without an important role for the real economy, and is therefore unsuited to resolve this second puzzle.

We point to a growing literature that investigates the expansionary effects of an appreciation of the local currency (against the US dollar) that may explain this second puzzle. Avdjiev *et al.* (2019) show that a weak dollar leads to increased investment in emerging markets. Aoki *et al.* (2018) provide a theory that allows for a stronger dollar to be expansionary for the rest of the world through balance sheet effects. Intuitively, if domestic collateral is denominated in local currency, a dollar depreciation increases local borrowing capacity in dollar terms, facilitates foreign investment and makes a weak dollar a stimulant rather than a drag on non-US economic activity.

5 Conclusion

We show a substantial change in the world economy's response to US monetary shocks. The US dollar shows a "textbook" response in the two decades following Bretton Woods, but has shifted in the the psat decades. Spillovers to the real economy of the rest of the world also show a similar sign reversal. To explain this shift, we sketch out a simple theory consistent with our findings if the risk-absorption capacity of the financial sector decreases when interest rates are high. We put forth three hypotheses of changes in the international monetary landscape that might have changed the nature of international macroeconomic policy spillovers.

We hope our analysis will stimulate further analysis–both empirical and theoretical. On the empirical side, it would be interesting to trace out the response of additional macroeconomic variables to US policy shocks and expand the analysis to smaller countries. More could be done to find the global factors that best predict the regime change circa 1990. On the theoretical side, our theory could be subjected to thorough quantitative analysis in a calibrated model. Our model has a reduced-form relationship between US interest rates and the banking system's riskiness. Carefully fleshing out the model's micro-foundations, and unpacking the reasons for risk aversion's interest sensitivity, may yield further insights.

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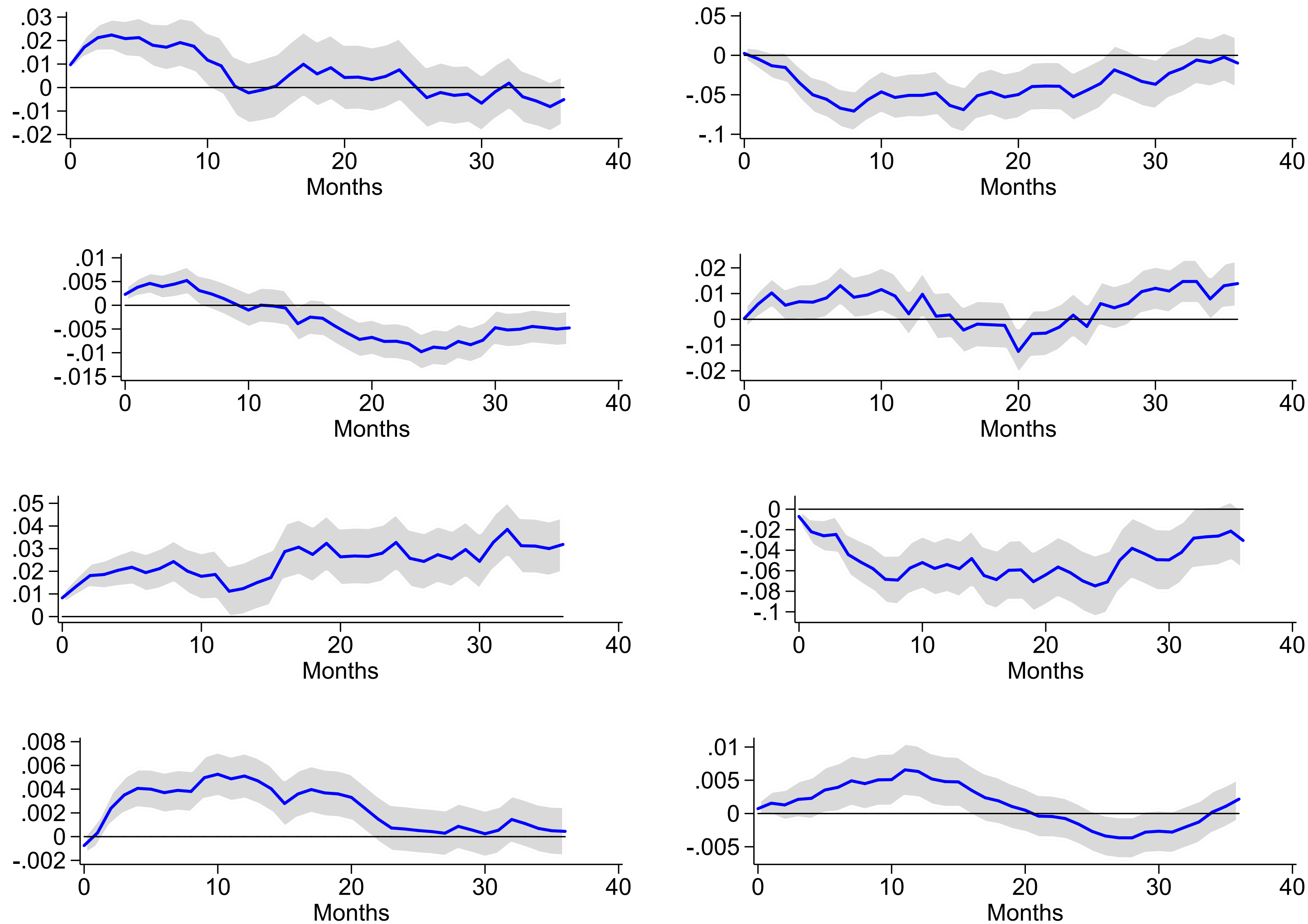
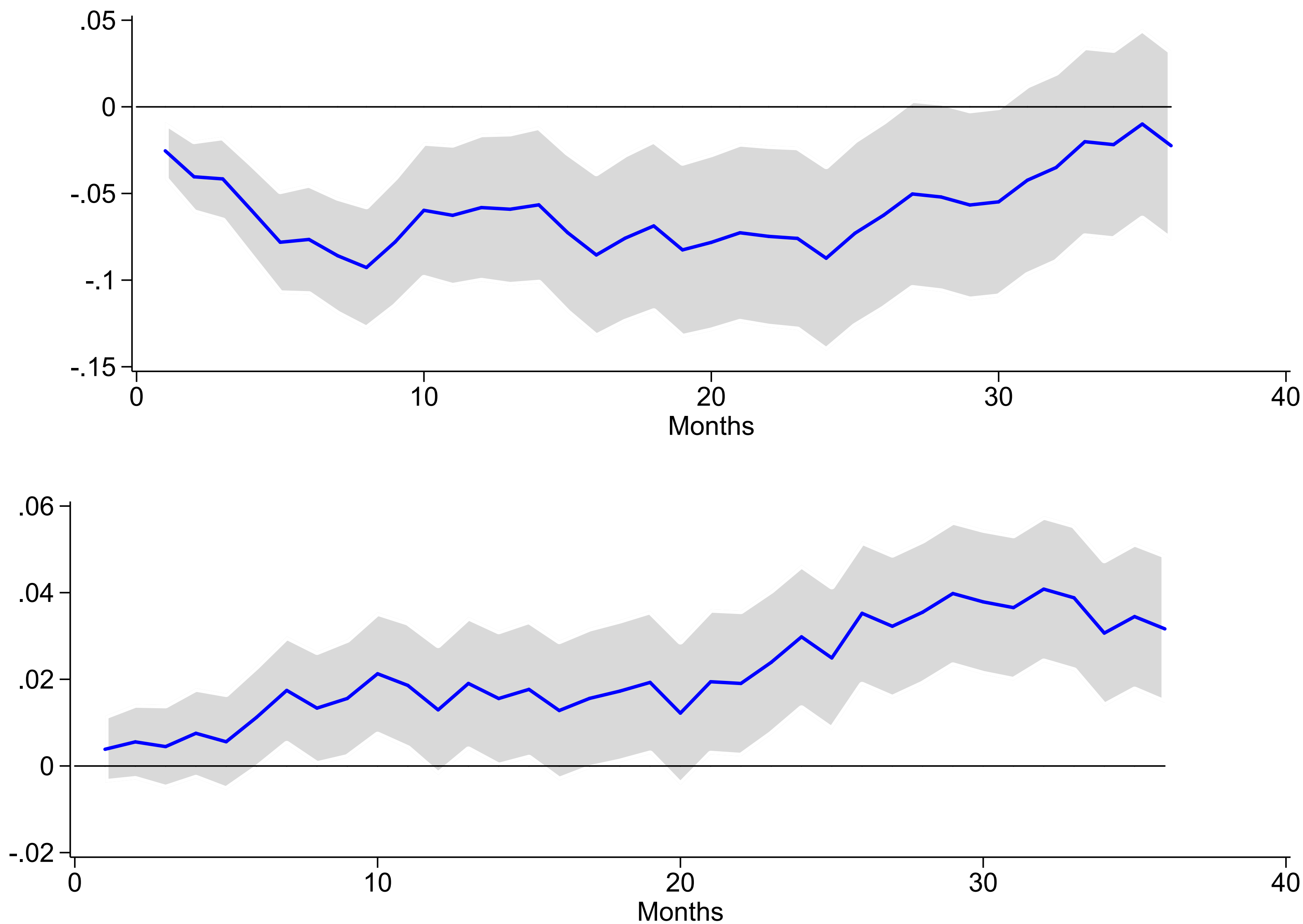
Figure 1: **Responses to (Romer & Romer 2004) Monetary Policy Shocks**



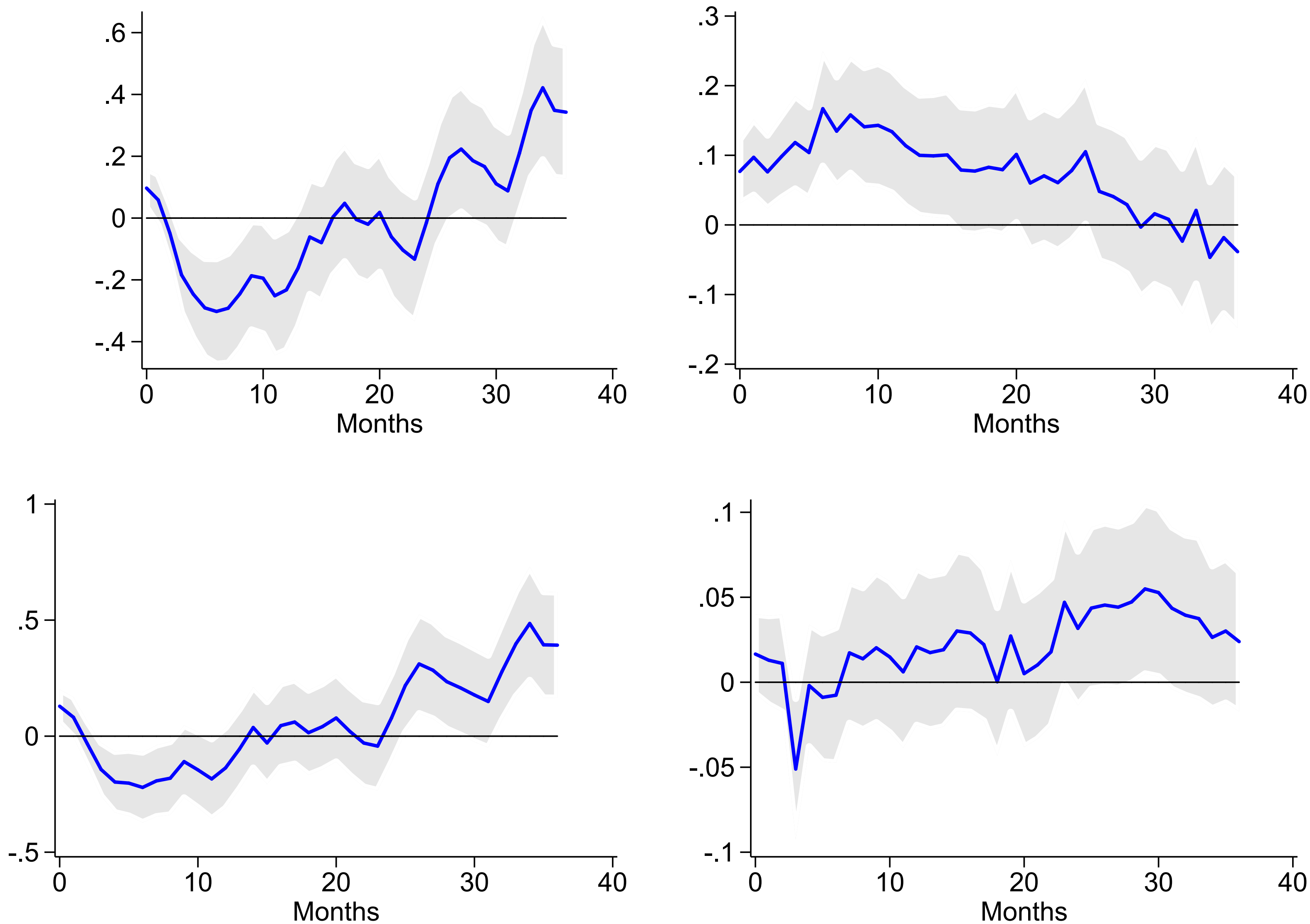
Note: The figure shows responses (in percent) to a 1 percentage point increase in the Federal Funds Rate identified by Romer & Romer (2004). The shocks are deviations from the Federal Reserve's systemic monetary policy response to its previous level; forecasts of the current, last quarters, and following two quarters of inflation and GDP; the change in these forecasts since the previous meeting of the Federal Open Market Committee; and its estimates of current unemployment. These are based based on real-time Green Book data. The left-hand column gives responses for 1973-1990. The right-hand column gives responses for 1991-2007. The first row shows responses of the nominal exchange rate (increase reflecting US dollar appreciations). The second row shows responses of non-US industrial production. The third row shows responses of the real exchange rate. The fourth row shows the change in the policy interest rate in the rest of the world (in percentage points). Estimates are local projections with country fixed effects, controlling for a country-specific quadratic time trends. The specification is given by (1). The shaded areas represent 95% Newey-West confidence bands.

