International Spillovers of Monetary Policy: The Role of Currency Compositions*

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Abstract

Since 1990, the US has gone from a net creditor to a net debtor. I study the implications of this for international spillovers of US monetary policy (MP). I find that a tightening of US MP tended to depress output abroad before 1990 but has no effects after 1990. This change in spillovers is largely explained by the foreigners' dollar wealth. I study this in a 3-region New Keynesian model with incomplete markets and partly dollarized balance sheets. In the model, foreigners with dollar wealth experience a positive wealth effect following a tightening of US MP, boosting consumption and output. The wealth effect is sizable: It explains more than half of the change in spillovers and is more important than standard exchange rate channels.

Keywords: Monetary policy, heterogeneous households, incomplete markets
JEL Codes: E21, E32, E52, F41

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1 Introduction

The US has been the hegemon of the global monetary system for many decades. This position shines a spotlight on the effects of US monetary policy (MP) internationally. However, since the 1980s there has been a dramatic shift in key characteristics of the US economy: The US has gone from having low public debt and being a net creditor to having high public debt and being a net debtor. In particular, US federal debt has increased from 30% of GDP in 1980 to 120% of GDP today, while the US net international investment position (NIIP) has gone from 10% of GDP to -70% of GDP over the same period. In this paper, I study the implications of this shift for the international spillovers of US MP.

To answer this, I start by turning to the data. First, I ask the question: Have the international spillovers of US MP changed since 1990? I answer this question in the affirmative. To do this, I use a panel of 37 small open economies (SOEs). Using difference-in-differences panel local projections, I find that a tightening of US MP before 1990 depressed output abroad. After 1990, output no longer falls in response to US MP tightening. Thus, I conclude that the average foreign economy is insulated from US MP tightening after 1990.

Next, I ask the question: Can the insulation of foreigners from US MP policy tightening be explained by the shift of the US from net creditor to net debtor? In particular, this change implies that foreigners must now hold significant net wealth in USD. To examine this, I construct a panel of the net wealth of foreign economies denominated in USD. This data shows that the average net wealth denominated in USD has gone from 0% of GDP before and around 1990 to 65% today. While there is heterogeneity across countries, the increase is a general trend that holds for both advanced and emerging economies.

Having established the increase in USD net wealth of foreigners since 1990, I study to which degree it can explain the insulation from US MP tightening using state-dependent panel local projections. Here, I find a clear pattern: Countries with a higher net USD wealth are more insulated from US MP tightening. This pattern holds both across time *within countries* and across countries *within time*. In addition to being statistically significant, this effect is also economically significant: The average increase in USD wealth of foreigners from before 1990 to after 1990 reduces the semi-elasticity of output to changes in the US interest rate by 0.4 percentage points.[1]

I then study what an increase in USD wealth abroad implies from a theoretical point of view. The work-horse model for understanding the transmission mechanism of MP is the New Keynesian model. In this model, the main transmission channel of monetary policy to other countries is often through trade. When the US tightens MP, this appreciates the USD and depreciates foreign currency. The depreciation of foreign currency creates expenditure switching, boosting exports and output abroad. On the other hand, a tightening of US MP creates a recession in the US, lowering US demand for foreign goods and hence foreign output.

I extend this model along two key dimensions. First, I add partly dollarized balance sheets in 3 sectors: The household sector, the firm sector, and the public sector. This means that agents in all 3 sectors can hold net wealth denominated in USD, which appreciates in value when the USD appreciates. Second, I assume that markets are incomplete via a constraint on households' capacity to borrow. This means that the model generates an endogenous distribution of wealth. Furthermore, this allows different households to hold different portfolios, i.e. to hold different amounts of the four assets in the economy. This is key to understanding revaluations of wealth.

Despite the complexity of the model, I show that my model implies an easy-to-interpret analytical expression for a key object: The semi-elasticity of foreign output with respect to US MP, both in cumulative present value terms. The expression contains well-known channels from the literature such as trade and exchange rate channels. However, the expression for the semi-elasticity of foreign output also uncovers a key channel in my model: The wealth channel of US MP. This channel reflects that when the US tightens MP, the USD appreciates, appreciating the value of assets denominated in USD. This makes foreigners who hold USD assets richer, so they consume more, boosting output in general equilibrium.

The key parameter governing the size of the wealth channel is the wealth denominated in USD held abroad. When foreigners hold no USD wealth, the wealth channel is absent. When they hold an empirically realistic amount of USD wealth, the wealth channel is sizable. I find that the wealth channel explains an increase in the semi-elasticity of around 0.4 percentage points. Since I estimate that the semi-elasticity has dropped from around -0.6 before 1990 to around 0 after 1990, the wealth channel can explain the majority of the insulation from US MP since 1990.

1. Specifically, the semi-elasticity measured in *cumulative present value* terms. I define this quantity precisely in Section 4.

One might ask if my results are specific to my particular model and calibration. I show that this is not the case. In particular, I show that my expression for the semi-elasticity of foreign GDP with respect to US MP is general in the sense that it still holds in a large class of models that depart from some of the assumptions of my model. Furthermore, despite the complexity of the model, the semi-elasticity only depends on a select few parameters that are well-identified in the data such as trade shares and the sizes of the different economies. Thus, my results are largely robust to essentially all even somewhat plausible different parameter values.

I conclude that structural changes in the US economy around the 1980s and 1990s such that the US is now a net debtor instead of a net creditor has central implications for the international transmission of US MP: Before 1990, US MP tightening was on average recessionary. This is no longer the case due to the insulation offered by USD wealth held abroad which appreciates when the US tightens MP.

1.1 Related literature

My paper contributes to three strands of literature. The first is on the international spillovers of US MP. I find that US MP created recessions abroad before 1990, which is consistent with the majority of previous empirical studies, c.f. Maćkowiak (2007), Georgiadis (2016), Dedola et al. (2017), Iacoviello and Navarro (2019), Vicondoa (2019), Degasperi et al. (2021), and Bräuning and Sheremirov (2021). Of particular relevance, I study how these US MP spillovers have changed over time, in the sense that foreigners are more insulated after 1990. A particularly relevant paper is Ilzetzki and Jin (2021), who study exactly the same question. They find that tighter US monetary policy caused industrial production to decline abroad before 1990, but stimulates the economy after 1990. This is the same result that I establish. Ilzetzki and Jin (2021) consider this change in spillovers to be puzzling. My paper provides a possible theory of this change in spillovers.[2]

My paper also contributes to the literature on models of small open economies and transmission of international shocks, see for instance Fleming (1962), Mundell (1963), Backus et al. (1992), Backus and Smith (1993), Obstfeld and Rogoff (2000),

2. Ilzetzki and Jin (2021) also focus on a theory of exchange rate determination. In my paper, the real exchange rate is taken directly from the data. Additionally, Ilzetzki and Jin (2021) find that the real exchange rate depreciates before 1990 but appreciates after, with the latter being puzzling. I find a depreciation both before and after 1990, consistent with theory. The difference is probably due to my data having more countries and a significantly longer post-1990 sample.

Gali and Monacelli (2005), Adolfson et al. (2007), Justiniano and Preston (2010), and Christiano et al. (2011). More specifically, my paper contributes to the literature on international spillovers of US MP, see Ahmed et al. (2021), Zhang (2022), and Akinci and Queralto (2024) for some recent contributions.

My paper also contributes to the literature on HANK models. Early HANK models include Werning (2015), McKay and Reis (2016), and Kaplan et al. (2018), with a large number of contributions to the literature since then. Noticeably, HANK papers have mostly focused on closed economies, in contrast with my paper, which is for an open economy. Recently, a smaller but expanding literature on open economy HANK models has begun, including, Auclert et al. (2021c), Zhou (2022), Aggarwal et al. (2022), Oskolkov (2023), Sundram (2024), and Druedahl et al. (2024).

A particularly relevant paper is Ferra et al. (2020), who study current account reversals in HANK economies with foreign currency borrowing. The central transmission channel in my paper is very similar to theirs. The key difference is that I study US MP spillovers and how they have changed since 1990, empirically grounded in estimated panel local projections. Instead, they focus on currency account reversals in Hungary. Another closely related paper is Ferrante and Gornemann (2022), who study the effects of devaluations in small open economies. The key similarity to my paper is the emphasis on the role of dollarization. The differences are that they focus on depreciations and not US monetary policy spillovers, and the transmission mechanism is very different. In particular, their transmission mechanism goes through a financial accelerator mechanism, something not required in my model, and their transmission does not take into account the increased role of the US as a net debtor, something which is central in my paper.

1.2 Structure

In Section 2, I present my empirical results on international spillovers of US MP across time and countries. In Section 3, I write up my model of foreign US MP spillovers. In Section 4, I show that the model implies a strong wealth effect in the foreign US MP spillovers. Finally, I conclude in Section 5.

2 Empirics

In this section, I study empirically international spillovers of US MP. Details on the data are presented in Appendices A.1 and A.2. First, I motivate my analysis with a simple empirical fact: The US has gone from a net creditor before 1990 to a net debtor after 1990. Second, I show that this structural shift coincides with a change in the international spillovers of US MP: Foreign GDP on average dropped in response to a US MP tightening before 1990 but increases after 1990. Third, I exploit the panel dimension of my data to show that this change in US MP spillovers not just coincides with the US being a net debtor after 1990 but is explained by it in the following sense: Foreign countries which hold net wealth denominated in USD are exactly the countries which tend to gain from a US MP tightening.

2.1 The US as a Net Debtor

Since around the 1980s, there has been a dramatic shift in the US economy. Before then, the US federal government was consistently reducing the federal debt as a share of GDP through a combination of federal surpluses and GDP growth. However, since around the 1980s federal debt has dramatically increased a percent of GDP, c.f. the left panel of Figure 1.

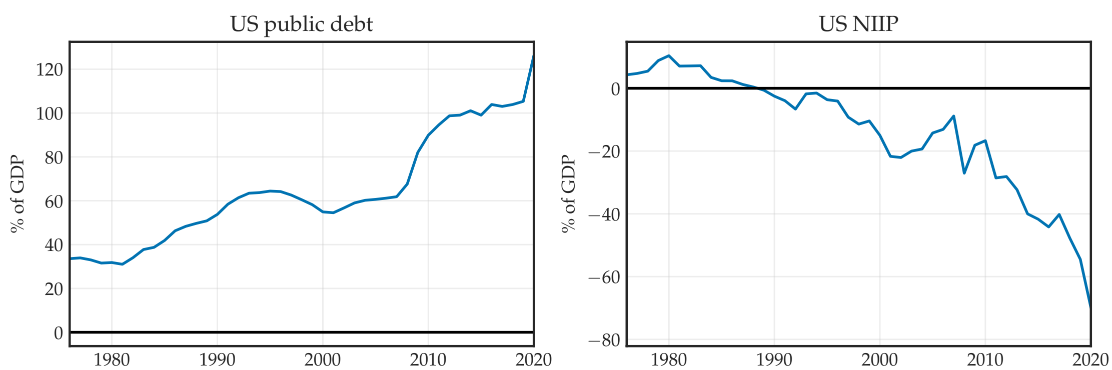

Figure 1: US Public Debt and NIIP

Note: The figure shows the total public debt for the US in the left panel based on data from the US Department of the Treasury. The right panel shows the NIIP over time for the US based on data from the US Bureau of Economic Analysis. Data retrieved from the Federal Reserve Bank of St. Louis. The NIIP is the "net international investment position".

A large share of the debt issued by the US is owned by foreigners. This is reflected in the right panel of Figure 1, which shows the US net international investment position (NIIP), i.e. the value of the assets held by US economic agents less the supply of assets by US agents.

In line with the expansion of US public debt (an asset supplied by the US), the US NIIP has gone from positive in the 1970s and 1980s, to negative after around 1990. Put simply, this implies that the US as a whole has gone from a net creditor to a net debtor.

This means that the US used to lend more to foreigners than foreigners borrowed from the US on net, while today the US borrows more from foreigners than foreigners borrow from the US on net.

Consider now this fact from the point of view of foreigners: They lend more to the US than the US borrows from them. If these assets are denominated in USD, this suggests that the wealth of foreigners denominated in USD has expanded dramatically. To study this, I construct a dataset of the net wealth denominated in USD for a sample of 37 SOEs, see Appendix A.2 for details on how I construct the data. I refer to this as the net wealth of foreigners denominated in USD (NWFU). To be specific, the NWFU of country i in year t is

$$\text{NWFU}_{i,t} \equiv (\text{USD-denominated assets})_{i,t} - (\text{USD-denominated liabilities})_{i,t}.$$

From the point of view of a foreign country, an example of an asset denominated in USD is US government bonds.[3] An example of a liability denominated in USD is foreign bonds which the foreign government pays back with USD. The NWFU then measures if foreigners have more assets or liabilities denominated in USD.

Figure 2 shows the evolution of the average NWFU from 1976 to 2020 for a sample of 37 SOEs as a percent of GDP. The figure shows that the NWFU has increased from slightly negative or around zero in the late 1970s and early to mid-1980s to very positive around 1990 and afterward. As I show in Appendix A.3, this pattern is not just driven by a few outlier countries and the pattern is the same for both advanced and developing economies.

The fact that foreigners now hold significant wealth in USD potentially has significant implications for the international spillovers of US MP for a simple reason. When the US tightens monetary policy, standard models would imply an appreciation of the USD. Since foreigners on net hold wealth denominated in USD, this means that foreigners become richer, which insulates foreigners from any other potential negative effects of a US MP tightening. I refer to this as the wealth channel of US MP. This is the main focus of my paper.