Figure 2: **Responses to (Romer & Romer 2004) Monetary Policy Shocks: Difference in Difference**



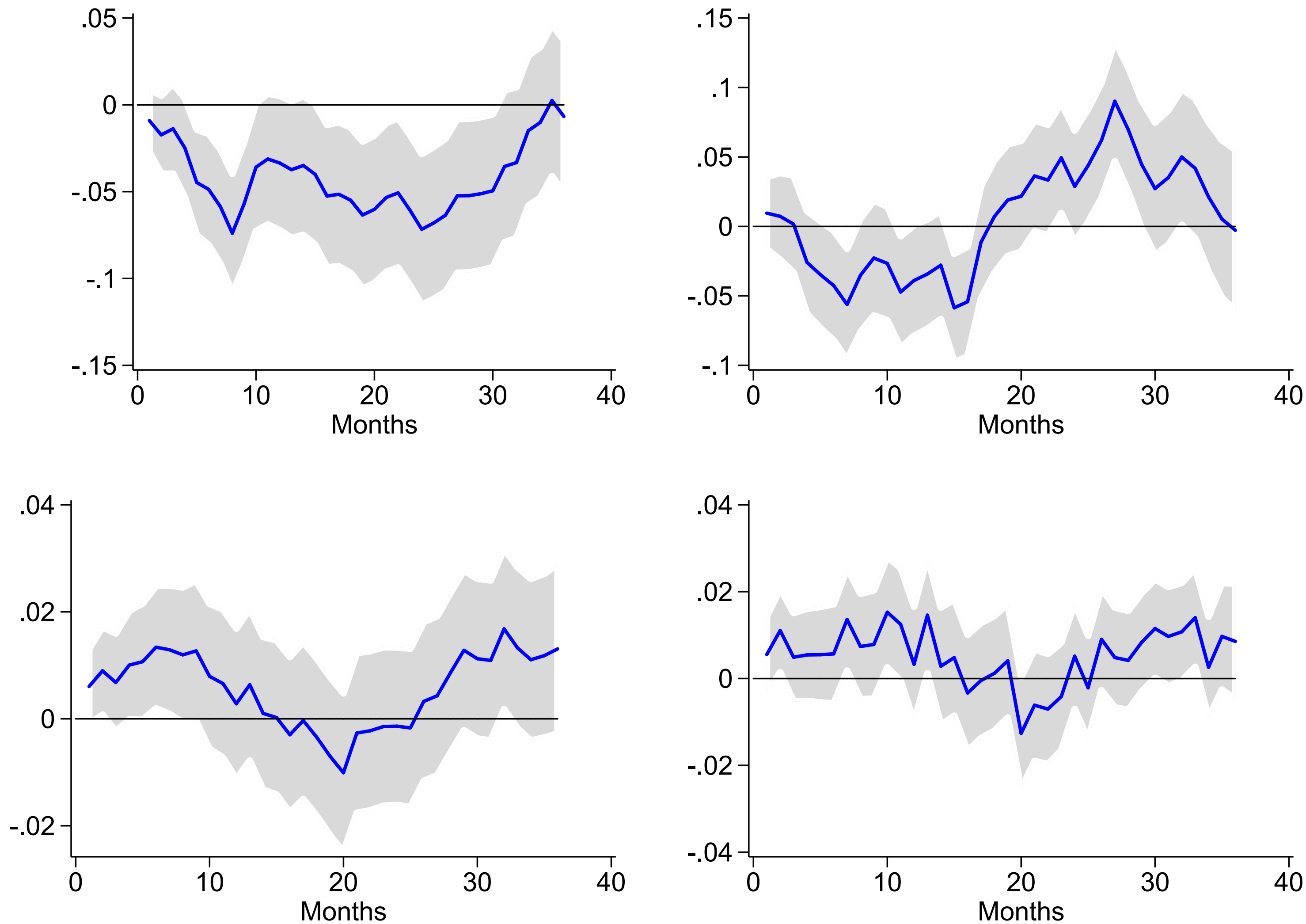
Note: The figure shows the difference in responses (in percent) to a 1 percentage point increase in the Federal Funds Rate identified by Romer & Romer (2004) before and after 1990. The specification is shown in (2) and the plotted coefficients are the values of $\beta_{2,h}$. The top panel row shows the nominal exchange rate response (increase reflecting US dollar appreciations). The bottom panel shows responses of non-US industrial production. Estimates are local projections with country fixed effects, controlling for a country-specific quadratic time trends. The shaded areas represent 95% Newey-West confidence bands.

Figure 3: **Responses to High Frequency Monetary Policy Shocks 1990-2007**



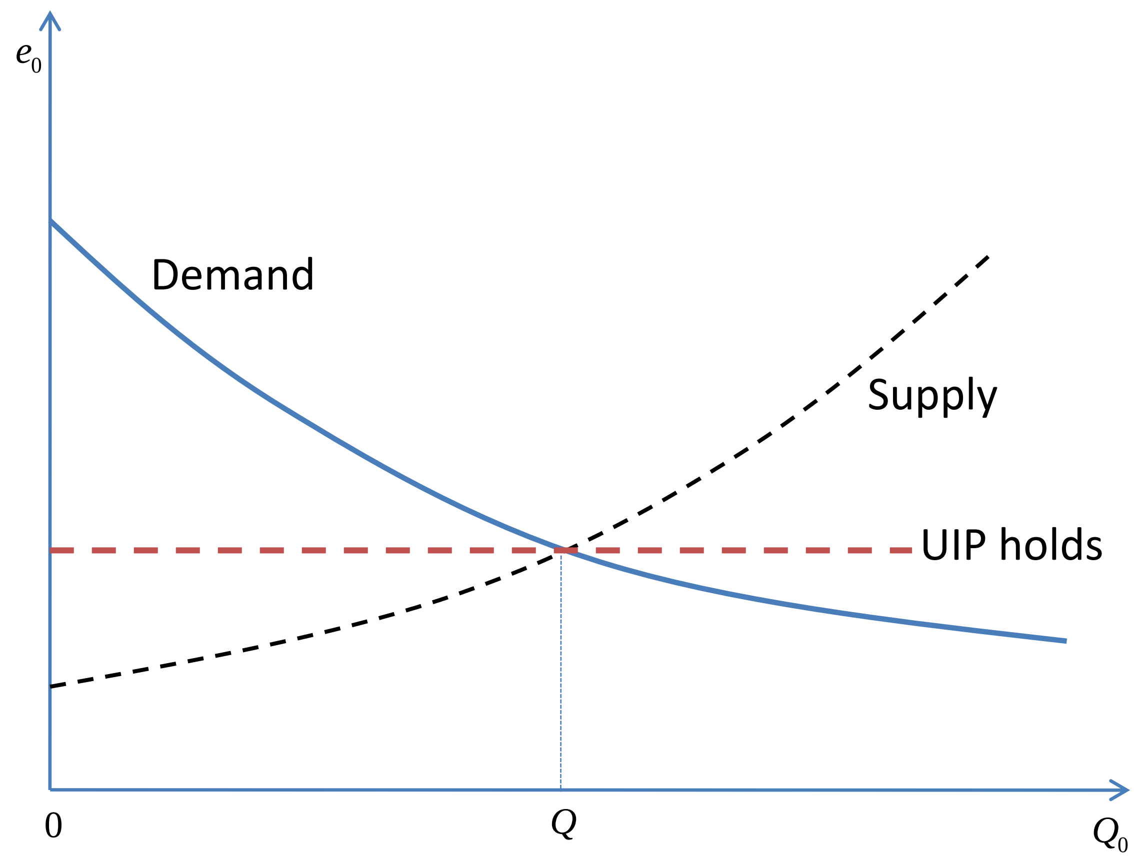
Note: The figure shows responses (in percent) to a 1 percentage point increase in the Federal Funds Rate instrumented by changes in Federal Funds futures in a 30 minute window around Fed announcements (Gürkaynak *et al.* 2005). The responses are for 1990-2007. The left hand column shows the nominal exchange rate (top) and real exchange rate (bottom, increase reflecting US dollar appreciations). The right-hand column shows responses of non-US industrial production. (top) and the non-US policy interest rate.Estimates are local projections with country fixed effects, controlling for country-specific quadratic time trends. The specification is given by 1. The shaded areas represent 95% Newey-West confidence bands.

Figure 4: **Response to US Monetary Policy Shocks: High Income and Emerging Markets**



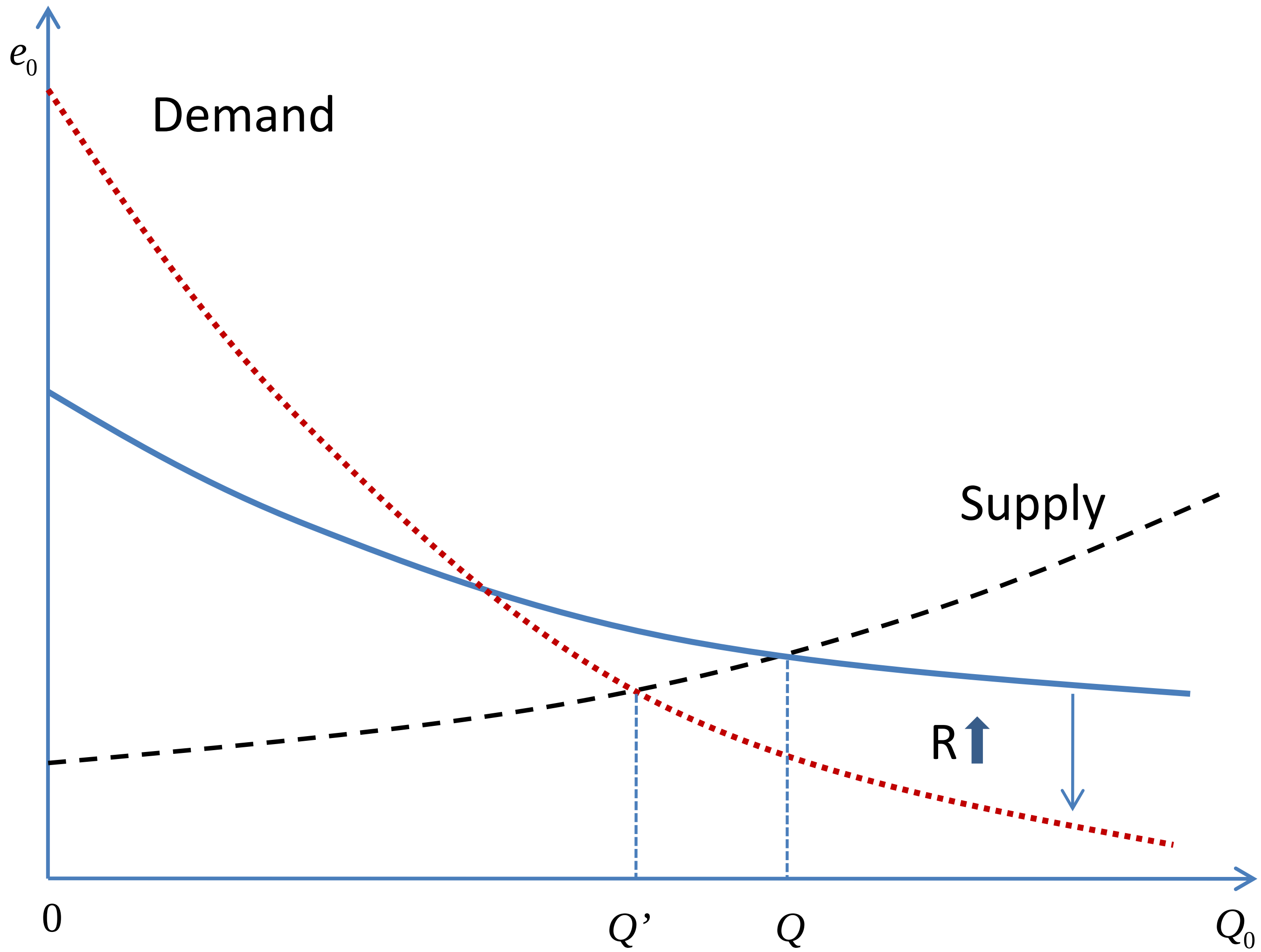
Note: The figure shows the response of exchange rates (top row) and industrial production (bottom row) to Romer & Romer (2004) monetary policy shocks. The left-hand column shows responses for high income countries; the right-hand column shows responses for developing countries. Shaded areas represent 95% (Newey-West) confidence intervals.