In summary, I have established that the US economy underwent a structural shift in the 1980s, such that it went from a net creditor to a net debtor today. This means that the average foreigner post 1990 has more assets than liabilities in US. Motivated by this, I proceed by asking two questions. First, has the international spillovers of US

3. Another obvious example is US stocks.

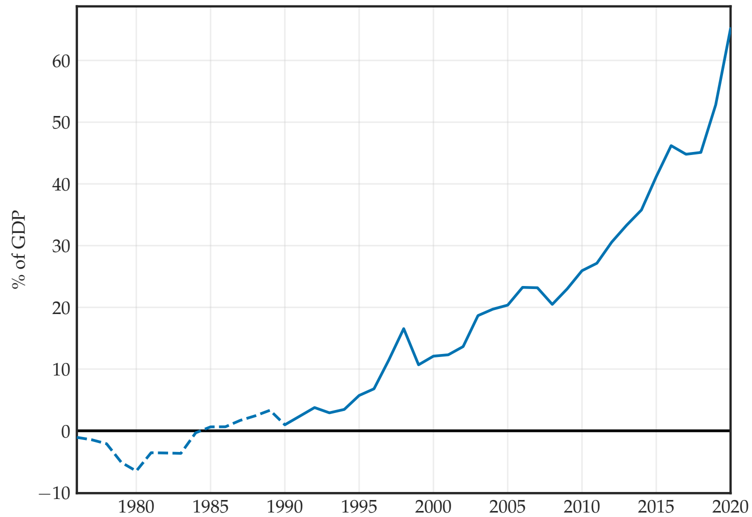

Figure 2: Net Wealth of Foreigners Denominated in USD (NWFU)

Note: The figure shows the average NWFU (in percent of GDP) for non-US countries over time. Data based on Bénétrix et al. (2015) and Juvenal et al. (2020). Dashed lines indicate extended time series, cf. Appendix A.2.

MP also undergone a structural shift after 1990? And if so, does this have anything to do with the net wealth held by foreigners?

2.2 International Spillovers of US MP

I now consider the international spillovers of US MP onto GDP of foreign countries. To do this, I use panel local projections. Before presenting the empirical method, I start by presenting the panel data itself.

2.2.1 Data

I consider a panel of 37 SOEs including both advanced and emerging economies (c.f. Appendix A.1). The main outcome variable is (log real) GDP of each of these SOEs, which is measured at a quarterly frequency and seasonally adjusted. I take this data from the database provided by Iacoviello and Navarro (2019). I also take the US MP shock series from this database. These shocks are based on a standard recursive approach in the sense that they are the residuals of the US federal funds rate on a series of controls and their lags. I also consider robustness to three different series of US MP shocks.

For net wealth of foreigners denominated in USD, I use and expand the data from Bénétrix et al. (2015) and Allen et al. (2023). See Appendix A.2 for details. This data is at the yearly frequency. Further details on the data are given in Appendix A.1

2.2.2 Changing US MP Spillovers

My goal is to estimate the international spillovers of US MP onto foreign GDP. I do this by estimating a regression of (log real) GDP in country i at time t, $y_{i,t}$, on a US MP shock, z_t. I include country fixed effects and country-specific time trends in this regression. Since the focus of my paper is how the spillovers change over time, I also include an interaction term multiplying the monetary policy shock by a dummy, D_t, similar to the differences-in-differences literature. Following Ilzetzki and Jin (2021), this dummy takes the value 1 after 1990 (inclusive) and 0 before 1990. I estimate this regression for difference horizons $h = 0, 1, \dots$ to obtain the dynamic response of real GDP to the US MP shock, i.e. local projections (Jordà 2005). In summary, I estimate the following difference-in-differences panel data local projections:

$$y_{i,t+h} = \alpha_i^{(h)} + \beta^{(h)} z_t + \delta^{(h)} z_t D_t + \kappa^{(h)} D_t + \sum_{j=1}^{p} \gamma_j^{(h)} y_{i,t-j} + \sum_{j=1}^{p} \delta_j^{(h)} z_{i,t-j} + \tau_{i,t}^{(h)} + \varepsilon_{i,t}^{(h)}, \tag{1}$$

where $\alpha_i^{(h)}$ are the country fixed effects, $\tau_{i,t}^{(h)}$ are country-specific linear and quadratic time trends, and $\varepsilon_{i,t}^{(h)}$ are the residuals. I use $p = 2$ lags. The key coefficients of interest are $\beta^{(h)}$ and $\delta^{(h)}$. These measure the average dynamic response of log real GDP to a US MP tightening. In particular, $\beta^{(h)}$ measures the average percent change in GDP h periods after a 1 percentage point tightening of US MP before 1990. $\delta^{(h)}$ then measures by how many percentage points this is different after 1990. Thus, $\beta^{(h)} + \delta^{(h)}$ measures the response of GDP after 1990. Plotting these objects, $\beta^{(h)}$ and $\beta^{(h)} + \delta^{(h)}$, as a function of h gives the usual impulse response functions of foreign GDP to a US MP tightening before and after 1990, respectively.

The results are shown in Figure 3. The first panel shows the dynamic response of foreign GDP (the IRF) before 1990, i.e. estimates of $\beta^{(h)}$. The panel shows that US MP tightening was recessionary before 1990. In particular, a 1 percentage point tightening of US MP leads to more than a 0.4% drop in foreign GDP after 2-3 years.

In contrast, the second panel of Figure 3 shows the IRF after 1990, i.e. estimates of $\beta^{(h)} + \delta^{(h)}$. This shows that US MP is no longer recessionary after 1990: At no horizon can I reject the null of US MP not affecting foreign GDP. The third and final panel shows the difference between the responses before 1990 and after 1990, i.e. estimates of $\delta^{(h)}$. The difference is around zero or positive but statistically insignificant at most horizons. At a few horizons, the difference is positive and statistically significant, indicating that countries are more insulated from US MP tightening after 1990. In Appendix A.4, I show that this result is robust to various different specifications.

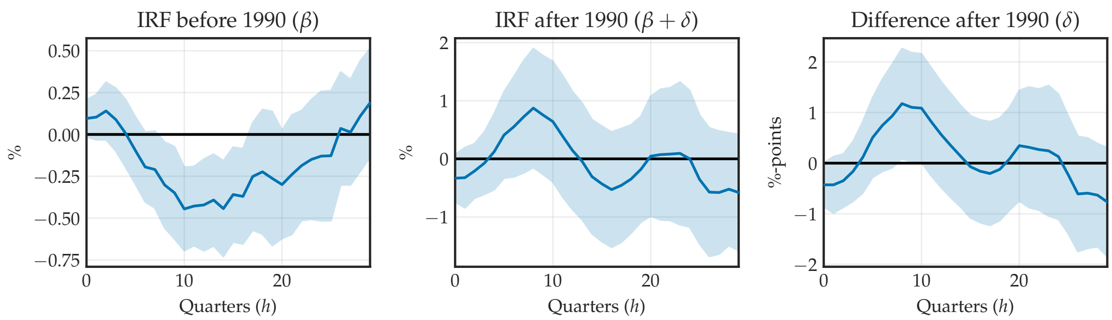

Figure 3: Spillovers of US MP Onto Foreign GDP Before and After 1990

Note: The coefficients are from OLS estimation of eq. (1). 90% confidence intervals using Driscoll-Kraay standard errors.

In conclusion, I have provided evidence that US MP created recessions abroad before 1990 as measured by a drop in foreign GDP. After 1990, their is no clear recession: Foreign GDP on average does not respond to a tightening of US MP.

2.2.3 The NWFU as a Determinant of US MP Spillovers

Having provided evidence of a shift in US MP spillovers after 1990, I now ask if this has anything to do with the net wealth denominated in USD held by foreigners. In particular, I test if a higher NWFU is associated with less negative (more positive) spillovers of US MP. To do this, I use an approach that is very similar to the one in Section 2.2.2. The only difference is that I replace the post-1990 dummy by the NWFU abroad. Thus, the regression now has the interpretation of state-dependent local projections, following the approach of Cloyne et al. (2023). To be specific, I estimate the following regression:

$$y_{i,t+h} = \alpha_i^{(h)} + \beta^{(h)} z_t + \delta^{(h)} z_t \widetilde{\text{NWFU}}_{i,t} + \kappa^{(h)} \widetilde{\text{NWFU}}_{i,t} + \sum_{j=1}^{p} \gamma_j^{(h)} y_{i,t-j}$$
$$+ \sum_{j=1}^{p} \delta_j^{(h)} z_{i,t-j} + \tau_{i,t}^{(h)} + \varepsilon_{i,t}^{(h)}, \qquad (2)$$

where the notation is the same as in eq. (1). The only difference is $\widetilde{\text{NWFU}}_{i,t} = \text{NWFU}_{i,t-4} - \overline{\text{NWFU}}$, which measures the de-meaned lagged NWFU, (as $\overline{\text{NWFU}}$ is the average NWFU across countries and time). This is the method suggested by

Cloyne et al. (2023). I use the NWFU from the previous year (4 quarters ago) to deal with the possibility that the shock affects the NWFU contemporaneously. When using the NWFU in the regression, I extend the series so as not to lose the majority of my observations. I discuss how I do this in Appendix A.2.

The interpretation of eq. (2) is as follows. $\beta^{(h)}$ measures the average percent change in foreign GDP h periods after a 1 percentage point tightening of US MP for a country with an average NWFU. On the other hand, $\beta^{(h)} + \delta^{(h)}x$ measures the average percent change in foreign GDP h periods after a 1 percentage point tightening of US MP for a country with a particular NWFU: $\widetilde{\text{NWFU}}_{i,t} = x$.

The results are shown in Figure 4. The first panel shows the average dynamic response of foreign GDP (the IRF) for a country with an average NWFU, i.e. estimates of $\beta^{(h)}$. The panel shows that US MP tightening is recessionary for countries with an average NWFU. Next, I consider the IRF for a country with a NWFU of 24%, which is the average NWFU after 1990. This is shown in the second panel of Figure 3. This shows that US MP is not recessionary for countries with a NWFU of 24%: At no horizon can I reject the null of US MP not affecting foreign GDP.

The third panel shows the coefficient on the interaction term, i.e. estimates of $\delta^{(h)}$. I use this to test if the difference between the first and second panels is statistically insignificant. I clearly find that this is the case, implying that countries with a higher NWFU tend to have a more positive response of GDP to a US MP tightening, i.e. are more insulated from US MP. In Appendix A.5, I show that this result is robust to various different specifications, including using different shock series.

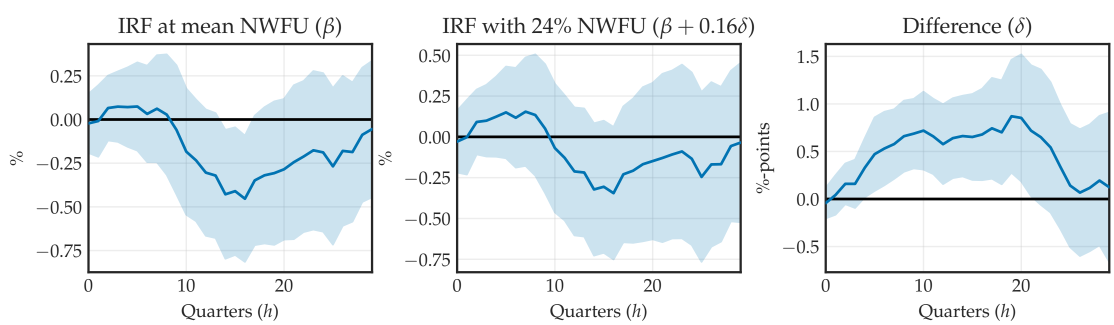

Figure 4: Spillovers of US MP Onto Foreign GDP for Different NWFU

Note: The coefficients are from OLS estimation of eq. (2). 90% confidence intervals using Driscoll-Kraay standard errors.

I conclude that the empirical evidence supports that countries with a higher NWFU on average are more insulated from US MP tightening.

2.2.4 A Joint Test

I have now shown that (i) countries are more insulated from US MP tightening after 1990 and that (ii) countries with a higher NWFU are more insulated from US MP tightening. One explanation is that (ii) is driving (i), i.e. that countries are more insulated after 1990 due to having a higher NWFU. However, it is possible that (i) and (ii) happen to occur at the same time but have nothing to do with each other, i.e. that countries are more insulated from US MP spillovers over time and that the NWFU has risen over time, but that the higher NWFU is not what causes this insulation.

To rule out these simultaneous but independent trends over time in the NWFU and spillovers of US MP, I exploit the panel dimension of my data. In particular, I add terms to the regression interacting the US MP shock with both the NWFU and the time dummy. Thus, I estimate if the effect of the NWFU on US MP spillovers holds not only across time but also within time across countries. In particular, I consider the following local projections which interacts the terms in equations (1) and (2):

$$
\begin{aligned}
y_{i,t+h} = {} & \beta_1^{(h)} z_t + \beta_2^{(h)} D_t + \beta_3^{(h)} \widetilde{\text{NWFU}}_{i,t} + \beta_4^{(h)} z_t D_t + \beta_5^{(h)} z_t \widetilde{\text{NWFU}}_{i,t} \\
& + \beta_6^{(h)} D_t \widetilde{\text{NWFU}}_{i,t} + \beta_7^{(h)} z_t D_t \widetilde{\text{NWFU}}_{i,t} + \sum_{j=1}^{p} \gamma_j^{(h)} y_{i,t-j} \\
& + \sum_{j=1}^{p} \delta_j^{(h)} z_{i,t-j} + \alpha_i^{(h)} + \tau_{i,t}^{(h)} + \varepsilon_{i,t}^{(h)}.
\end{aligned} \tag{3}
$$

This is similar to a triple differences-in-differences approach. To understand this regression, consider first the coefficient on z: β_1. This simply measures US MP spillovers before 1990 for a country with an average NWFU. My hypothesis is that this is negative, consistent with Section 2.2.2, i.e. that US MP spillovers on average created a recession abroad before 1990.

Consider next the coefficient on the interaction between the US MP shock and the post-1990 indicator: β_4. This measures the change in US MP spillovers after 1990, holding fixed the NWFU. If the NWFU is the only thing driving the change in spillovers after 1990, this coefficient should be zero. However, I note that if other things are also changing spillovers after 1990, this coefficient could take on a non-zero value without being inconsistent with the NWFU as a driver.

To understand the NWFU as a driver of US MP spillovers, consider the coefficient on the interaction between the US MP shock and the NWFU: β_5. It measures the effect of the NWFU on US MP spillovers before 1990. My hypothesis is that it is positive: A higher NWFU is associated with insulation from US MP.

Consider then the coefficient on the interaction between the US MP shock, the NWFU, and the time indicator: β_7. This measures the additional effect of the NWFU on US MP spillovers after 1990 compared to before 1990. If the β_5 is positive as expected, there is no reason to expect the second β_7 also to be positive, since this would suggest that countries are more insulated from having a higher NWFU after 1990 compared to before 1990.

The results are shown in Figure 5. The Figure shows that $\beta_1^{(h)} < 0$ at some horizons, i.e. that US MP spillovers tend to depress foreign GDP before 1990, as expected. Furthermore, $\beta_4^{(h)}$ is not statistically different from zero at any horizon. This is as expected: It suggests that the change in spillovers after 1990 found in Section 2.2.2 are explained by the change in the NWFU since $\beta_4^{(h)}$ measures exactly the change in spillovers after 1990 keeping the NWFU fixed.

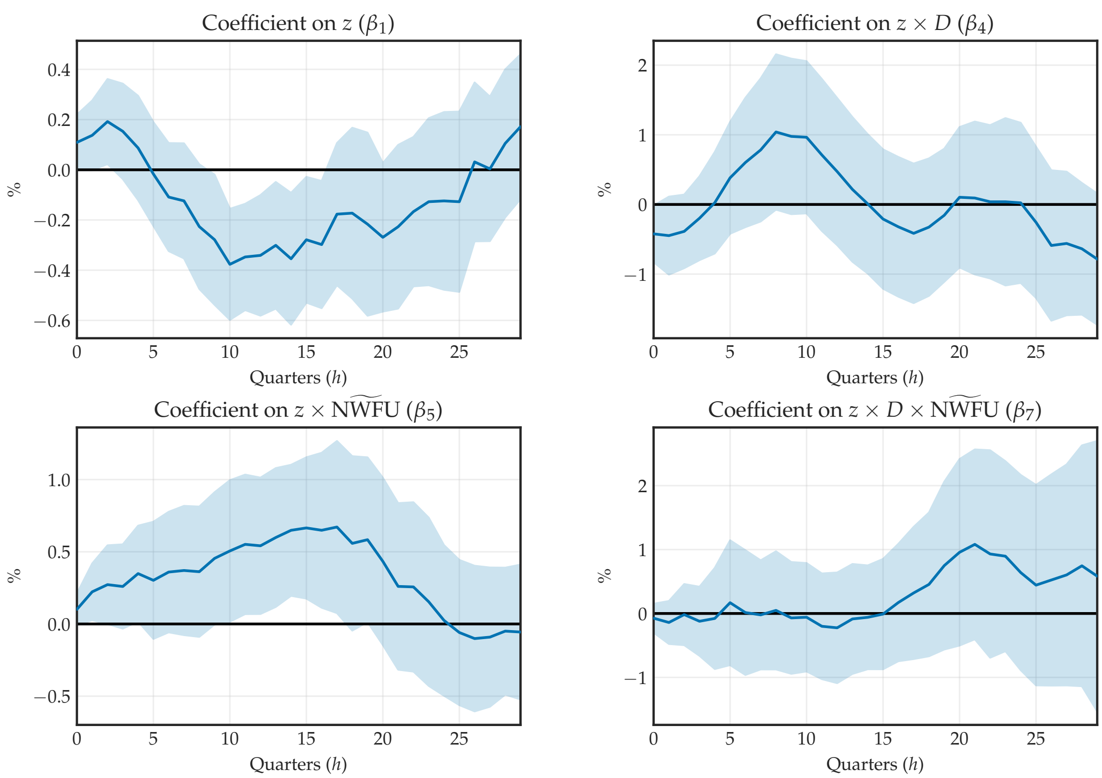

Figure 5: Spillovers of US MP Onto Foreign GDP With NWFU and Time Interactions

Note: The coefficients are from OLS estimation of eq. (3). 90% confidence intervals using Driscoll-Kraay standard errors.

Lastly, I note that $\beta_5^{(h)} > 0$ at many horizons, while $\beta_7^{(h)}$ is statistically indistinguishable from 0 at all horizons. Both are as hypothesized. This exactly suggests that a higher NWFU is associated with more insulation from US MP spillovers both before and after 1990 and that there is no difference in how much insulation a higher NWFU offers after 1990 compared to before 1990.

In summary, I find that countries with a higher NWFU are more insulated from US MP tightening as in Section 2.2.3. This holds both within time across countries and within countries across time.

3 A Model of US MP Spillovers

3.1 Model Setup

In this section, I present a 3-region general equilibrium model with incomplete markets, heterogeneous households, and partly dollarized balance sheets. The builds on standard open-economy New Keynesian models with monopolistic competition and sticky wages, similar to Gali and Monacelli (2005) and Auclert et al. (2021c).

3.1.1 Households

The core of my problem is a standard incomplete markets household problem (Aiyagari 1994, Bewley 1979, Huggett 1993, Imrohoroğlu 1989). I consider an incomplete markets household problem because it implies that constrained households react immediately and (potentially) strongly to changes in net worth. There is a continuum of households that are heterogeneous along three dimensions:

1. The realizations of their idiosyncratic income shocks, e.
2. Their discount factor, β.
3. Their portfolio, $\{a_j\}$, for $j \in \mathcal{A}$, where $\mathcal{A}$ is the set of assets.

A household with last-period portfolio $\{a_j\}$, discount factor β, and idiosyncratic earnings e at time $t = 0, 1, \ldots$ chooses consumption c, and portfolio $\{a'_j\}$. Primes denote next-period variables. They do so to solve the following dynamic problem:

$$V_t(\{a_j\}_{j\in\mathcal{A}}, e, \beta) = \max_{c,\{a'_j\}_{j\in\mathcal{A}}} u(c) + \beta \mathbb{E}_t \left[V_{t+1}(\{a'_j\}_{j\in\mathcal{A}}, e', \beta) \right],$$

$$\text{s.t.}$$

$$c + \sum_{j\in\mathcal{A}} a'_j = \sum_{j\in\mathcal{A}} (1 + r_{j,t}) a_j + Z_t e,$$

$$a \geq 0,$$

where the aggregate variables are labor income, Z_t, and asset returns, $\{r_{j,t}\}_j$. $a = \sum_{j\in\mathcal{A}} a_j$ is the total net assets. u and v are the utility of consumption and the disutility of labor supply, respectively. Labor supply, N_t, is chosen by the labor union, c.f. Section 3.1.6. This is standard in the HANK literature, see for instance Auclert et al. (2023) and Auclert et al. (2021a).

Furthermore, log idiosyncratic income risk, $\log e$, follows an AR(1) process with independent and identically distributed (IID) normal innovations with standard deviation σ^e. I discretize this as a Markov chain and normalize such that $\mathbb{E}[e] = 1$. Utility of consumption and disutility of labor follow standard functional forms,

$$u(c) = \frac{c^{1-\sigma}}{1-\sigma} \quad \text{and} \quad v(n) = \Gamma n^{1+\frac{1}{\phi}},$$

where $\sigma > 0$ is the inverse elasticity of intertemporal substitution, $\phi > 0$ is the Frisch elasticity of labor supply, and $\Gamma > 0$ is a normalization constant. Household real disposable labor income is

$$Z_t = w_t N_t - T_t, \tag{4}$$

where w_t is the real wage rate and T_t are lump-sum taxes. The real wage rate is $w_t = W_t/P_t$, where W_t is the nominal wage rate and P_t is the consumer price index (CPI). I denote aggregate consumption and aggregate net assets by C_t and A_t.

The presence of borrowing constraints relates my paper to a large literature on borrowing constraints, in particular in open economy models. Of particular relevance to my paper, Gourinchas (2021) emphasizes the borrowing constraint for the transmission of US MP. Gourinchas (2021) assumes that households' borrowing is bounded by some postulated function of the exchange rate. This implies that a depreciation of the foreign currency forces households to de-lever and cut back consumption. This happens endogenously in my model without postulating how the borrowing constraint is a function of the exchange rate: A depreciation of foreign currency reduces the net worth of US currency borrowers, so they cut back consumption to meet their higher debt obligations.

Aggregate consumption can be split into consumption of three goods: One produced by the foreign economy, one produced by the US, and one produced by the RoW. Then, foreign consumption of foreign goods, $C_{f,t}$, US goods, $C_{u,t}$, and RoW-goods are given by

$$C_{x,t} = \alpha_x \left(\frac{P_{x,t}}{P_t} \right)^{-\eta} C_t, \tag{5}$$

for $x \in \{f, u, r\}$, where $\alpha_f + \alpha_u + \alpha_r = 1$ and $\eta \geq 0$ is the elasticity of substitution between goods. The CPI is then

$$P_t = \begin{cases} \left[\alpha_f P_{f,t}^{1-\eta} + \alpha_u P_{u,t}^{1-\eta} + \alpha_r P_{r,t}^{1-\eta} \right]^{\frac{1}{1-\eta}} & \text{if } \eta \neq 1 \\ P_{f,t}^{\alpha_f} P_{u,t}^{\alpha_u} P_{r,t}^{\alpha_r} & \text{if } \eta = 1 \end{cases}, \tag{6}$$

where $P_{f,t}$, $P_{u,t}$, and $P_{r,t}$ are the price of the goods in the foreign economy.

Regarding assets, making dependence on the individual, i, clear, I define portfolio weights for the assets as w_j^i for all i and $j \in \{p, B, u, r\}$. Specifically, I choose weights for the first three assets and then let the RoW weights follow, i.e. $w_r^i = 1 - w_p^i - w_B^i - w_u^i$. I then let the portfolio be given according to these weights, i.e.

$$a_j^i = w_j^i a^i,$$

for all i and $j \in \mathcal{A}$. The real rate of return on wealth for household i is then

$$r_{a,t}^i = \sum_{i \in \mathcal{A}} w_j^i r_{j,t}.$$

Using this, I re-state the household problem as

$$\begin{aligned} V_t(a_j, e, \beta) = \max_{c, a_j'} u(c) + \beta \mathbb{E}_t \left[V_{t+1}(\{a_j'\}_{j \in \mathcal{A}}, e', \beta) \right], \\ \text{s.t.} \\ c + a_j' = (1 + r_{a,t}^i) a_j + Z_t e, \\ a \geq 0, \end{aligned}$$

which is a completely standard incomplete markets problem except with an interest rate specific to the individual.

Consider now $w_j^i = w_j$ for all households, i.e. that households have the same portfolio weights (but not necessarily the same wealth). In this case, I define the aggregate ex-post return as

$$r_{a,t} = \sum_{j \in \mathcal{A}} w_j r_{i,t}.$$

In this case, the household problem is as before, but with an identical interest rate for all households. Thus, the individual $\{r_{j,t}\}_{j \in \mathcal{A}}$ do no matter for a given $r_{a,t}$. This is the baseline of my analysis.

3.1.2 Firms

The production side is standard, see Gali and Monacelli (2005), Galí (2015), and Auclert et al. (2021c). Specifically, there is a continuum of monopolistically competitive firms. The typical firm produces foreign goods, Y_t, with linear technology in labor:

$$Y_t = N_t.$$

I assume that prices are fully flexible, such that the price of foreign goods is set as a markup, μ, over nominal marginal costs, W_t:

$$P_{f,t} = \mu W_t. \tag{7}$$

The firm holds $A^F_{u,t}$ US bonds. The firm does not re-balance its portfolio, so this value is fixed at A^F_u. The real dividends are then profits obtained by selling the produced goods and earning interest on the foreign bonds:

$$D_t = \frac{P_{f,t} Y_t - W_t N_t}{P_t} + r_{u,t} A^F_u. \tag{8}$$

In the baseline model, firms hold no dollars: $A^F_u = 0$. Later, I consider what happens when firms hold dollars. The total value of firms at the end of the period is given by

$$p_t = \frac{D_{t+1} + p_{t+1}}{1 + r_t}.$$

When foreign goods are sold abroad, their price in foreign currency is set using the respective nominal exchange rates, $E_{u,t}$ and $E_{r,t}$:

$$P^u_{f,t} = \frac{P_{f,t}}{E_{u,t}} \quad \text{and} \quad P^r_{f,t} = \frac{P_{f,t}}{E_{r,t}}, \tag{9}$$

where $P^u_{f,t}$ and $P^r_{f,t}$ are the prices of foreign goods in the US and RoW, respectively.