Figure 5: **Demand and Supply for US Dollar Assets**



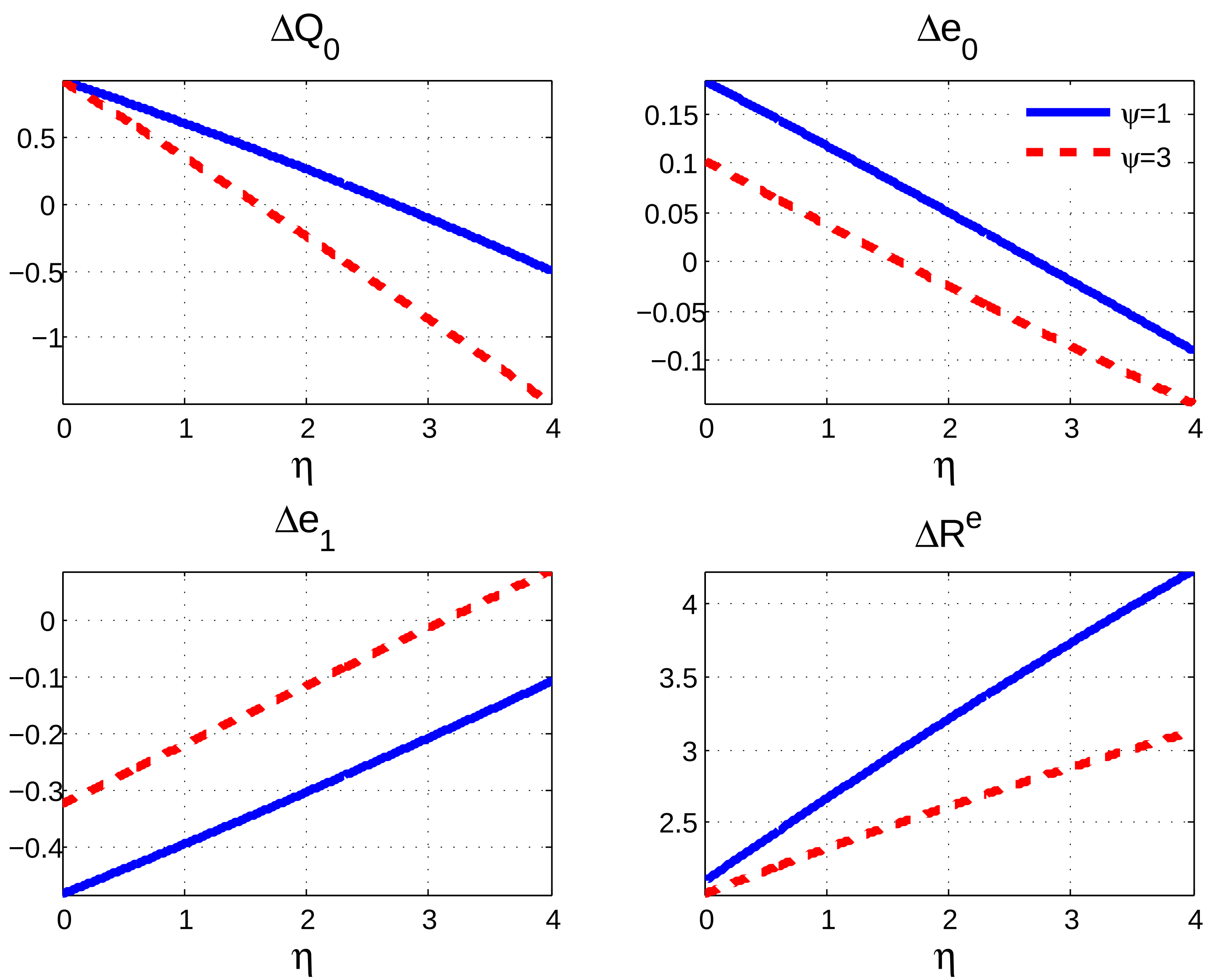
Note: The figure shows a general demand and supply model for US dollar assets. Exchange rate is on the y-axis, with an increase reflecting a dollar appreciation. Q represents the quantity of assets. When UIP holds, the demand curve is horizontal at the exchange rate consistent with the UIP condition. More generally, the demand curve may be downward sloping as in the solid line.

Figure 6: **Demand and Supply of dollars: an increase in interest rates**



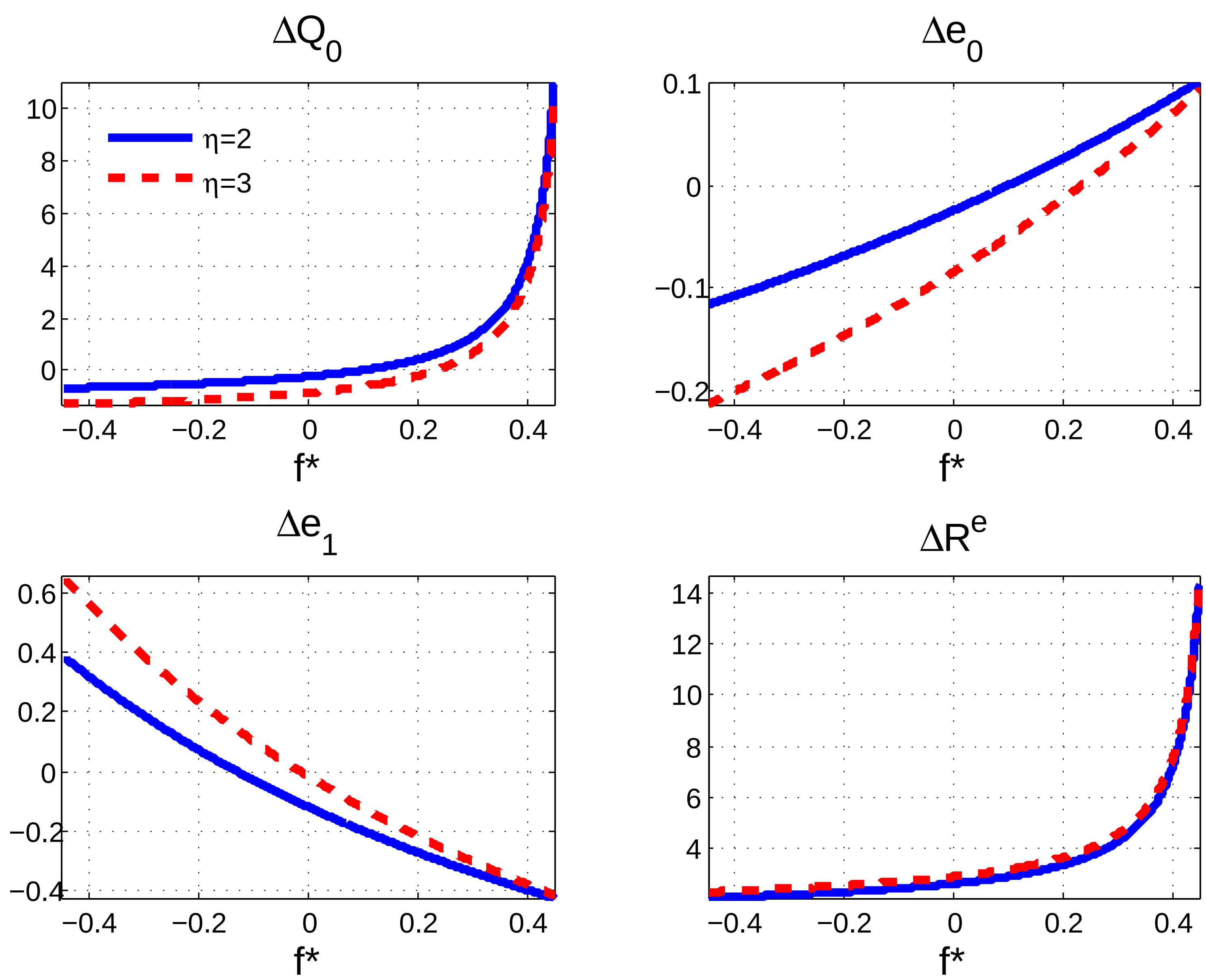
Note: The figure illustrates supply and demand for dollar bonds in the model of exchange rate determination with interest-elastic risk aversion of Section 4. The price on the y axis is the current (time zero) exchange rate in yen per dollar. The quantity on the x axis is net demand and supply of long dollar positions or dollar bonds (relative to yen bonds). The (upward sloping) supply curve is determined by the current account deficit, where a stronger dollar (higher e_0 worsens the current account deficit, inducing greater net dollar borrowing from the non-financial sector. The (downward sloping) demand curve is determined by limits on the financial sector's lending capacity: limits on its net FX exposure. A stronger dollar (higher e_0) implies a greater expected dollar depreciation, which lowers the financial sector's expected returns and lowers their demand for long dollar positions. An increase in the US interest rate has two effects. First, it increases dollar returns and thus increases the financial sector's demand for long-dollar position at any given current exchange rate. Second, it reduces risk aversion, thus lowering the financial sector's demand for net FX exposure, lowering its demand for dollar bonds.