3.1.3 US and the RoW

The foreign country trades with the US and the RoW. The US and the RoW are characterized by the same equations, so I will write out the equations only once for $x \in \{u, r\}$, with u referring to the US and r referring to the RoW.

Output in the US and the RoW are $Y_{u,t}$ and $Y_{r,t}$. The consumption of foreign goods by US and RoW consumers are then given by

$$C^x_{f,t} = (1 - \alpha_f) \left(\frac{P^x_{f,t}}{P^x_t} \right)^{-\gamma} Y_{x,t}, \tag{10}$$

where $\alpha^u_f \in (0, 1)$, $\alpha^r_f \in (0, 1)$, and where P^r_t and P^u_t are the CPI in the US and the RoW. The nominal exchange rates are

$$E_{x,t} = \frac{P_{x,t}}{P^x_{x,t}}. \tag{11}$$

Thus, a depreciation of the foreign currency is associated with a higher exchange rate. The real exchange rates are defined as

$$Q_{x,t} = \frac{E_{x,t} P^u_t}{P_t}, \tag{12}$$

For simplicity, I denote the real exchange rate of the foreign economy towards the US by $Q_t \equiv Q_{u,t}$. The US and the RoW are large compared to the SOE, so I set both the prices of their own goods in their own currency and their CPI's to be fixed: $P^x_{x,t} = P^x_{x,ss}$ and $P^x_t = P^x_{ss}$.[4]

Both the US and the RoW issue bonds. The US government issues exponentially decaying long-duration bonds, $A_{u,t}$, with price q_t. The bonds pay a unit coupon each period and decay at rate $\delta \in [0, 1]$, cf. Auclert and Rognlie (2023) and Auclert et al. (2020). The standard case of one-period bonds is obtained for $\delta = 0$. The price

4. One might think that it is a strong assumption that the US CPI is fixed since one of the key goals of US MP is to affect US inflation. However, this is no problem when studying *international spillovers* of US MP: The only way the US CPI matters to the foreign economy is through its effect on the real exchange rate. Since I take the real exchange rate from the data, it is irrelevant what happens to the underlying US CPI in the sense that it would be canceled out by movements in the nominal exchange rate such as to obtain exactly the same real outcomes.

of the long US bonds is given by

$$q_t = \frac{1 + \delta q_{t+1}}{1 + i_{u,t}}. \tag{13}$$

The RoW simply issues one-period bonds. The UIP conditions arbitraging away returns across economies are given by

$$1 + i_t = (1 + i_{x,t}) \frac{E_{x,t+1}}{E_{x,t}} - \varepsilon_{x,t}, \tag{14}$$

where $\varepsilon_{u,t}$ and $\varepsilon_{r,t}$ are exogenous deviations from UIP. The deviations from UIP allow me to match simultaneously the movements in interest rates and exchange rates, which would otherwise be inconsistent with the data.

3.1.4 Government

The government issues real one-period bonds, B_t, with real interest rate r_t. It buys foreign goods and raises taxes. Furthermore, it holds foreign bonds, $A^G_{u,t}$. Thus, the government's budget constraint is

$$B_t + T_t + (1 + r_{u,t}) A^G_{u,t-1} = (1 + r_{t-1}) B_{t-1} + \frac{P_{F,t}}{P_t} G_t + A^G_{u,t}.$$

For government behavior, I assume that government spending and holdings of foreign bonds are fixed:

$$G_t = G_{ss}, \quad \text{and} \quad A^G_{u,t} = A^G_u.$$

The level of taxes is set to ensure that real bonds return to steady state according to the following rule:

$$T_t = T_{ss} + \phi_B (B_{t-1} - B_{ss}).$$

In the baseline model, the government plays no role: $B_{ss} = G_{ss} = A^u_G = 0$. Later, I consider what happens when the government has dollars on its balance sheet.

3.1.5 Central Bank

The central bank sets the nominal interest rate, i_t, according to the following rule:

$$i_t = (1 + r_{ss})(1 + \pi_{t+1}) - 1.$$

This implies that the real interest rate, r_t, is fixed. I choose this because:

1. It is a standard tool to simplify the analysis in the literature, see Woodford (2011), McKay et al. (2016), Auclert et al. (2021c), and Auclert et al. (2023).

2. It strikes "a middle ground between loose policy (like at the zero lower bound) and tight policy (like with an active Taylor rule)", as argued in Auclert et al. (2023).

3. It is consistent with what happens in the data in response to a US MP shock, c.f. Appendix A.4.

The Fisher equation defines the real interest rate:

$$1 + r_t = \frac{1 + i_t}{1 + \pi_{t+1}}.$$

3.1.6 Labor Union

I assume sticky wages according to a standard New Keynesian wage Phillips curve, cf. Auclert et al. (2024):

$$\pi_{W,t}(1 + \pi_{W,t}) = \kappa_W \left(\frac{\Gamma N_t^{\frac{1}{\phi}}}{(C_t^*)^{-\sigma} Z_t / N_t} - 1 \right) + \beta \pi_{w,t+1}(1 + \pi_{w,t+1}), \tag{15}$$

$$C_t^* \equiv \left(\int_i e_t^i u'(c_t^i) di \right)^{-\frac{1}{\sigma}}, \tag{16}$$

where $\pi_{w,t} \equiv W_t / W_{t-1} - 1$ is nominal wage growth. One can micro-found this by a union setting nominal wages to maximize average household welfare with the same labor supply N_t for all households. The real interest rate rule implies that this Phillips curve does not matter for real outcomes.

3.1.7 Market Clearing

Production of goods Y_t goes to three sources: Foreign, US, and RoW consumption, as well as government spending. Thus, foreign goods market clearing is given by

$$Y_t = C_{f,t} + C^u_{f,t} + C^r_{f,t} + G_t. \tag{17}$$

3.1.8 Assets

There exist four assets in the economy: Foreign stocks, foreign bonds, RoW bonds, and US bonds: $\mathcal{A} = \{p, B, u, r\}$. US bonds are denominated in USD, so balance sheets are partly dollarized.[5] Foreign households hold all four assets. In the steady state, arbitrage ensures that the returns on all four assets are equalized, so households are indifferent between holding the different assets. Thus, I calibrate their portfolio to match the data.

The real ex-post returns on the four assets in the foreign economy are

$$r_{p,t} = \frac{p_t + D_t}{p_{t-1}} - 1, \tag{18}$$

$$r_{B,t} = r_{t-1}, \tag{19}$$

$$r_{u,t} = \frac{1 + \delta q_t}{q_{t-1}} \frac{Q_{u,t}}{Q_{u,t-1}} - 1, \tag{20}$$

$$r_{r,t} = (1 + i_{r,t-1}) \frac{Q_{r,t}}{Q_{r,t-1}} - 1. \tag{21}$$

Absent UIP deviations, these returns are equalized ex-post, i.e. in this case $r_{p,t} = r_{B,t} = r_{u,t} = r_{r,t}$ for $t = 1, 2, \ldots$.

3.1.9 International Flows

The NFA is the difference between the value of assets held abroad, $A_{f,t} + A_{u,t} + A^G_{u,t}$, and the value of the supply of foreign assets, $p_t + B_t$:

$$\text{NFA}_t = \underbrace{A_{f,t} + A_{u,t} + A_{r,t} + A^G_{u,t} + A^F_{u,t}}_{\text{Foreign asset demand}} - \underbrace{p_t - B_t}_{\text{Foreign asset supply}}. \tag{22}$$

5. See Ahmed et al. (2021) for another paper with partly dollarized balance sheets.

I also define the net US currency (USD) wealth of foreigners, NWFU_t, as the total holdings in US currency, i.e.

$$\text{NWFU}_t = A_{u,t} + A^G_{u,t} + A^F_{u,t}.$$

As in Auclert et al. (2021c), I consider the case where all assets supplied in the foreign economy are held by foreign households, such that $A_{f,t} = p_t + B_t$.

3.2 Equilibrium

In the following, I define a competitive foreign equilibrium given the US MP shock.

Definition 1 (Equilibrium)**.** *Given sequences for* $\{Y_{u,t}, Y_{r,t}, i^u_t, i^r_t, \varepsilon_{u,t}, \varepsilon_{r,t}\}$*, an initial household distribution over assets, earnings, discount factors, and portfolio composition, a competitive equilibrium is a path of household policies, distributions, prices, and quantities, such that (i) all households solve their dynamic programming problem, (ii) firms optimize, (iii) monetary and fiscal policy follow their rules, and (iv) the goods market clears.*

3.3 Solution

I solve the model assuming perfect foresight with respect to aggregate variables (i.e. with no aggregate risk) and linearize the model around an initial steady state, yielding impulse response functions (IRFs). I write the model up in the sequence space (Auclert et al. 2021b), such that the IRF of a variable X_t is $d\boldsymbol{X} = (dX_0, dX_1, \dots)'$ with $dX_t \approx X_t - X_{ss}$. These IRFs derived under perfect foresight are equivalent to the IRFs in the model with aggregate risk due to certainty equivalence.

Regarding numerical implementation, I proceed as follows. For the household's dynamic programming problem, I use the endogenous gridpoint method (EGM) of Carroll (2006). I then use the "fake news algorithm" from Auclert et al. (2021b) to approximate the Jacobian of the household problem around the deterministic steady state. The steady state is described in Appendix B.1.

I solve for the non-linear transition path using the numerical Jacobians of the aggregate variables supplied to a numerical solver. I find that the linear and non-linear transition paths are very similar, so I use the linear solution.[6]

6. In practice, the solution is implemented using the GEModelTools library, which is available online at github.com/NumEconCopenhagen/GEModelTools

3.4 Calibration

In this section, I present the calibration of the model. I refer to this calibration of the model as the "baseline" model. In general, I keep the calibration standard. Other than that, my calibration strategy is to match the average economy before 1990, when the average NWFU was around 0%. With a calibration to pre-1990 data, I then isolate the effects of increasing the NWFU, as happened after 1990.

The calibration is given in Table 1. For the parameters of the instantaneous utility function, I choose standard values, all in line with Auclert et al. (2021c). I set the coefficient of relative risk aversion to unity, $\sigma = 1$. For the income process, I set the autocorrelation to $\rho_e = 0.966$ and the standard deviation to $\sigma_e = 0.5$ to match the income process in Floden and Lindé (2001).

For the discount factor, I group households into two types: Patient and impatient, each with measure one-half. The impatient households have discount factor $\overline{\beta} - \Delta_\beta$, while the patient ones have discount factor $\overline{\beta} + \Delta_\beta$, with $\Delta_\beta > 0$. I calibrate $\overline{\beta}$ and Δ_β to match the steady state NFA — which I vary throughout the text, but keep at 0 as a baseline — and an annual MPC — which I also vary, but keep at 0.51 as a baseline.[7] Having a high MPC is crucial for my results. A high MPC is very well-established in the data, cf. Fagereng et al. (2021), Parker et al. (2013), Agarwal and Qian (2014), Jappelli and Pistaferri (2010), and Johnson et al. (2006).

Next, I turn to firms. I set the markup, μ, to match a realistic level of wealth. In particular, I set $\mu = 1.15$ to get $A/Y = 7.48$, which corresponds to the level of wealth in Kaplan et al. (2018) excluding housing.

Since monetary policy follows a real rate rule, nominal rigidities are side-stepped in the sense that they only matter for nominal outcomes. Thus, the calibration of nominal rigidities is not important, and I simply follow the calibration from Auclert et al. (2024) directly by setting $\kappa_w = 0.03$.

The parameters governing trade are important for my model. I set the parameter governing imports from the US to $\alpha = 0.04$, consistent with the average imports-from-US/GDP ratio of 4%. Similarly, I set $\alpha_R = 0.37$, consistent with an imports/GDP ratio of 41%. Lastly, I set ζ, to 0.053 to match the output response in the data in Section 2.

I set the steady state interest rate to 1.7%, which is the median in my sample. For δ, I use the IIP data from the IMF, where the maturity of the net asset position in foreign

7. An annual MPC of 0.51 matches Fagereng et al. (2021).

currency is split into two: "Less than a year" and "more than a year". I calibrate δ to a weighed average of these two: δ_{short} and δ_{long}. For the short maturity, I use $\delta_{\text{short}} = 0$. For the long maturity, I use US bonds, which have an average maturity of 18 quarters, c.f. Auclert et al. (2021c), yielding $\delta_{\text{long}} = 0.96$. For the weights, I use the shares in the IIP data. This yields $\delta = 0.73 \cdot 0.96 = 0.7$. I consider robustness to this calibration.

Symbol	Description	Value	Justification
σ	CRRA coefficient	1	Standard value
ϕ	Frisch elasticity	1	Standard value
ρ_z	Log income autocorrelation	0.966	Floden and Lindé (2001)
σ_z	Log income std. dev.	0.5	Floden and Lindé (2001)
β	Average discount factor	0.971	Asset market clearing
β_Δ	Discount factor dispersion	0.01	Annual MPC $= 0.51$
μ	Markup	1.15	$A/Y = 7.48$
κ_w	NKWPC slope	0.03	Auclert et al. (2023)
α_U	US good share in cons.	0.04	Average SOE trade with US
α_R	RoW good share in cons.	0.37	Average SOE trade with RoW
α_F	Foreign good share in cons.	0.59	$\alpha_F = 1 - \alpha_U - \alpha_R$
ζ	Elasticity of Y wrt. Q	0.053	$\sum_{t=0}^{\infty} dY_t/(1+r)^t$
r	Interest rate	0.017	Average for SOE
δ	Foreign asset maturity	0.7	BOP data

Table 1: Model Calibration

Note: This table shows the calibration of parameter values.

4 Model Analysis

4.1 The Shock

I consider the IRF to a US MP shock. For this purpose, I need a US MP shock to feed into the model. By a US MP shock, I mean paths of 4 variables: The US interest rate,

i_u, US output, Y_u, RoW output, Y_r, and the UIP deviation, ε_u.[8] I estimate these using local projections on pre-1990 data as in Section 2. Specifically, I estimate the following local projections on data for 1965-1989 for the US:

$$y_{t+h} = \alpha^{(h)} + \beta^{(h)} z_t + \sum_{j=1}^{p} \gamma_j^{(h)} y_{t-j} + \sum_{j=1}^{p} \delta_j^{(h)} z_{t-j} + \tau_t^{(h)} + \varepsilon_t^{(h)}, \tag{23}$$

where $y \in \{Y_u, i_u, Q\}$ and the rest is as in Section 2. For GDP for the RoW, I take the pre-1990 estimate from Figure 4 in Section 2.

The resulting shock is shown in Figure 6. The shock features a higher US interest, which induces a hump-shaped recession in the US and a hump-shaped appreciation of the USD.

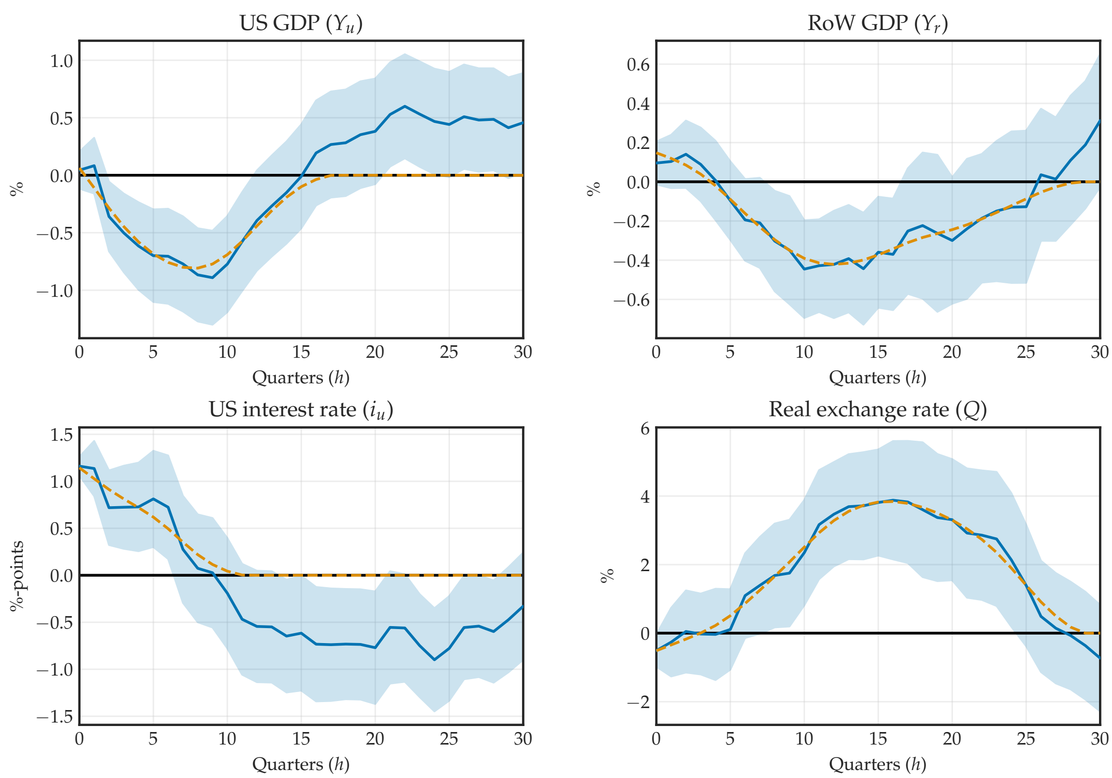

Figure 6: US MP Shock in the Data and the Model

Note: The coefficients are from OLS estimation of regression eq. (23). 90% confidence intervals using Driscoll-Kraay standard errors.

8. In practice, I let Q be exogenous and remove the UIP condition. This is equivalent to keeping the UIP condition and backing out the UIP deviation required to match the response of Q.

4.2 The Response to a US MP Shock

With the shock in mind, I consider the response of the SOE. First, I consider the case of a neutral NWFU, corresponding to before 1990. I report IRFs in Figure 7. The figure shows how the US MP tightening creates a recession in the foreign economy measured by a drop in both GDP and consumption. This is driven by a drop in demand from the US and the RoW due to the US MP tightening. The outflow of capital depreciates the foreign currency (as shown in Figure 6), which induces substitution towards foreign goods, insulating net exports and hence GDP somewhat. In Appendix B.2, I consider what happens in a version of the model with a representative agent.

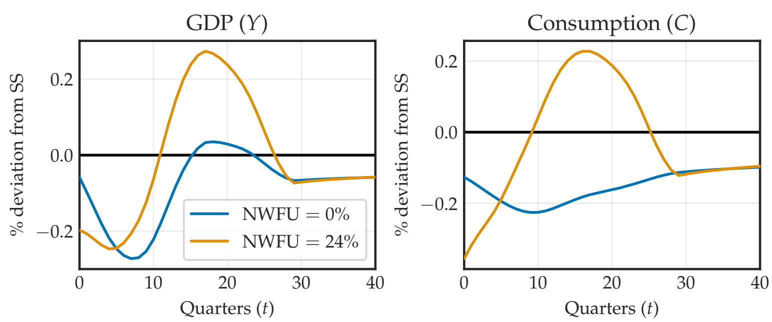

Figure 7: IRFs to a US MP Shock

Note: IRFs, i.e. $100 \cdot d\boldsymbol{X}$ for $X \in \{Y, C\}$, to a US MP shock in two models: One with 0% NWFU and one with 24% NWFU.

I now increase the NWFU to 24% of annual GDP, consistent with the average SOE after 1990. I report IRFs in this case in Figure 7. In sharp contrast with Figure 7, Figure 7 now no longer shows a clear recession in the foreign economy. Instead, the figure shows a hump-shaped response of GDP and consumption: They fall initially but quickly rise again, reaching a peak after around 4 years, after which they fall slightly before returning slowly to steady state. To understand the difference between the response of output with 0% NWFU and 24% NWFU, I now turn to decomposing the response of output.

4.3 Decomposing the Response of Output

I now present a decomposition of the response of output to a foreign monetary policy shock. To do this, I define the semi-elasticity of a variable X with respect to the US interest rate as:

$$\epsilon_X \equiv \sum_{t=0}^{\infty} \frac{dX_t/X_{ss}}{(1+r)^t} \Bigg/ \sum_{t=0}^{\infty} \frac{di_{u,t}}{(1+r)^t}.$$

This measures how many percent X increases in response to a 1 percentage point tightening of US monetary policy, both measured in cumulative present value terms.[9] If, for instance, $X = Y$, ϵ_Y measures how many percent output in the foreign economy increases in response to a 1 percentage point tightening of US monetary policy.

When considering interest rates, I define instead the slope of a variable X with respect to the US interest rate in the same way except without dividing by X_{ss} which is close to 0 for interest rates:

$$\tilde{\epsilon}_X \equiv \sum_{t=0}^{\infty} \frac{dX_t}{(1+r)^t} \Bigg/ \sum_{t=0}^{\infty} \frac{di_{u,t}}{(1+r)^t}.$$

This simply has the interpretation of a slope: When X is an interest rate, $\tilde{\epsilon}_X$ measures how many percentage *points* X increases when the US interest rate increases by 1 percentage point.

I consider these measures for three reasons. First, it summarizes the response of any variable to the US MP shock in a single number. This allows me to compare impulse responses that are non-monotonic over time and take on both positive and negative values, such as the impulse responses in Figure 7. Second, it is a quantity often considered in the literature. Third, it turns out that exactly this quantity has a nice expression in my model. I now proceed by deriving an expression for this quantity in Proposition 1, which also serves as a decomposition of the response of foreign output.

Proposition 1. *Following a US MP shock, the semi-elasticity of foreign output can be written as a function of the semi-elasticities of (1) US demand (ϵ_{Yu}), (2) RoW demand (ϵ_{Yr}), (3) the real exchange rate (ϵ_Q), and (4) the slope of the real return on USD assets to the US interest*

9. Henceforth, I drop specifying "in cumulative present value terms" when referring to the semi-elasticity.

rate ($\tilde{\epsilon}_{ru}$) as follows:

$$\epsilon_Y = \underbrace{Y_u \epsilon_{Yu}}_{\text{US demand}} + \underbrace{Y_r \epsilon_{Yr}}_{\text{RoW demand}} + \underbrace{\frac{1}{1-\alpha_f}\left[\zeta - \alpha_u\right]\epsilon_Q}_{\text{Exchange rate}} + \underbrace{NWFU \frac{\alpha_f}{1-\alpha_f}\tilde{\epsilon}_{ru}}_{\text{USD wealth}}, \quad (24)$$

where ζ is the elasticity of output w.r.t. the real exchange rate holding C, Y_u and Y_r fixed.

Proof. See Appendix B.3. □

This proposition is useful because it decomposes the response of foreign GDP into four channels. Of these channels, the first 3 channels are pinned down by the data in Section 2 and a few model parameters. In particular, the paths of $Y_u t$, Y_r, and Q_t are taken directly from Section 2, which pins down ϵ_{Yu}, ϵ_{Yr}, and ϵ_Q. What is particularly useful is that the fourth and last channel — the wealth channel — is the only channel that changes when the NWFU changes. In other words, the differences between the response of output in Figure 7 have to come from the wealth channels. With this in mind, let me now turn to the explanations of the channels are as follows:

1. **US and RoW demand.** Higher interest rates in the US ($di_u > 0$) induce a recession abroad ($dY_u < 0$ and $dY_r < 0$). As foreign households consume less of all goods, they also consume fewer domestically produced goods, dragging down output in the domestic economy ($dY < 0$).

2. **Exchange rate.** The exchange rate affects output through two distinct channels, one for each of the terms in the bracket. The first term is the expenditure switching channel: When the real exchange rate depreciates ($dQ > 0$), domestically produced goods become cheaper, so households substitute towards them, increasing domestic output ($dY > 0$). The second term is the real income channel: When the real exchange rate depreciates ($dQ > 0$), domestic households become poorer in real terms, lowering consumption and thus output ($dY < 0$), see Auclert et al. (2021c).

3. **USD wealth.** A higher interest rate in the US affects the real return on USD assets in the foreign economy by affecting both the (nominal) price of USD bonds and the real exchange rate. To the degree that the $r_{u,t}$ increases, this implies that the wealth of foreigners increases. The foreigners spend this wealth, boosting consumption and therefore output in general equilibrium.

While the first 3 channels are standard, the latter is the focus of this paper. To understand this channel, one point remains: How does US MP affect the *real* return on USD bonds *in the foreign economy*. To understand this, note first that the higher US interest rate decreases the price of USD bonds due to arbitrage. This can be seen by linearizing equation (13) to arrive at:

$$\frac{dq_t}{q} = -\frac{1}{1+r} \sum_{s=0}^{\infty} \left(\frac{\delta}{1+r} \right)^s di_{u,t+s}.$$

The drop in the nominal price of USD bonds causes a negative re-valuation effect on impact, which lowers the period-0 real return on USD bonds in the foreign economy. However, the higher nominal interest rate then promises a larger return in the future, increasing the real return on USD bonds in the foreign economy for $t = 1, 2, \ldots$.

Additionally, a tightening of US MP policy appreciates the real exchange rate due to UIP. A real appreciation of USD, $Q_t / Q_{t-1} > 1$, implies that a given nominal return is worth more in real terms, increasing the real return on USD bonds. Note that the estimated path of the real exchange rate is hump-shaped: The real exchange rate initially appreciates (after a slight depreciation on impact), reaching a peak after 4 years, after which it depreciates. Thus, this effect initially increases the real return on USD bonds, after which it reduces it.

With this, I show the semi-elasticity in the two models in the first two columns of Table 2. I find that a 1 percentage point tightening of US monetary policy caused foreign output to fall by -0.63% on average before 1990. When increasing the NWFU to 24%, the semi-elasticity drops to -0.27%, i.e. the severity of the recession is more than cut in half. This does not reflect the trade and exchange rate channels: Both of these are unchanged, as Proposition 1 suggests. Instead, it reflects the wealth effect: With a higher NWFU, households become richer following a tightening of US MP, so they increase consumption, boosting output in general equilibrium. For comparison's sake, the semi-elasticity in the data after 1990 is -0.01%. This suggests that a US MP tightening no longer creates recessions abroad. Since this change in the semi-elasticity is larger than the 0.37 from the wealth effect in column 2, it suggests that the increase in the NWFU cannot explain all of the change in US MP spillovers. In particular, the increase in the NWFU can explain more than half of the change in the international spillovers after 1990 compared to before. This suggests that there is some space left for other factors to explain changes in US MP spillovers.