Figure 7: **Effect of an Increase in US Interest Rates: The Role of the Interest Elasticity of Risk Aversion**



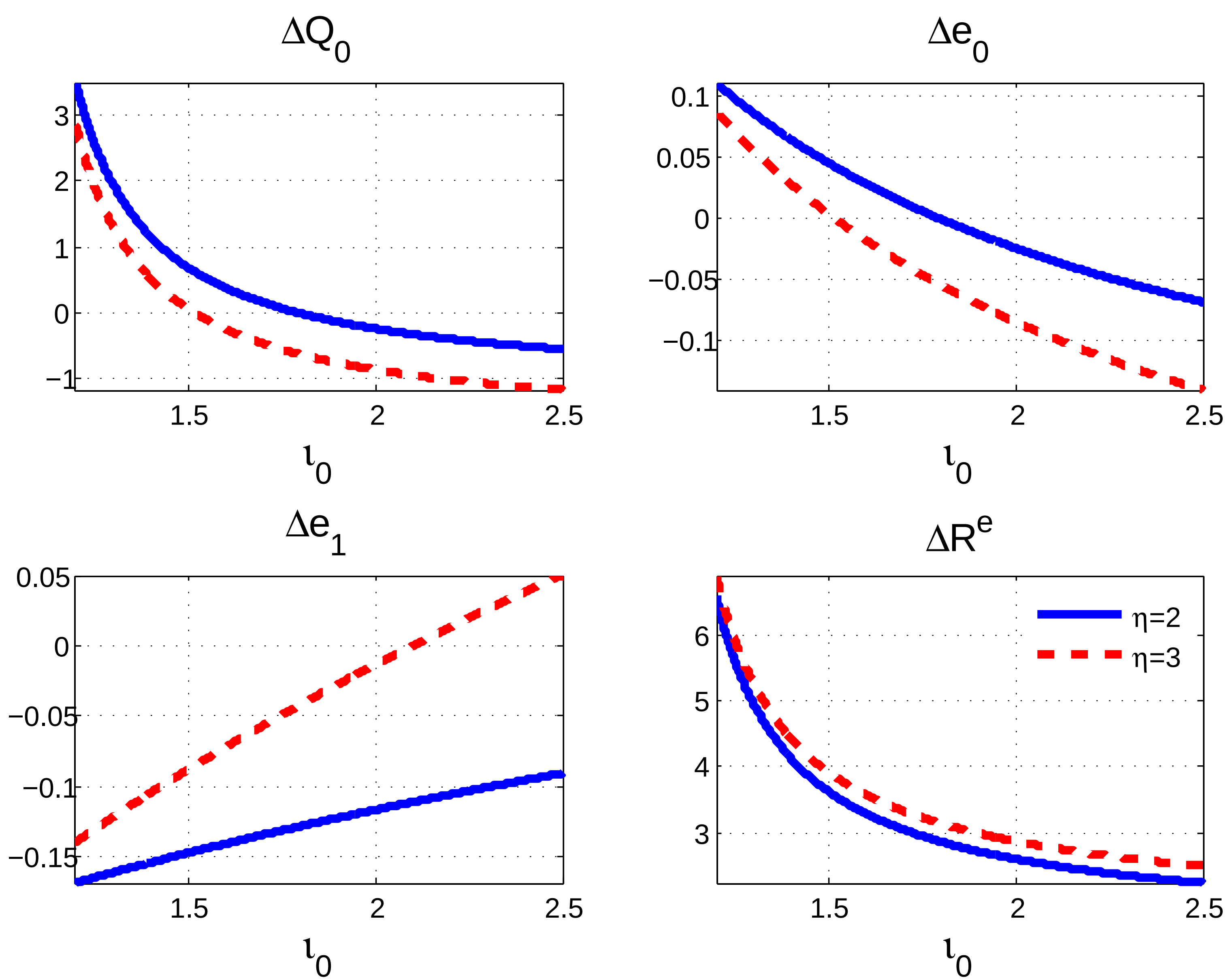
Note: The figure presents the response of a number of variables to a one percentage point increase in the US interest rate in the theoretical model of Section 4. The horizontal axis represents values of the elasticity of risk aversion with respect to the US interest rate η. Going clockwise from the upper-left-hand corner, the panels represent (i) the net foreign exchange (dollar) position of the financial sector; (ii) the response of the exchange rate on impact, with an increase representing a US dollar appreciation; (iii) excess returns obtained by financiers; (iv) the long run exchange rate response. The US dollar appreciates less (depreciates more) in response to an increase in US interest rates as the elasticity of risk aversion with respect to interest rates increases.

Figure 8: **Effect of an Increase in US Interest Rates: The Role of Dollar Demand**



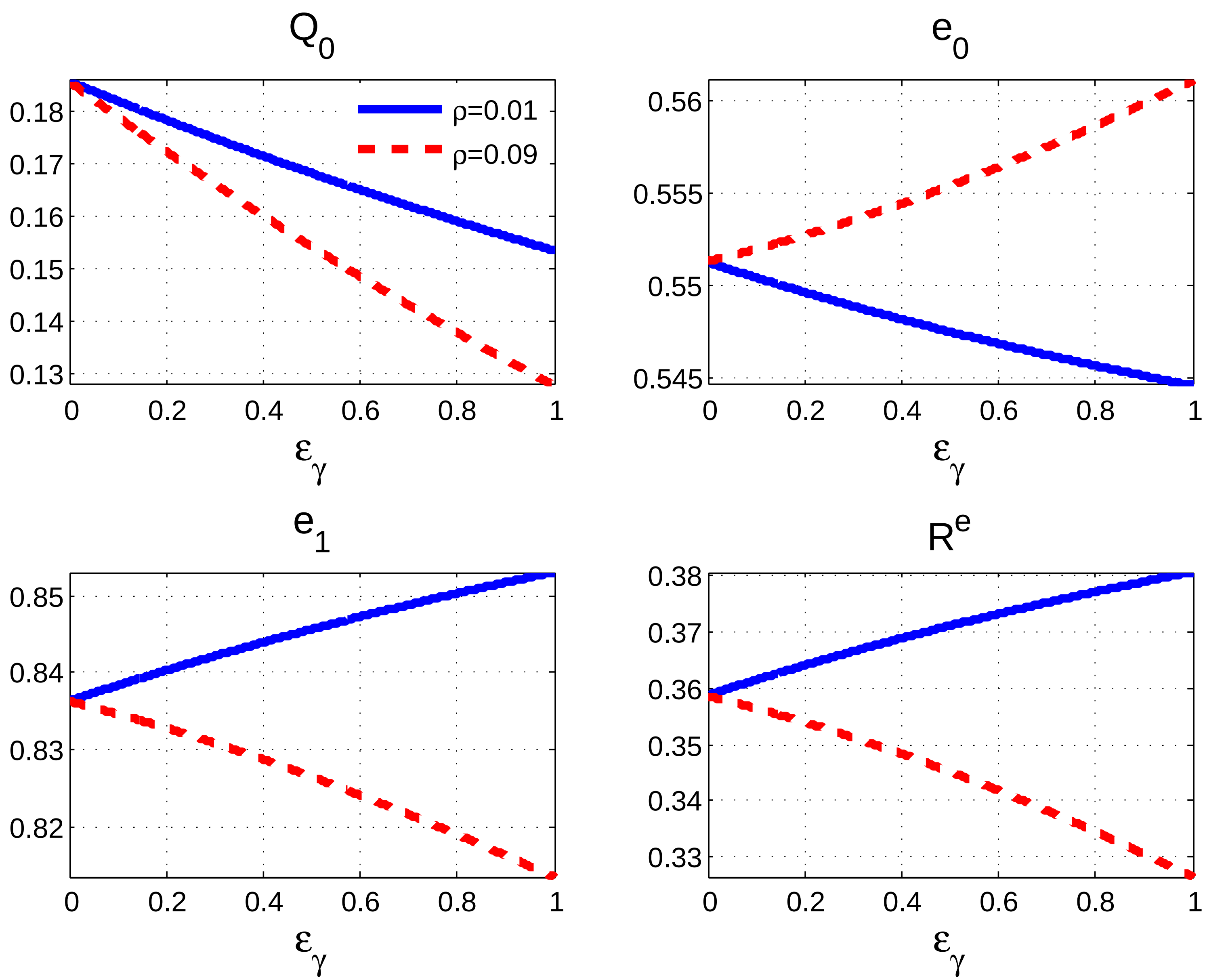
Note: The figure presents the response of a number of variables to a one percentage point increase in the US interest rate in the theoretical model of Section 4. The horizontal axis represents values of an exogenous demand for a long position in US dollars from the non-financial sector f^*. Going clockwise from the upper-left-hand corner, the panels represent (i) the net foreign exchange (dollar) position of the financial sector; (ii) the response of the exchange rate on impact, with an increase representing a US dollar appreciation; (iii) excess returns obtained by financiers; (iv) the long run exchange rate response. The US dollar appreciates less (depreciates more) in response to an increase in US interest rates as the non-financial sector's demand for dollar borrowing increases.

Figure 9: **Effect of an Increase in US Interest Rates: The Role of a Widening US Current Account**



Note: The figure presents the response of a number of variables to a one percentage point increase in the US interest rate in the theoretical model of Section 4. The horizontal axis represents values of the weight on foreign tradable goods in the US consumer demand. Going clockwise from the upper-left-hand corner, the panels represent (i) the net foreign exchange (dollar) position of the financial sector; (ii) the response of the exchange rate on impact, with an increase representing a US dollar appreciation; (iii) excess returns obtained by financiers; (iv) the long run exchange rate response. The US dollar appreciates less (depreciates more) in response to an increase in US interest rates as US consumers increase their demand for foreign tradable goods (leading to a larger US current account deficit).

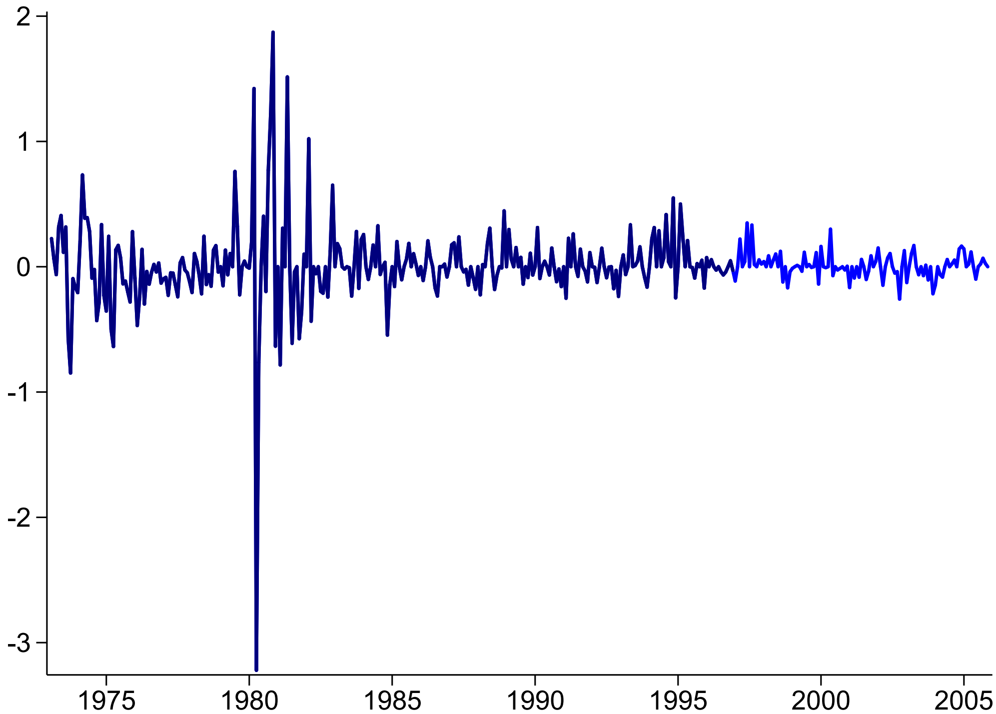
Figure 10: **Risk Aversion Shocks in a "Flight to Safety" Mechanism**



Note: The figure presents the response of a number of variables to a one percentage point increase in the US interest rate in the theoretical model of Section 4. The horizontal axis represents values of the weight on foreign tradable goods in the US consumer demand. Going clockwise from the upper-left-hand corner, the panels represent (i) the net foreign exchange (dollar) position of the financial sector; (ii) the response of the exchange rate on impact, with an increase representing a US dollar appreciation; (iii) excess returns obtained by financiers; (iv) the long run exchange rate response. The US dollar appreciates less (depreciates more) in response to an increase in US interest rates as US consumers increase their demand for foreign tradable goods (leading to a larger US current account deficit).