	NWFU = 0% (1965-1989)	NWFU = 24% (1990-2020)	NWFU = 65% (2020)
Semi-elasticity, $\epsilon_Y =$	-0.63	-0.27	0.35
+ US demand	-0.51	-0.51	-0.51
+ RoW demand	-0.33	-0.33	-0.33
+ Exchange rate	0.21	0.20	0.18
+ USD wealth	0.00	0.37	1.01

Table 2: The Semi-elasticity of Foreign Output With Respect to the US Interest Rate

Note: The first row shows the semi-elasticity of (the cumulative present value) of foreign output with respect to the (cumulative present value) of the US interest rate. The next four rows show the decomposition from Proposition 1. The columns indicate different calibrations of the NWFU, corresponding to different values in the data.

4.4 Robustness: What Does the Wealth Effect Depend On?

I now aim to answer the following question: To what degree do we know that the wealth effect matters so much for the international spillovers of US MP? In particular, I ask to what degree the strength of the wealth channel in Table 2 is realistic or to what degree it is robust to different calibrations. I separate this into two parts: Things that the wealth effect does *not* depend on and things that the wealth effect *does* depend on. I start with the things that the wealth effect does not depend on, and hence things that Table 2 are robust to changing.

4.4.1 What the Wealth Effect Does *Not* Depend On

A central implication of Proposition 1 is that the semi-elasticity of foreign output is independent of the MPC of households. This is shown in the following corollary.

Corollary 1. *The semi-elasticity of output, ϵ_Y, is independent of MPCs.*

Proof. This follows directly from the fact that MPCs do not enter eq. (24). □

Why does the MPC not matter? Intuitively, one might expect that higher MPCs imply a larger wealth effect as households consume more out of capital gains. However, this is only true *initially*. This is the case because the *present-value* MPC is always

1: Any income has to be spent at some point in time in a present-value sense. Mathematically, $\sum_{t=0}^{\infty} \frac{\partial C_t / \partial Z_s}{(1+r)^{t-s}} = 1$. Because Proposition 1 is stated in terms of present values and the present-value MPC is always 1, the (instantaneous) MPC does not matter.

The fact that MPCs do not matter also implies that a representative agent model with *incomplete* markets also has the same semi-elasticity of output, ϵ_Y. I show this in Appendix B.2. However, this is not true in a *complete* markets representative agent model due to international consumption insurance, see Auclert et al. (2021c). Thus, the assumption that matters is not about MPCs or heterogeneity, but that markets are incomplete and not complete.

Another implication of Proposition 1 is that the semi-elasticity of foreign output is independent of the NWFU composition, i.e. is independent of who holds the USD assets: Households, firms, or the government. This is summarized in the following corollary.

Corollary 2. *The semi-elasticity of foreign output, ϵ_Y, is independent of who holds the USD assets: Households, the government, or firms. In other words, ϵ_Y is the same for any values of $(A_{u,ss}, A_u^G, A_u^F)$, as long as their sum, $NWFU = A_{u,ss} + A_u^G + A_u^F$, is fixed.*

Proof. This follows directly from the fact that $(A_{u,ss}, A_u^G, A_u^F)$ do not enter eq. (24) individually, but only the NWFU enters. □

To demonstrate this, Figure 8 shows IRFs in three cases

1. Baseline: USD holdings are only with households and the annual MPC is 0.51.

2. Government with USD holdings: A case where USD holdings are split across households and the government, i.e.

$$A_u^G = A_{u,ss} = \frac{\text{NWFU}_{ss}}{2}.$$

   I also set $\phi_B = 0.33$.

3. Low MPC: A case where the annual MPC is calibrated to 0.3.

The figure shows that the IRFs are very similar. In fact, by Corollary 1, the semi-elasticities summarizing the paths are exactly the same in all 3 versions.

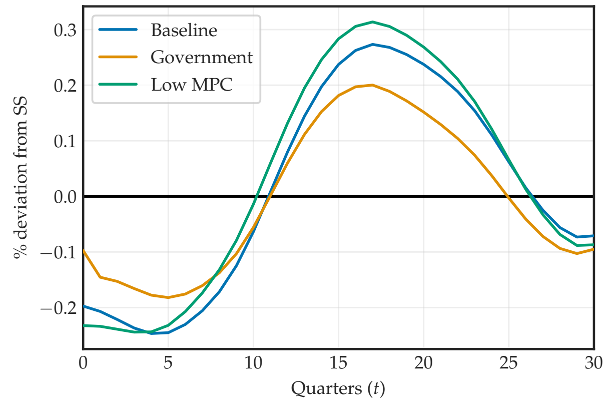

Figure 8: Output Response (dY_t) in Different Models

Note: The figure shows IRFs of output, i.e. $100 \cdot d\boldsymbol{Y}$, to a US MP shock for three model versions: The baseline model, a version where the government has USD on its balance sheets, and a version with a low MPC.

4.4.2 What the Wealth Effect *Does* Depend On

Having established what the wealth effect does not depend on, I now consider what the wealth effect does depend on and hence what could change Table 2.

To see what the wealth effect depends on, I look to Proposition 1. First, the proposition shows that the wealth effect depends on the NWFU and the degree of openness, α_f. Both of these are well observed in the data. For any country at any point in time, I can simply look in my dataset to get these parameters. Hence, there should not be much debate about these quantities and their effect on the wealth effect.

However, in a slightly more subtle way, Proposition 1 also shows that the wealth effect depends on a third quantity: The semi-elasticity of r_u. This is naturally affected directly by the US interest rate. But it also depends on the real exchange rate, since r_u is the real return in the foreign economy. Fortunately, both i_u and Q are taken directly from the data in Section 2. However, the dependence of r_u on these two still depends on model parameters. It turns out that the response of r_u can be written as

$$d\boldsymbol{r_u} = \boldsymbol{\Theta}(r,\delta)d\boldsymbol{i_u} + (\boldsymbol{I} - \boldsymbol{L})d\boldsymbol{Q},$$

c.f. Appendix B.4. The notation here indicates that the Jacobian $\boldsymbol{\Theta}(r,\delta)$ depends only on the two parameters r and δ. Of these two parameters, r is pinned down well in the data, while δ is less well pinned down. Note further that that $d\boldsymbol{i_u}$ and $d\boldsymbol{Q}$ are estimated directly. This means that δ is what matters for the PV of $d\boldsymbol{r_u}$ and hence the wealth effect, alongside α_F and the NWFU. In Figure 9, I therefore show the wealth effect for various values of these parameters. As the figure shows, the wealth effect is quite robust to different values of δ, which is the only parameter not pinned down well in the data.

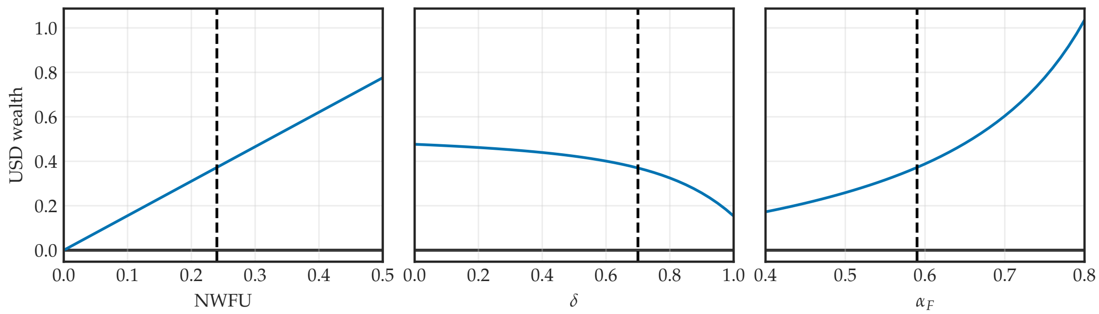

Figure 9: Wealth Effect for Different Parametrizations

Note: The figure shows the magnitude of the wealth effect (as a semi-elasticity) for different parametrizations of the model. The y-axis is common across panels.

4.5 Implications

I have now established that (i) the negative spillovers of US MP have disappeared after 1990, that (ii) countries have become much more long the USD in the same period, and that (iii) countries more long the USD are more insulated from US MP tightening. I now ask the question: Given the relation between NWFU and spillovers in (iii), can the observed drop in spillovers from (i) be explained by the drop in NWFU in (ii)? To do this, I take the implied insulation from a higher NWFU on US MP spillovers implied by both the model and the data and compare it to the estimated total change in spillovers of 0.63%.

Start with the model. Here, an increase in the NWFU from 0% to 24% implies an insulation of about 0.37% on output, c.f. Table 2. Thus, the model suggests that the rise in NWFU can explain around half of the insulation from US MP from −0.63% to −0.01%. Consider now the empirics. Here, an increase in the NWFU from 0% to 24% implies an insulation of about 0.41% on output (computed using the difference in Figure 4). This is very close to the model. Thus, the state-dependent local projections suggest that the rise in NWFU can explain a little over half of the drop in US MP spillovers. Both agree that the rise in NWFU has added insulation from spillovers of US MP. This suggests that the movement away from USD (net) debt to USD net wealth has been crucial in explaining that spillovers of US MP tightening on foreign GDP are no longer negative.

5 Conclusion

I show that the US has gone from a net creditor to a net debtor since around 1990. At the same time, there has been a significant rise in the net wealth denominated in USD held abroad (the NWFU). I study the implications of this for international spillovers of US monetary policy (MP). Using panel data local projections with a sample of 37 SOEs, I find that a tightening of US MP tended to depress output abroad before 1990. However, after 1990, a tightening of US MP has no effects on foreign GDP.

I study this in a 3-region New Keynesian model with incomplete markets and partly dollarized balance sheets. In the model, foreigners with USD wealth experience a positive wealth effect following a tightening of US MP, boosting consumption and output. I find that the wealth effect is sizeable: It explains more than half of the change in US MP spillovers and is more important than standard exchange rate channels.

As such, my paper challenges the conventional wisdom that "when the US sneezes, the RoW catches a cold". Furthermore, my paper is a success story: Deliberate policy choices to avoid foreign currency debt on the balance sheet have worked out in the sense that the negative spillovers of foreign monetary policy are no longer a big stability concern for these countries.

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A Empirical Appendix

A.1 Data

In this section, I present the variables used in the empirical analysis. I consider a sample of 37 countries covering advanced and emerging economies. I arrive at the sample as follows. I start with the sample of 50 countries from Iacoviello and Navarro (2019). I exclude 4 countries with a fixed exchange rate towards the US: Jordan, El Salvador, Venezuela, and Hong Kong. I then exclude 9 large countries: Canada, France, Germany, Italy, Japan, United Kingdom, China, Japan, and the US. The resulting sample contains 37 SOEs. I note that not all variables are available for all countries.

The 37 SOEs are the following: Argentina, Australia, Austria, Belgium, Botswana, Brazil, Chile, Colombia, Czech Republic, Denmark, Ecuador, Finland, Greece, Hungary, Iceland, Indonesia, Ireland, Israel, Luxembourg, Malaysia, Mexico, Netherlands, New Zealand, Norway, Peru, Philippines, Poland, Portugal, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, and Türkiye.

My sample spans as long as 1965-2016 at the quarterly frequency (except for the NWFU). For many variables and countries, there is not coverage for this whole time period. For selected variables, I consider data beyond 2016 when considering descriptive statistics.

A.2 Net Wealth Denominated in USD

My main two sources for the NWFU are Bénétrix et al. (2015) and Allen et al. (2023). As discussed in Bénétrix et al. (2015), they use various techniques to estimate the currency composition of investment positions of various countries across time. In particular, their estimation procedure has two steps. First, they calculate the currency composition within individual investment categories. Next, they calculate aggregate measures by weighting across categories. These weights are based on shares in international balance sheets. For more details, see Bénétrix et al. (2015) and Lane and Shambaugh (2010)

As Allen et al. (2023) is the most updated, I use this as my main dataset. I extend with this any available extra observations from Bénétrix et al. (2015).

To extend further back than 1990, I use an indicator series. This indicator series gives me data for 1976-1989. I use the US NIIP as an indicator. Therefore, I estimate a univariate regression of the NWFU on the US NIIP in sample (1990-2020) and then predict the NWFU out of sample (1976-1989) using this regression. I do this separately for each country. I believe using the US NIIP as an indicator of a country's NWFU is reasonable for two reasons. First, many of the USD assets on foreign countries' balance sheets are probably supplied by the US, so changes in a country's NWFU should largely be reflected in the US NIIP. Second, I find that the US NIIP is a relatively good indicator of a country's NWFU in sample: The mean R^2 across countries of the simple univariate regression is 0.39. Additionally, this regression is likely to *understate* changes in the NWFU for a country outside the sample: If the NIIP is a poor indicator for the NWFU, the slope will be close to zero and the country's NWFU will be approximately at its mean value outside the sample. The results are shown in Figure 2 in the main text.

Finally, to ensure that the state-dependent regression uses data all the way back to 1965 as in the other regressions, I need to have a measure of the NWFU for 1965-1975. This ensures that I can re-create the main IRFs when considering NWFU at its mean. Therefore, for these few years, I extend the NWFU backward using simply the first available data. Given that the NWFU is downward-trending, this would suggest that I tend to overestimate the NWFU, and hence *under-estimate* the effect of the NWFU on US MP spillovers.