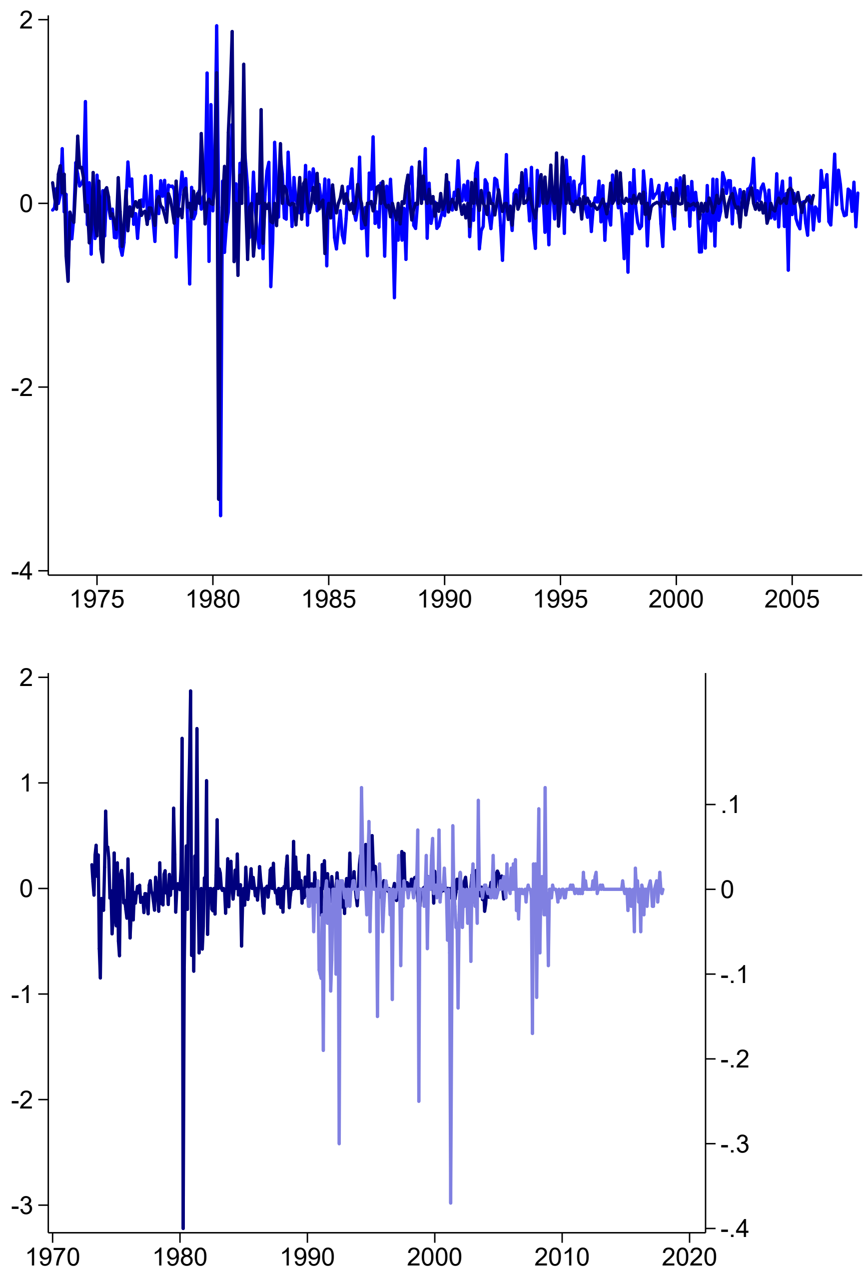
A Additional Figures and Tables

Figure A.1: **Extending the Romer & Romer (2004) Series of Monetary Policy Shocks**



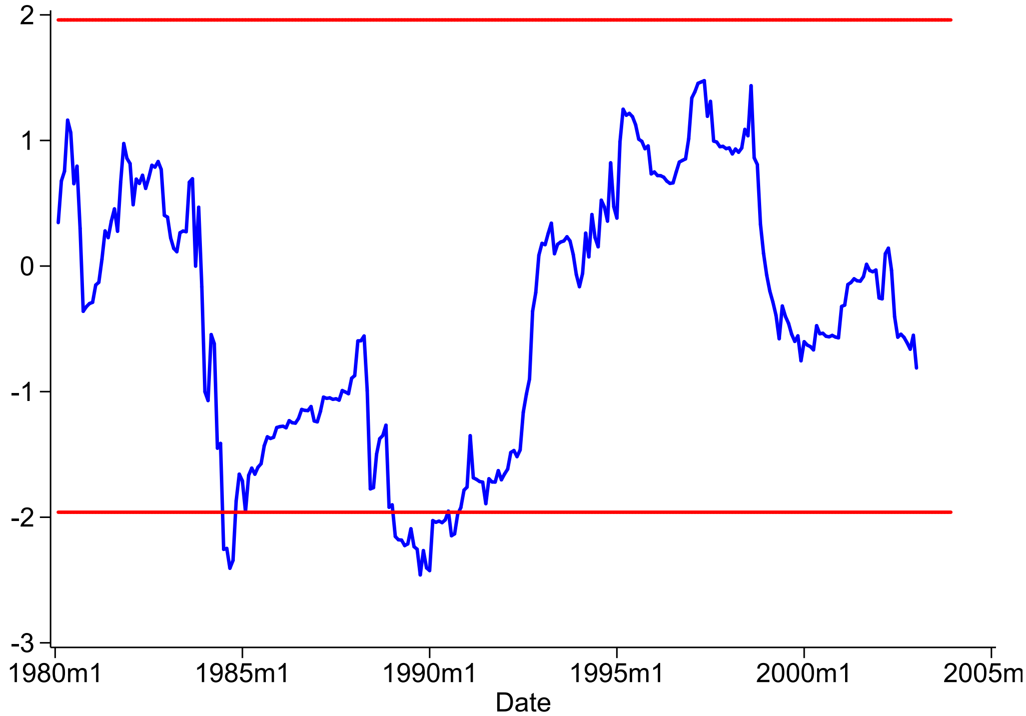
Note: The figure compares the original Romer & Romer (2004) shocks with our replication and extension of the series.

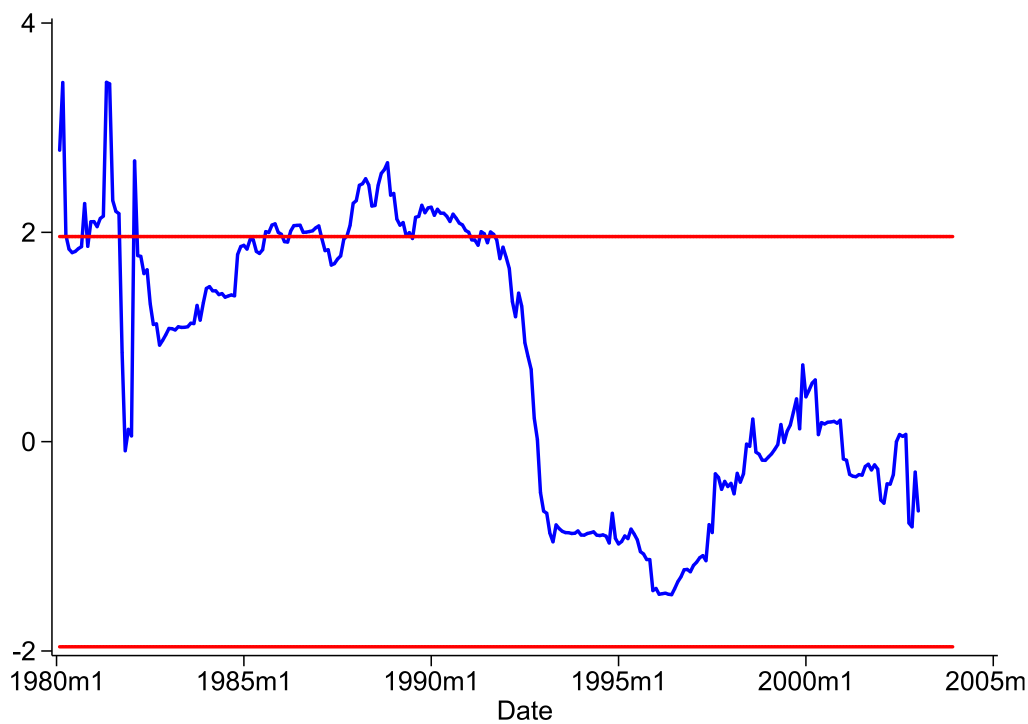
Figure A.2: **Comparing Monetary Policy Shocks**



Note: The figure compares monetary policy shocks using three different identification methods. The top panel compares Romer & Romer (2004) shocks (darker shade) with residuals from a VAR along the lines of Eichenbaum & Evans (1995) or Christiano *et al.* (1999) (lighter shade; correlation 0.14). The bottom panel compares Romer & Romer (2004) shocks (darker shade, left hand scale) to Gertler & Karadi (2015) high frequency shocks (lighter shade, right hand scale; correlation -0.02).

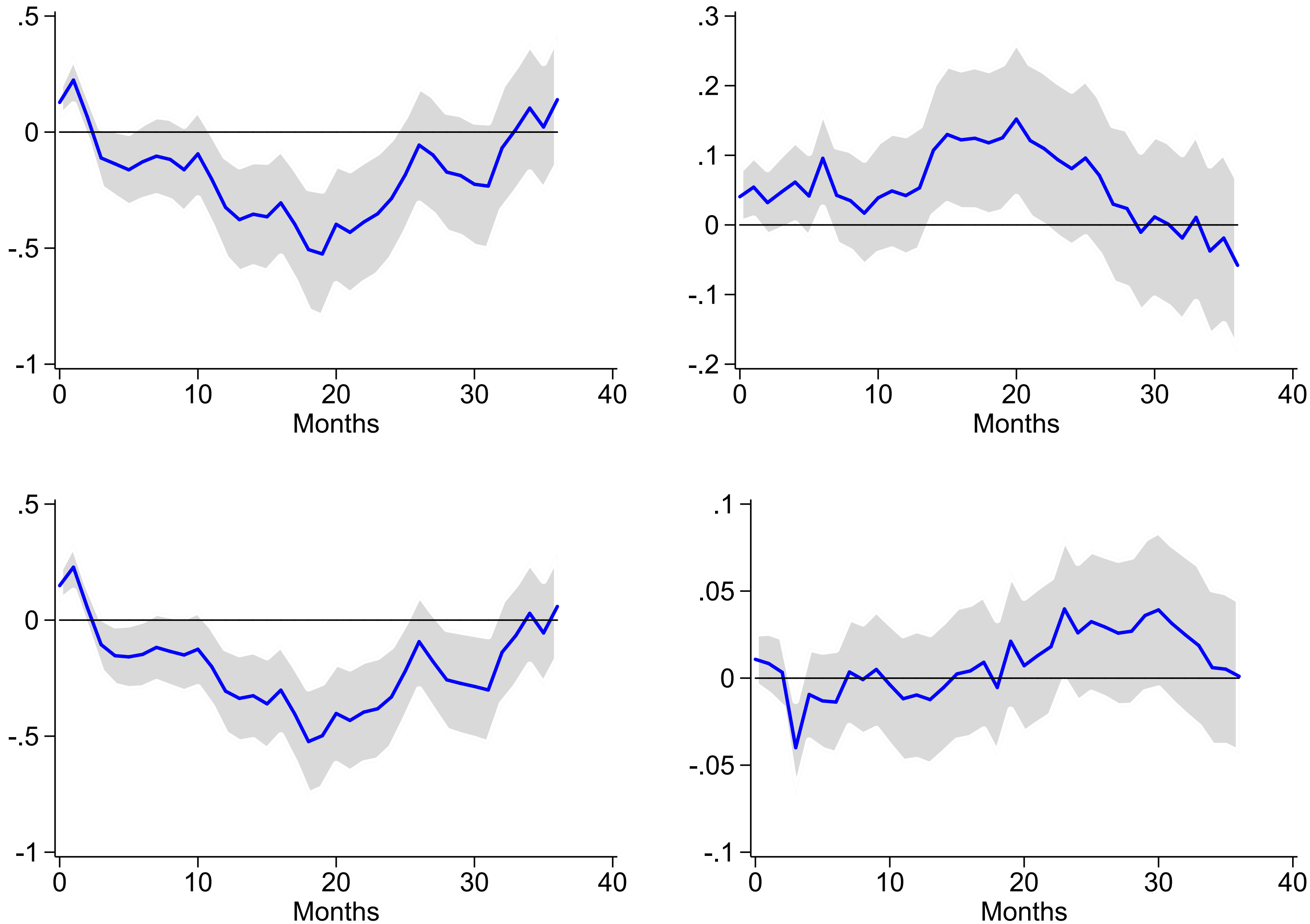
Figure A.3: **T-Statistic on Difference in Difference Regression**





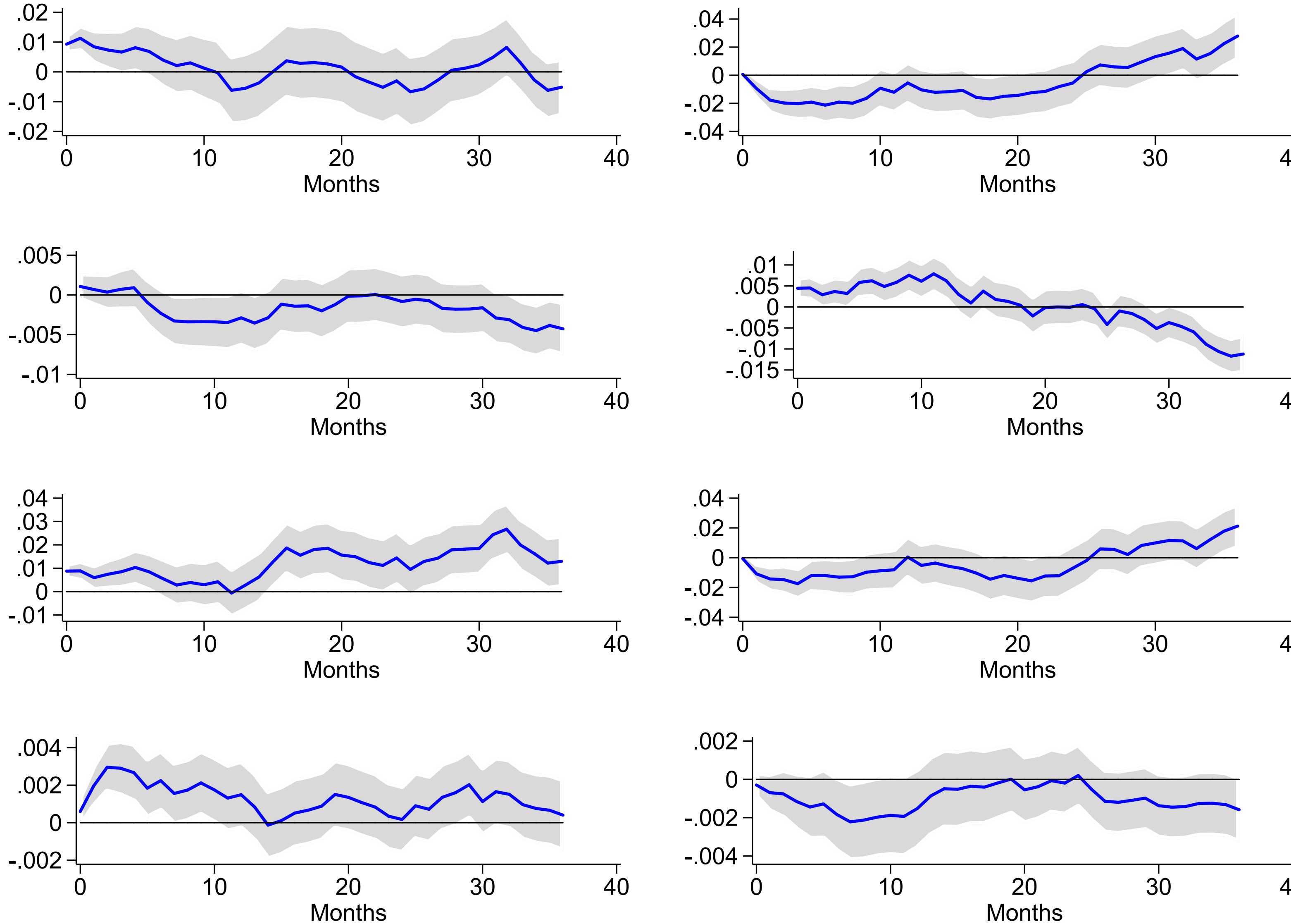
Note: The figure shows the T-statistic on the 12-month horizon local projection of the difference in difference of the response to a Romer & Romer (2004) shock between the early and late samples. The specification is shown in 2, and the reported T-statistics are for the coefficient $\beta_{2,12}$. Each month in the figure represents a regression with a different breakpoint, i.e. a different start date after which the indicator $\mathbb{1}(t)$ takes on a value of one. Regressions in the top panel have the nominal exchange rate as the dependent variable. Regressions in the bottom panel have ex-US industrial production as the dependent variable. The horizontal lines indicate the values +/-1.96 indicating statistical significance at the 95% confidence interval.

Figure A.4: **Responses to High Frequency Monetary Policy Shocks 1990-2017**



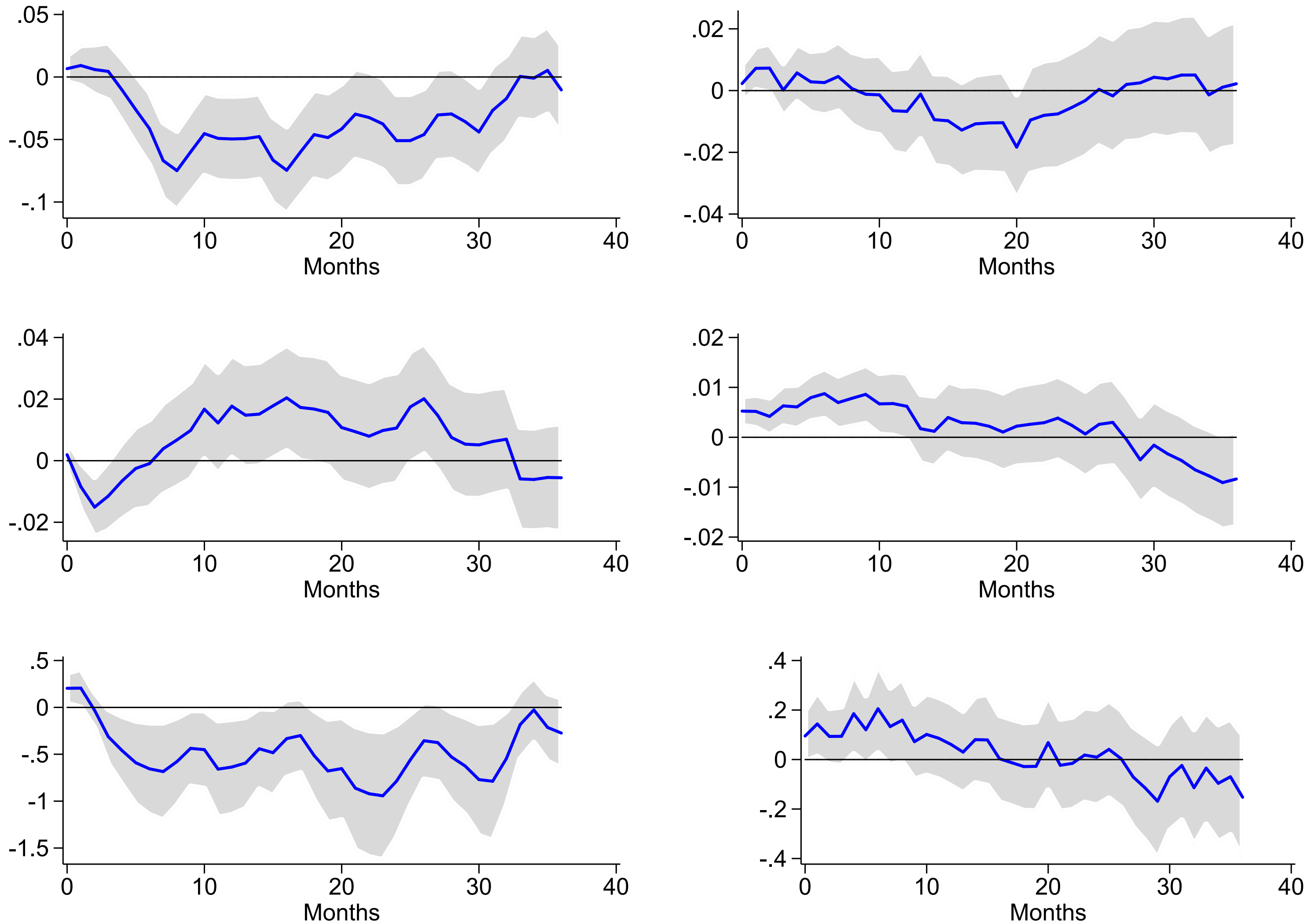
Note: The figure shows responses (in percent) to a 1 percentage point increase in the Federal Funds Rate instrumented by changes in Federal Funds futures in a 30 minute window around Fed announcements (Gürkaynak *et al.* 2005). The responses are for 1990-2007. The left hand column shows the nominal exchange rate (top) and real exchange rate (bottom, increase reflecting US dollar appreciations). The right-hand column shows responses of non-US industrial production. (top) and the non-US policy interest rate.Estimates are local projections with country fixed effects, controlling for country-specific quadratic time trends, and the control variables listed in Section 3. The specification is given by 1. The shaded areas represent 95% Newey-West confidence bands.

Figure A.5: **Responses to Monetary Policy Shocks: Recursive Identification (Eichenbaum & Evans 1995,Christiano *et al.* 1999**



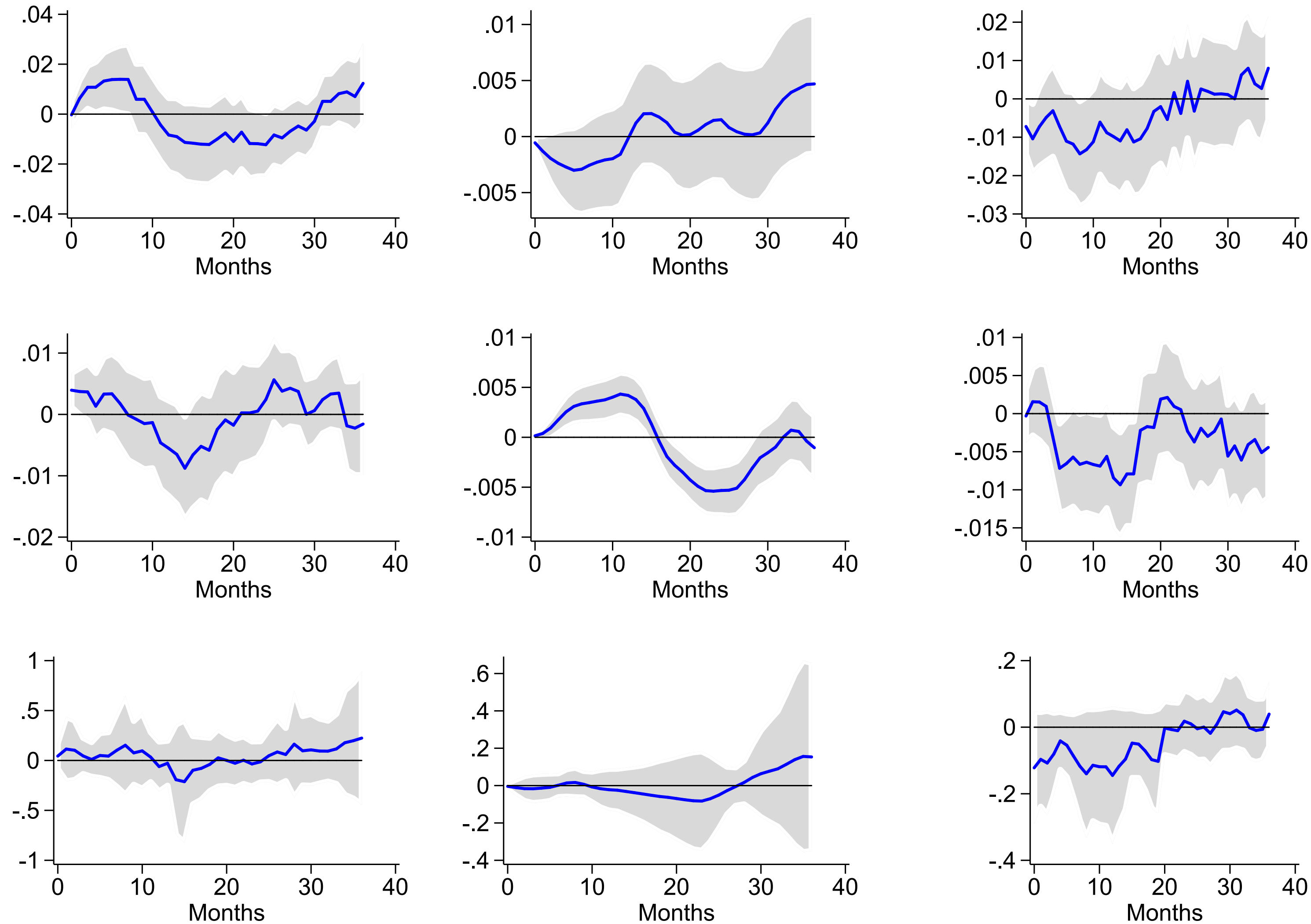
Note: The figure shows responses (in percent) to a 1 percentage point increase in the Federal Funds Rate identified as residuals from VARs, as in Eichenbaum & Evans (1995),Christiano *et al.* (1999). The shocks are residual Fed Funds Rate movements in a VAR also including US industrial production, CPI, and non-borrowed reserves. The left-hand column gives responses for 1973-1990. The right-hand column gives responses for 1991-2007. The first row shows responses of the nominal exchange rate (increase reflecting US dollar appreciations). The second row shows responses of non-US industrial production. The third row shows responses of the real exchange rate. The fourth row shows the change in the policy interest rate in the rest of the world (in percentage points). Estimates are local projections with country fixed effects, controlling for country-specific quadratic time trend. The specification is given by (1). The shaded areas represent 95% Newey-West confidence bands.