A.3 NWFU Descriptive Statistics

In Table A.1, I show the average NWFU and the average change in NWFU from 1990 to 2017 for countries in the sample.

Table A.1: NWFU by Country (% of GDP)

Country	NWFU	$\Delta NWFU$	Country	NWFU	$\Delta NWFU$
Singapore	208	208	Austria	7	7
Netherlands	127	127	Spain	6	6
Ireland	99	99	Poland	4	4
Switzerland	93	93	Australia	1	1
Hungary	42	42	Colombia	0	0
Norway	40	40	Finland	-2	-2
Belgium	33	33	Portugal	-3	-3
Sweden	29	29	Mexico	-4	-4
Denmark	23	23	Peru	-4	-4
Argentina	21	21	Philippines	-8	-8
Malaysia	19	19	Greece	-9	-9
Thailand	18	18	Brazil	-9	-9
Israel	17	17	New Zealand	-11	-11
South Korea	14	14	Turkey	-11	-11
Chile	12	12	Iceland	-11	-11
Czech Republic	9	9	Indonesia	-16	-16
South Africa	8	8	—	—	—

Note: The table shows the mean NWFU for each country and the average change in NWFU from 1990 to 2017 for that country.

Table A.2 shows the distribution of the NWFU over countries and time. As the table shows, there is considerable heterogeneity: Some countries have net liabilities in USD equal to almost their entire GDP, while other countries have net assets in USD equal to several times their GDP, with the median being around net neutral in USD.

Table A.2: Quantiles of NWFU (% of GDP)

Quantile	1%	10%	25%	50%	75%	90%	99%
NWFU	−39%	−19%	−8%	2%	16%	58%	260%

Note: The table shows quantiles across $\text{NWFU}_{i,t}$ as a percentage of GDP in that country at that point in time. The quantiles are across both countries (i) and years (t). The quantiles are based on data from 1976-2021.

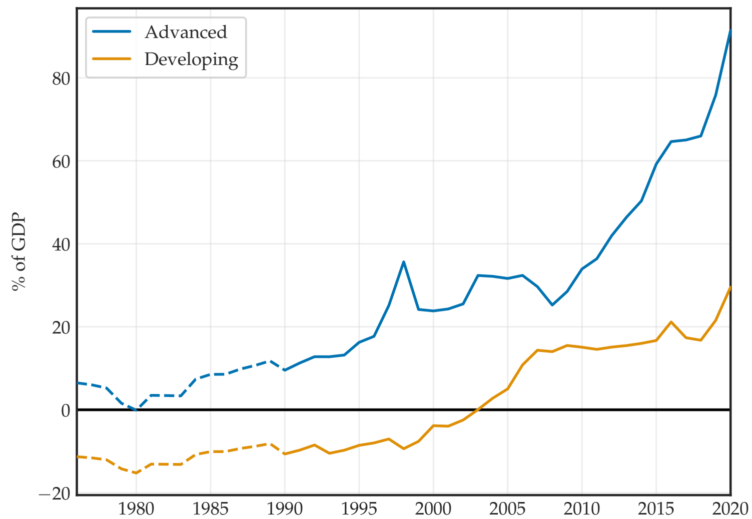

Figure A.1: NWFU for Advanced and Developing Economies

Note: See Figure 2. The figure splits the series into advanced and developing countries. The developing countries are Argentina, Brazil, Botswana, Chile, Colombia, Ecuador, Hungary, Indonesia, Mexico, Malaysia, Peru, Philippines, Poland, Thailand, Türkiye, and South Africa. The advanced are the rest.

A.3.1 Real Variables

I take log real GDP from the database provided by Iacoviello and Navarro (2019). For log real consumption, I turn to the OECD quarterly national account (QNA) database. My measure of real consumption is the volume estimate of seasonally adjusted private final consumption expenditure in USD dollars with fixed PPP (VPVOBARSA).

A.3.2 Shocks

My main shock series is the recursively identified US MP shock by Iacoviello and Navarro (2019). As a robustness check, I consider three alternative shock series. The first is the Romer-Romer shock series from Romer and Romer (2004) extended by Breitenlechner (2018). The second is the Aruoba-Drechsel shock series from Aruoba and Drechsel (2023). The third is the Miranda-Agrippino shock series from Miranda-Agrippino and Ricco (2021).

A.3.3 Exchange and Interest Rates

The nominal interest rates are "Central bank policy rates" from the Bank of International Settlements (BIS). The nominal exchange rate for each SOE towards the USD is taken from the BIS. I construct the real versions of these variables using data on the consumer price index also from the BIS. In particular, I construct that real exchange rate for each SOE as

$$\text{Real Exchange Rate} = \frac{(\text{Nominal Exchange Rate}) \times (\text{US CPI})}{\text{CPI}},$$

and the real interest rate as

$$\text{Real Interest Rate} = \frac{1 + \text{Nominal Interest Rate}}{1 + \text{Inflation}} - 1.$$

I exclude data on inflation for Brazil as they are a significant outlier.

A.4 Robustness: Changing US MP Spillovers

A.4.1 More Lags

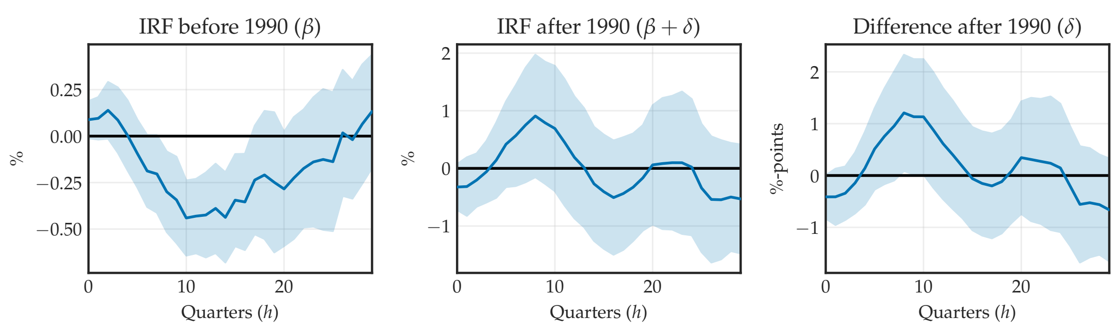

Figure A.2: Local Projections Before and After 1990 With 4 Lags

Note: See Figure 3. Using 4 lags instead of 2 lags.

A.4.2 Romer-Romer Shock

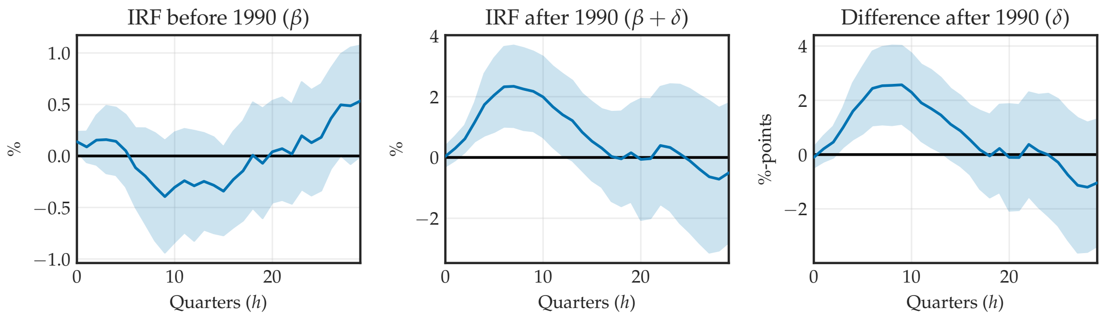

Figure A.3: Local Projections Before and After 1990 With Romer-Romer Shock

Note: See Figure 3. Using the Romer-Romer shock.

A.4.3 Consumption

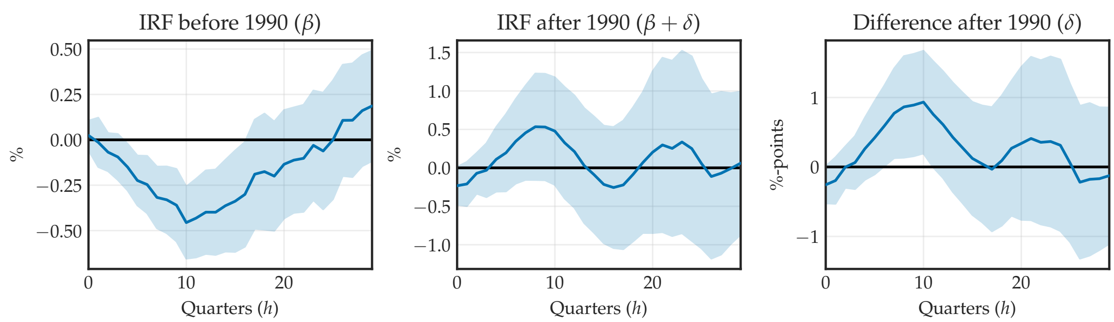

Figure A.4: Local Projections Before and After 1990 With Consumption

Note: See Figure 3. Using consumption instead of GDP.

A.4.4 Real Interest Rate

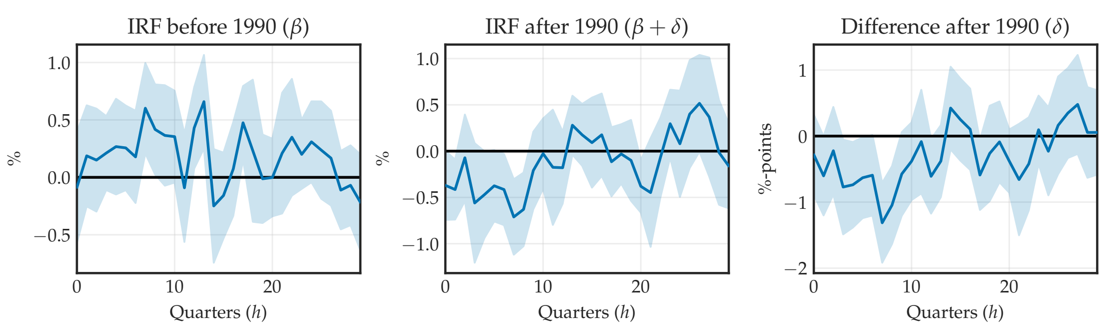

Figure A.5: Local Projections Before and After 1990 With Real Interest Rate

Note: See Figure 3. Using the real interest rate instead of GDP.

A.5 Robustness: The NWFU as a Determinant of US MP Spillovers

A.5.1 More Lags

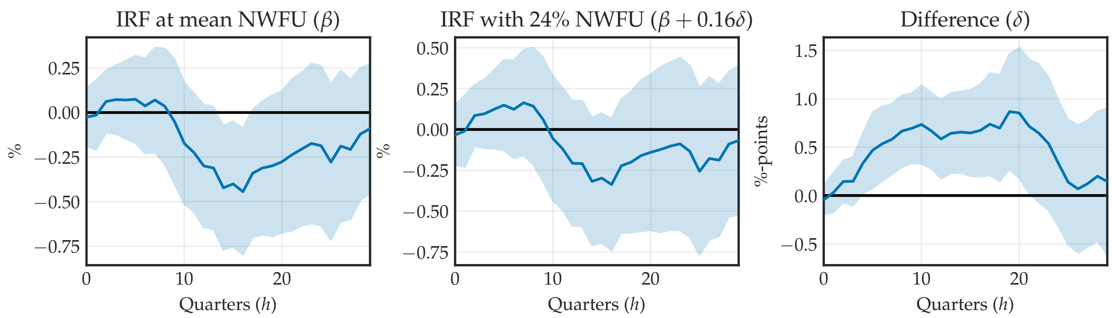

Figure A.6: State-Dependent Local Projections With 4 Lags

Note: See Figure 4. Using 4 lags instead of 2 lags.

A.5.2 Other Shocks

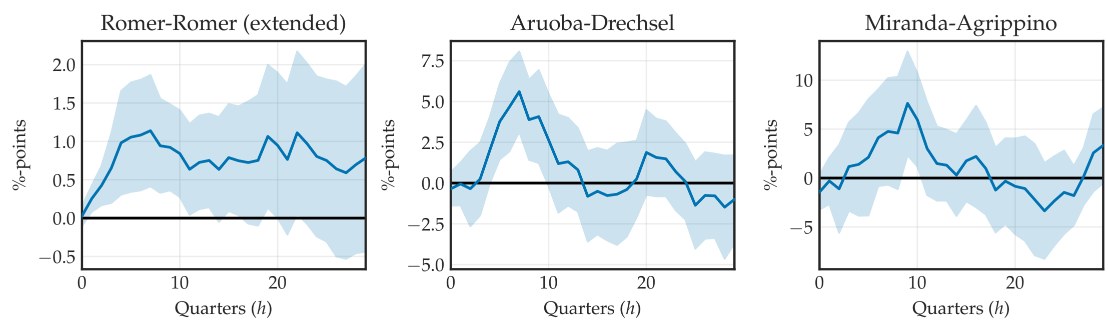

Figure A.7: Difference in State-Dependent Local Projections With Different Shocks

Note: See Figure 4. Shows estimates of the difference, i.e. estimates of δ. The Romer-Romer shocks are the shocks from Romer and Romer (2004) extended by Breitenlechner (2018). The Aruoba-Drechsel shocks are by Aruoba and Drechsel (2023). The Miranda-Agrippino shocks are by Miranda-Agrippino and Ricco (2021).