Figure A.6: **Response US Monetary Policy Shocks: Including Controls**



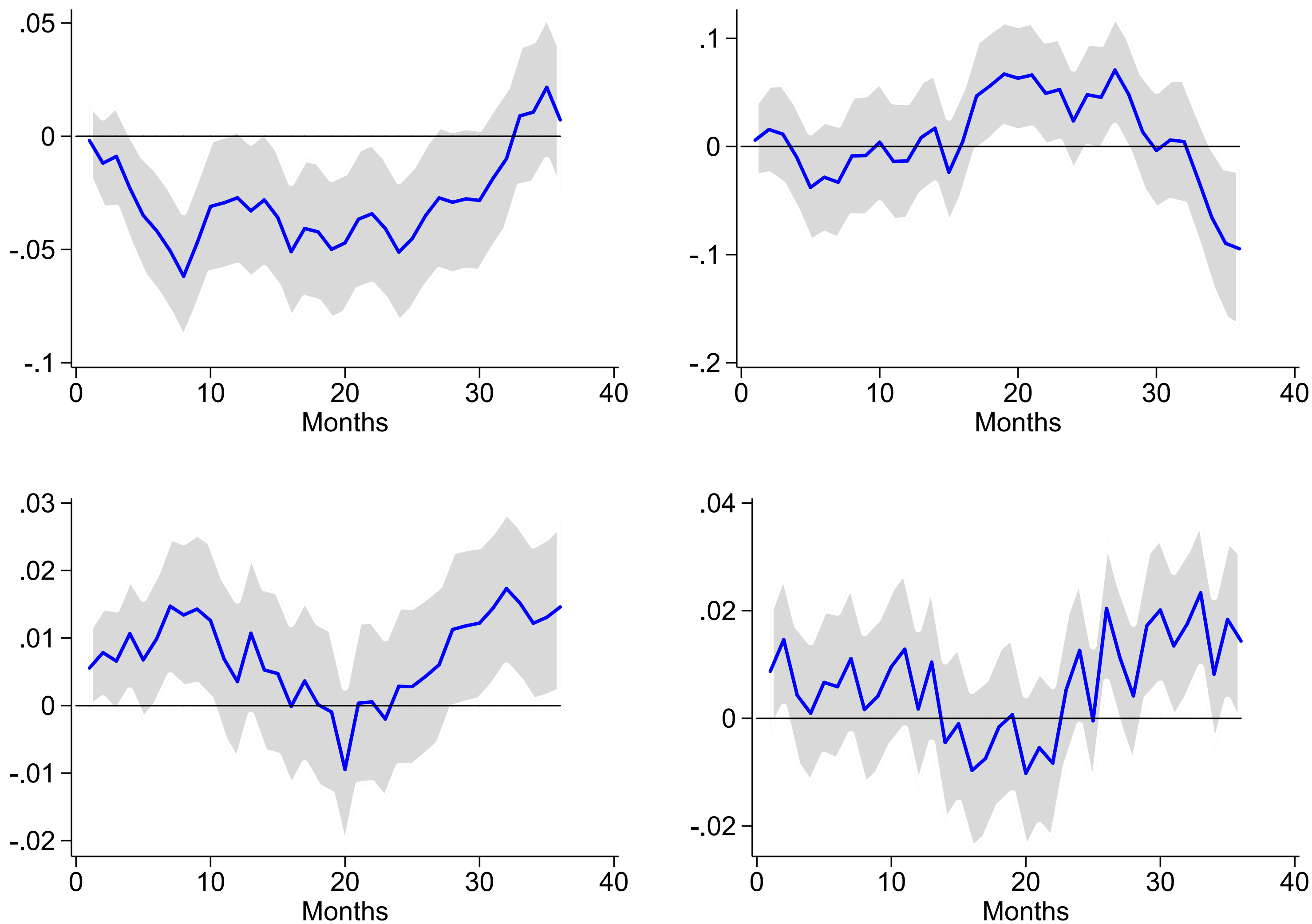
Note: The figure shows the response of the nominal exchange rate (left hand column) and industrial production (right hand column) to monetary policy shocks. Shocks are identified using Romer & Romer (2004) shocks (top row) Cholesky decomposition (middle row); and Gürkaynak *et al.* (2005) shocks used as instruments for the Federal Funds Rate (bottom row). All regressions are for the period 1990-2007. Shaded areas represent 95% (Newey-West) confidence intervals.

Figure A.7: **Response of US Variables to Monetary Policy Shocks**



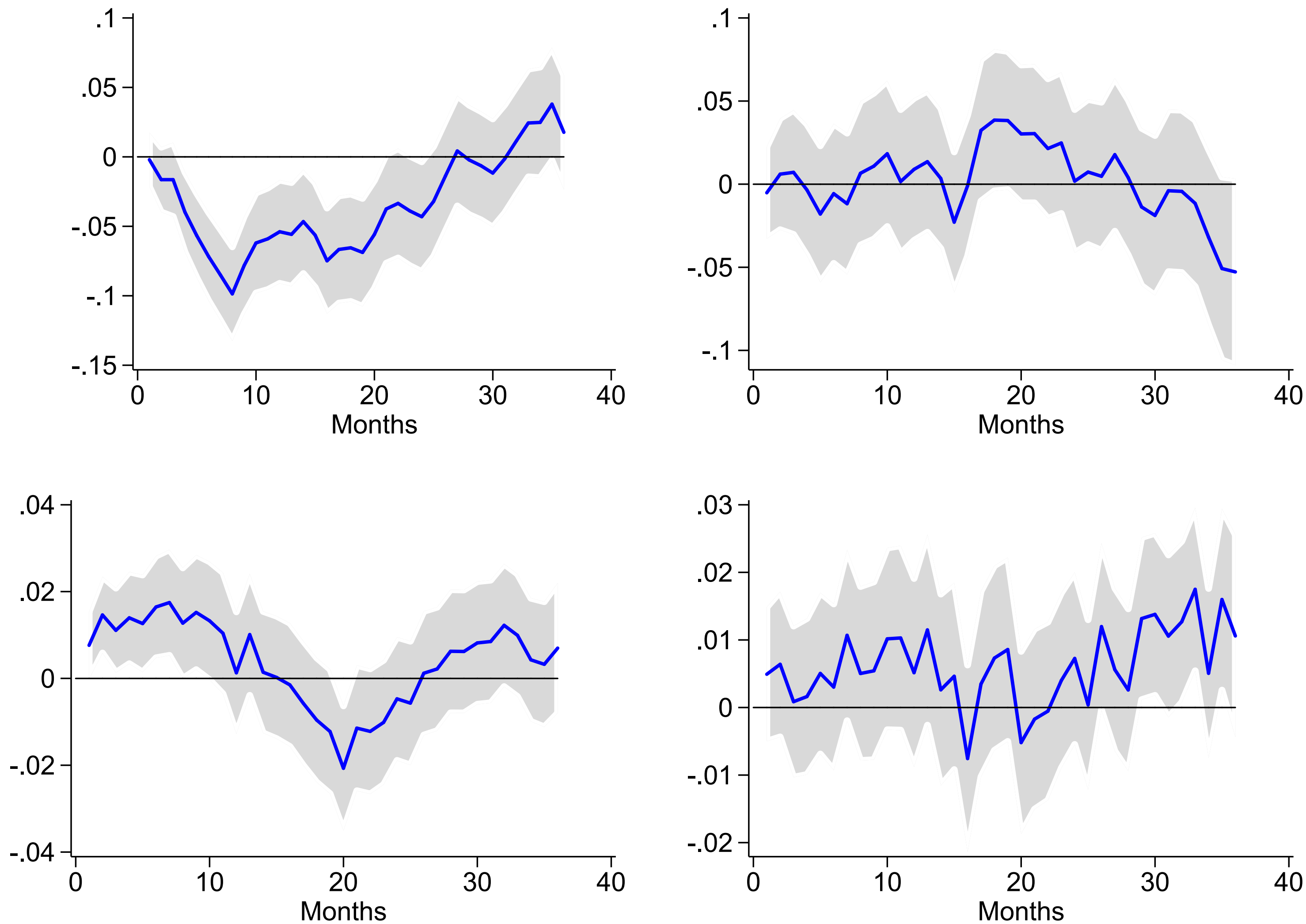
Note: The figure shows the response of three US macroeconomic variables to monetary policy shocks; the left-hand column shows responses of industrial production, the middle column shows inflation responses; and the rightmost column shows responses of the US stock market (the natural logarithm of the S&P500 index). Each row corresponds to a different identification method. The top row shows responses to Romer & Romer (2004) shocks; the middle row shows responses to shocks identified using Cholesky decomposition; the bottom row shows responses to Gürkaynak *et al.* (2005) shocks used as instruments for the Federal Funds Rate. All regressions are for the period 1990-2007. Shaded areas represent 95% (Newey-West) confidence intervals.

Figure A.8: **Foreign Responses to US Monetary Policy Shocks: Capital Account Openness**



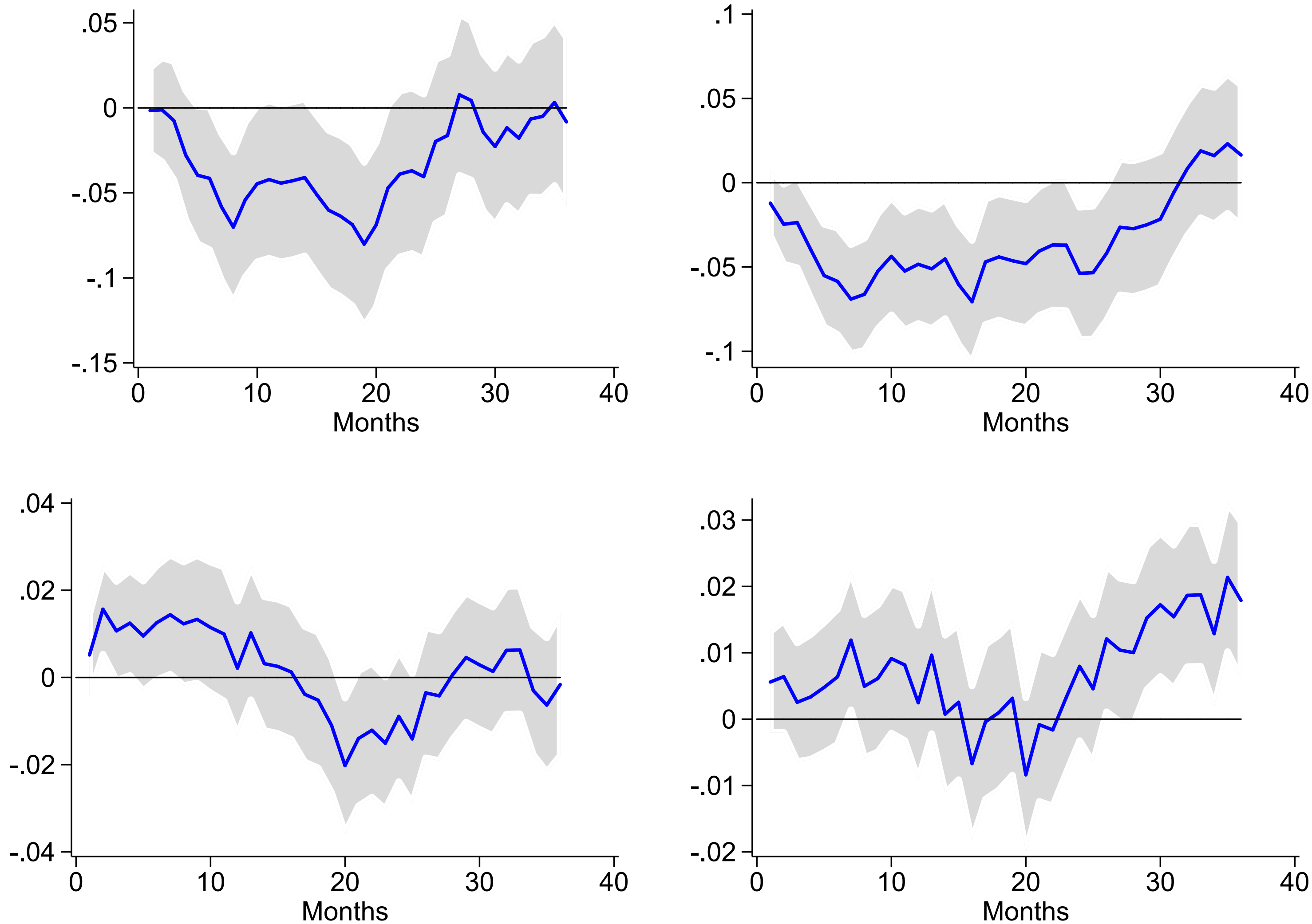
Note: The figure shows the response of exchange rates (top row) and industrial production (bottom row) to Romer & Romer (2004) monetary policy shocks. The left-hand column shows responses for country-months where the Chinn & Ito (2006) index was above median for the sample. The left-hand column periods when countries were financially open and the right-hand column shows periods when countries were financially closed.Shaded areas represent 95% (Newey-West) confidence intervals.

Figure A.9: **Response to US Monetary Policy Shocks: Financial Dollarization**



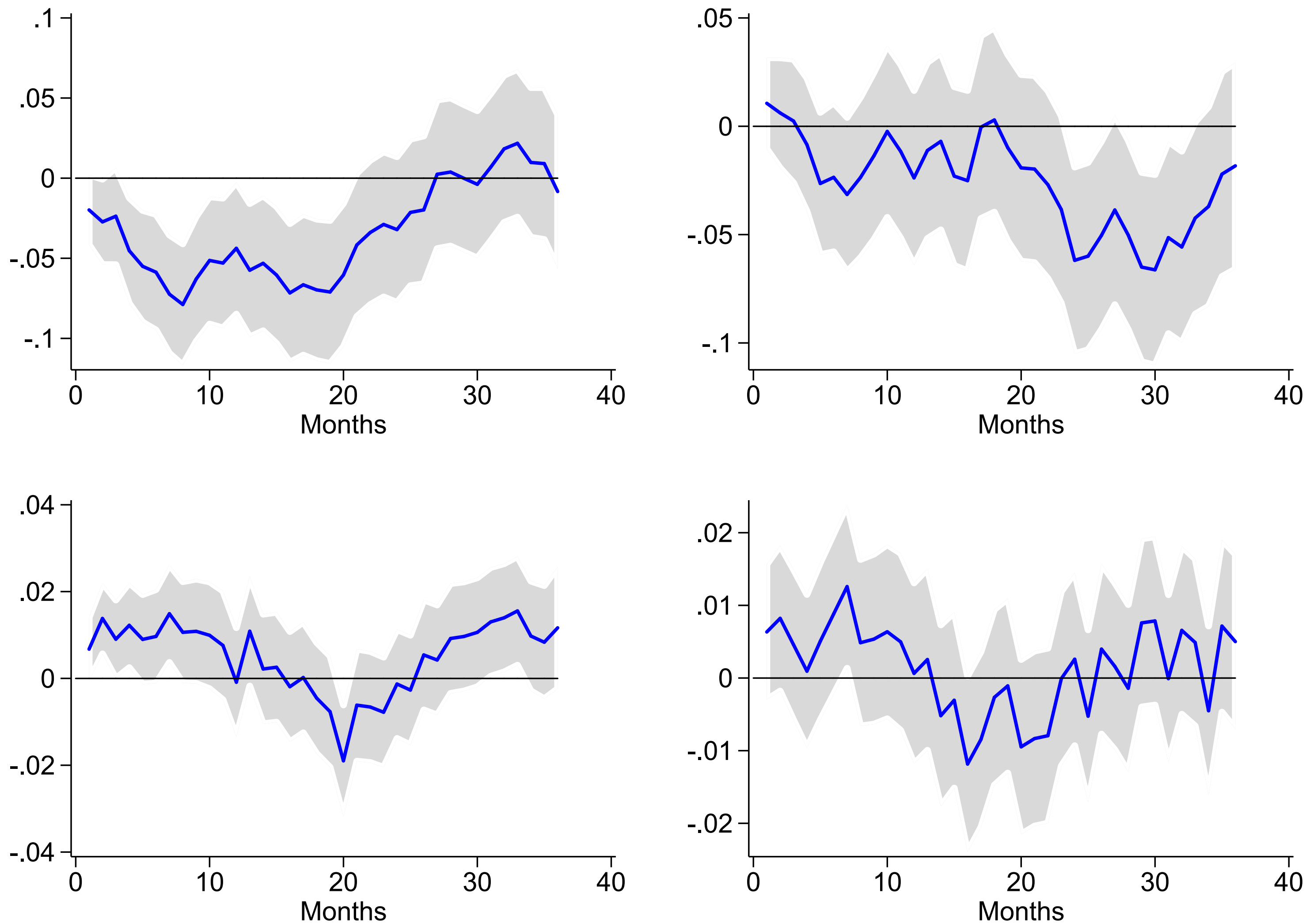
Note: The figure shows the response of exchange rates (top row) and industrial production (bottom row) to Romer & Romer (2004) monetary policy shocks. The left-hand column shows responses for periods when countries had a ratio of dollar-denominated financial assets plus liabilities as a share of GDP that was above the sample median. The right-hand column shows responses for periods when countries were less financially dollarized by the same metric. Shaded areas represent 95% (Newey-West) confidence intervals.

Figure A.10: **Response to US Monetary Policy Shocks: Openness to Trade**



Note: The figure shows the response of exchange rates (top row) and industrial production (bottom row) to Romer & Romer (2004) monetary policy shocks. The left-hand column shows responses for periods when countries had a ratio of trade (imports+exports) to GDP was above median for the sample. The right-hand column shows responses for country-period that were less open to trade. Shaded areas represent 95% (Newey-West) confidence intervals.

Figure A.11: **Response to US Monetary Policy Shocks: Current Account**



Note: The figure shows the response of exchange rates (top row) and industrial production (bottom row) to Romer & Romer (2004) monetary policy shocks. The left-hand column shows responses for periods when countries had a current account as share of GDP above median for the sample. This roughly corresponds to periods when the current account was in surplus. The right-hand column shows responses for periods of current account deficit. Shaded areas represent 95% (Newey-West) confidence intervals.

Table A1: Sample

Country	Exchange Rate	Industrial Production
Australia	1973-2020 (staring 1975 for nominal)	1973-2020
Brazil	2000-2020	1995-2020
Canada	1973-2020	1973-2020
Chile	2000-2020	1991-2020
China	2000-2020 (from 2005 for nominal)	NA
Colombia	2000-2020	2000-2020
Euro	1999-2020 (only nominal)	NA
France	1973-2020 (nominal only to 1998)	1973-2020
Germany	1973-2020 (nominal only to 1998)	1973-2020
India	1973-2020 (Starting 1976 for nominal)	1973-2020
Italy	1973-2020 (nominal only to 1998)	1973-2020
Japan	1973-2020	1973-2020
Mexico	2000-2020	1973-2020
New Zealand	1973-2020	1990-2020
Norway	1973-2020	1973-2020
Russia	2000-2020	2000-2020
South Africa	1995-2020	1973-2020
Sweden	1973-2020	1973-2020
Switzerland	1973-2020	1973-2020
Turkey	2000-2020	1980-2020
United Kingdom	1973-2020	1973-2020

B Details on Theory

The model we derive here is based on the GAMA model. In this setting, there are two countries, the US and Japan (representing the rest of the world), each populated by a unit measure of households. Each household inelastically supplies one unit of labor in each of the two periods and consumes three types of goods: a domestic and a foreign tradable good, and a nontradable good. Labor is internationally immobile. US households derive utility from the consumption of the three goods according to

$$\theta_0 \ln C_0 + \beta \mathbb{E}\left[\theta_1 \ln C_1\right],$$

where the consumption basket takes the form

$$C_t = \left[(C_{N,t})^{\chi_t} (C_{H,t})^{a_t} (C_{F,t})^{\iota_t}\right]^{\frac{1}{\chi_t + a_t + \iota_t}}.$$

$C_{N,t}$ denotes the consumption of nontradable goods, $C_{H,t}$ the consumption of domestic tradable goods, and $C_{F,t}$ the consumption of foreign tradable goods. The nontradable good is the numeraire with a price of one unit of domestic currency.

Consumers in each country trade in a risk-free domestic currency bond solely with the financial intermediary. Their intertemporal budget constraint is

$$\sum_{t=0}^{1} R^{-t} \left(C_{N,t} + P_{H,t} C_{H,t} + P_{F,t} C_{F,t} \right) = \sum_{t=0}^{1} R^{-t} \left(Y_{N,t} + P_{H,t} Y_{H,t} \right),$$

where $P_{H,t}$ is the US dollar price of domestic tradable goods, $P_{F,t}$ the dollar price of foreign tradable goods; $Y_{H,t}$ is domestic tradable output and $Y_{NT,t}$ nontradable output. The domestic interest rate is denoted as R.

The Japanese household faces a symmetrical problem, with preferences of the form

$$\theta_0^* \ln C_0^* + \beta^* \mathbb{E} \left[\theta_1^* \ln C_1^* \right],$$

where

$$C_t^* = \left[\left(C_{N,t}^* \right)^{\chi_t^*} \left(C_{H,t}^* \right)^{\xi_t} \left(C_{F,t}^* \right)^{a_t^*} \right]^{\frac{1}{\chi_t^* + \xi_t + a_t^*}}, \quad t = 0, 1.$$

All '$*$' variables denote those of Japanese households.

Households in each country maximise the expected utility of consumption while choosing the intratemporal allocation of domestic and foreign tradable goods, as well as nontradable goods. The US household's optimal intratemporal allocation of consumption satisfies

$$\chi_t / C_{N,t} = \lambda_t,$$
$$a_t / C_{H,t} = P_{H,t} \lambda_t,$$
$$\iota_t / C_{F,t} = P_{F,t} \lambda_t,$$

where λ_t is the multiplier associated with the budget constraint. As in the original GAMA model, we make the simplifying assumption that $Y_{N,t} = \chi_t$, which, combined with the market clearing condition $C_{NT,t} = Y_{NT,t}$, implies that $\lambda = 1$ in all states. This assumption, which neutralises variations in household marginal utility, is made following for analytical convenience. First order conditions lead to a convenient expression for the dollar value of US imports from Japan (in units of domestic nontradable goods): $P_{F,t} C_{F,t} = \iota_t$; and similarly, the yen value (in units of Japanese nontradable goods) of US exports to Japan: $P_{H,t}^* C_{H_t}^* = \xi_t$. Let e_t denote the exchange rate, defined as the price of a dollar in yen (the units of Japanese nontradable goods that can be exchanged for one unit of US nontradable goods).[20] US net exports amount to:

$$NX_t = \frac{\xi_t}{e_t} - \iota_t.$$

The last optimality condition is the Euler equation:

$$1 = \mathbb{E}\left[\beta R \frac{U'_{1,C_{N,1}}}{U'_{0,C_{N,0}}}\right] = \mathbb{E}\left[\beta R \frac{\chi_1 / C_{N,1}}{\chi_0 / C_{N,0}}\right] = \beta R.$$

The simplifying assumption that $C_{NT,t} = \chi_t$ implies the equation reduces to $R = 1/\beta$. Constant marginal utility owing to this assumption implies that there is no precautionary or intertemporal motive for consumption smoothing. This result does not affect the core mechanism at hand and we focus on exogenous changes to R in our subsequent analysis.

[20]The notation is consistent with the notation in the previous section in that an increase in the exchange rate reflects a dollar appreciation.