A.5.3 Not Extending NWFU Backwards

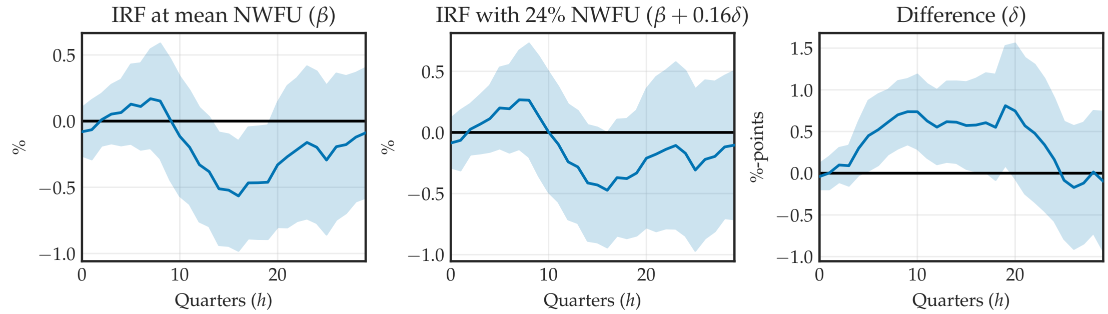

Figure A.8: State-Dependent Local Projections Without Extended NWFU

Note: See Figure 4. Using only NWFU starting in 1976.

A.5.4 Consumption

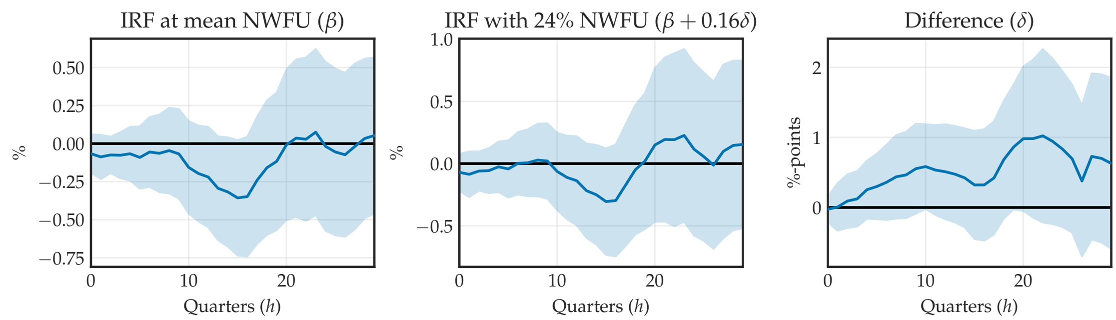

Figure A.9: State-Dependent Local Projections With Consumption

Note: See Figure 4. Using consumption instead of GDP.

B Model Appendix

B.1 The Steady State

I consider a steady state with zero inflation, $\pi_{ss} = 0$. I normalize all prices (except wages and bonds) to 1, $P_{f,ss} = P^u_{f,ss} = P^r_{f,ss} = P_{ss} = P^u_{ss} = P^r_{ss} = P^u_{u,ss} = P^r_{r,ss} = E_{u,ss} = E_{r,ss} = Q_{ss} = 1$. This implies that nominal and real returns are the same in steady state. Furthermore, arbitrage implies that all returns are the same in steady state, and this value is calibrated: $r_{ss} = r_{f,ss} = r_{u,ss} = i_{ss} = i_{f,ss} = i_{u,ss}$.

B.2 Representative Agent Model

I consider a representative agent (RANK) model. Growth rates of consumption are determined by the Euler equation:

$$C_t^{-\sigma} = \beta(1 + r_t)C_{t+1}^{-\sigma},$$

The level of consumption is given by

$$C_0 = (1 - \beta) \left[(1 + r_0^a) A_{ss} + \sum_{t=0}^{\infty} \frac{Z_t}{(1 + r)^t} \right],$$

using $r_t = r$ for all t.

Figure B.1 shows IRFs in the baseline model compared to the RANK model. The figure shows that the IRFs are very similar in the RANK and HA models. In particular, Proposition 1 implies that the semi-elasticities are the same.

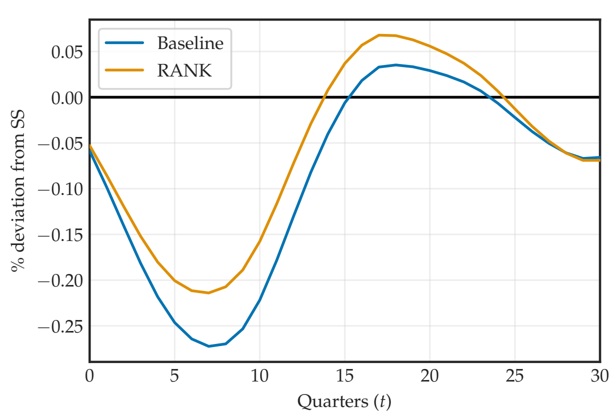

Figure B.1: IRFs to a US MP Shock With a Representative Agent

Note: The figure shows IRFs of output, i.e. $100 \cdot dY$, to a US MP shock for two model versions: The baseline model and the RANK model.

B.3 Proof of Proposition 1

I start by linearizing some key equations that I use to prove the proposition.

B.3.1 Foreign Consumption of Foreign Goods

Linearizing CPI in eq. (6) yields

$$dP_t = \alpha_f dP_{f,t} + \alpha_u dP_{u,t} + \alpha_r dP_{r,t}. \tag{25}$$

Next, linearizing the nominal exchange rate in eq. (11) yields

$$dE_{u,t} = dP_{u,t} - dP^u_{u,t}. \tag{26}$$

Similarly, linearizing the real exchange rate in eq. (12) implies that

$$dQ_t = dE_{u,t} + dP^u_t - dP_t. \tag{27}$$

Inserting eq. (26) into eq. (27) with $dP^u_t = dP^u_{u,t} = 0$ yields

$$dQ_t = dP_{u,t} - dP_t.$$

Solving for $dP_{u,t}$, I find that

$$dP_{u,t} = dQ_t + dP_t. \tag{28}$$

Analogously for the RoW:

$$dP_{r,t} = dQ_{r,t} + dP_t. \tag{29}$$

Note here that real UIP for the RoW implies $dQ_{r,t} = 0$. Inserting eq. (28) and eq. (29) into the linearized CPI in eq. (25) yields

$$dP_t = \alpha_f dP_{f,t} + \alpha_u(dQ_t + dP_t) + \alpha_r(dQ_{r,t} + dP_t).$$

Solving for $dP_t - dP_{f,t}$ yields

$$dP_t - dP_{f,t} = \frac{\alpha_u}{\alpha_f} dQ_t + \frac{\alpha_r}{\alpha_f} dQ_{r,t}. \tag{30}$$

Linearizing consumption of foreign goods from eq. (32), I find that

$$dC_{f,t} = \alpha_f \left[dC_t - \eta C_{ss} \left(dP_{f,t} - dP_t\right)\right]. \tag{31}$$

Inserting eq. (30) yields

$$dC_{f,t} = \alpha_f dC_t + \eta C_{ss} \alpha_u dQ_t, \tag{32}$$

where I used $dQ_{r,t} = 0$.

B.3.2 US and RoW Consumption of Foreign Goods

I am interested in $dP^u_{f,t} - dP^u_t$. I start by noting that $dP^u_t = 0$, so

$$dP^u_{f,t} - dP^u_t = dP^u_{f,t} = dP_{f,t} - dE_{u,t},$$

where the second equality follows from PCP in eq. (9). Inserting eq. (27) with $dP^u_t = 0$ yields

$$dP^u_{f,t} - dP^u_t = (dP_{f,t} - dP_t) - dQ_t. \tag{33}$$

Inserting eq. (30) yields

$$dP^u_{f,t} - dP^u_t = -\frac{\alpha_u + \alpha_f}{\alpha_f} dQ_t - \frac{\alpha_r}{\alpha_f} dQ_{r,t}. \tag{34}$$

Consider now $dP^r_{f,t} - dP^r_t$. Analogous to eq. (33), it holds that

$$dP^r_{f,t} - dP^r_t = (dP_{f,t} - dP_t) - dQ_{r,t}.$$

Inserting $dQ_{r,t} = 0$ and eq. (30) yields

$$dP^r_{f,t} - dP^r_t = -\left(\frac{\alpha_u}{\alpha_f} dQ_t + \frac{\alpha_r}{\alpha_f} dQ_{r,t}\right) = -\frac{\alpha_u}{\alpha_f} dQ_t, \tag{35}$$

where I used $dQ_{r,t} = 0$ again.

Linearizing US consumption of foreign goods in eq. (10) yields:

$$dC^u_{f,t} = (1 - \alpha_f) \left[dY^u_t - \gamma \left(dP^u_{f,t} - dP^u_t\right) Y_{u,ss}\right]. \tag{36}$$

Inserting eq. (34) yields

$$dC^u_{f,t} = (1-\alpha_f)dY^u_t + \gamma \frac{(\alpha_u + \alpha_r)(\alpha_u + \alpha_f)}{\alpha_f} Y_{u,ss} dQ_t. \tag{37}$$

Similarly, using eq. (35) in the linearized eq. (10) gives

$$dC^r_{f,t} = (1-\alpha_f)dY^r_t + \gamma \frac{(\alpha_u + \alpha_r)\alpha_u}{\alpha_f} Y_{r,ss} dQ_t. \tag{38}$$

B.3.3 Output

Linearizing goods market clearing in eq. (17) (with $dG_t = 0$) gives

$$d\boldsymbol{Y} = d\boldsymbol{C_f} + d\boldsymbol{C^u_f} + d\boldsymbol{C^r_f}.$$

Inserting the expression for $d\boldsymbol{C_f}$, $d\boldsymbol{C^u_f}$, and $d\boldsymbol{C^r_f}$ in equations (32), (37), and (38) with $Y_{r,ss} = Y_{u,ss}$ yields

$$\begin{aligned} d\boldsymbol{Y} &= \alpha_f d\boldsymbol{C} + \eta \alpha_u C_{ss} d\boldsymbol{Q} + (1-\alpha_f)d\boldsymbol{Y_u} + \gamma \frac{(\alpha_u + \alpha_r)(\alpha_u + \alpha_f)}{\alpha_f} Y_{u,ss} dQ_t \\ &+ (1-\alpha_f)d\boldsymbol{Y_r} + \gamma \frac{(\alpha_u + \alpha_r)\alpha_u}{\alpha_f} Y_{r,ss} d\boldsymbol{Q}. \end{aligned}$$

Collecting terms, this can be written as

$$d\boldsymbol{Y} = \alpha_f d\boldsymbol{C} + (1-\alpha_f)(d\boldsymbol{Y_u} + d\boldsymbol{Y_r}) + \zeta d\boldsymbol{Q}, \tag{39}$$

where

$$\zeta \equiv \frac{\eta \alpha_u \alpha_f C_{ss} + \gamma(1-\alpha_f)(2\alpha_u + \alpha_f)Y_{u,ss}}{\alpha_f}.$$

When considering $\eta = \gamma$, this implies that

$$\begin{aligned} \zeta &= \eta \frac{\alpha_u \alpha_f C_{ss} + (1-\alpha_f)(2\alpha_u + \alpha_f)Y_{u,ss}}{\alpha_f}, \\ \eta = \gamma &= \zeta \frac{\alpha_f}{\alpha_u \alpha_f C_{ss} + (1-\alpha_f)(2\alpha_u + \alpha_f)Y_{u,ss}}. \end{aligned}$$

B.3.4 Consumption Function

I write the linearized consumption function as

$$d\boldsymbol{C} = \boldsymbol{\mathcal{J}}^{C}_{Z} d\boldsymbol{Z} + \sum_{j\in\mathcal{A}} \boldsymbol{\mathcal{J}}^{C}_{rj} d\boldsymbol{r}_j, \tag{40}$$

where the Jacobians are

$$\boldsymbol{\mathcal{J}}^{C}_{Z} \equiv \frac{\partial \boldsymbol{C}}{\partial \boldsymbol{Z}}, \quad \boldsymbol{\mathcal{J}}^{C}_{rj} \equiv \frac{\partial \boldsymbol{C}}{\partial \boldsymbol{r}_j},$$

for $j \in \mathcal{A}$. Using the firm FOC from eq. (7) and solving for W_t gives

$$W_t = \frac{P_{f,t}}{\mu}.$$

Inserting this into eq. (4) gives

$$Z_t = \frac{1}{\mu}\frac{P_{f,t}}{P_t} Y_t - T_t.$$

Linearizing and inserting eq. (30) then gives

$$dZ_t = \frac{1}{\mu}\left[dY_t - \frac{\alpha_u}{\alpha_f} dQ_t\right] - dT_t.$$

Inserting this into the linearized consumption function in eq. (40), it follows that

$$d\boldsymbol{C} = \frac{1}{\mu}\boldsymbol{\mathcal{J}}^{C}_{Z} d\boldsymbol{Y} - \boldsymbol{\mathcal{J}}^{C}_{Z} d\boldsymbol{T} - \frac{\alpha_u}{\alpha_f}\frac{1}{\mu}\boldsymbol{\mathcal{J}}^{C}_{Z} d\boldsymbol{Q} + \sum_{j\in\mathcal{A}} \boldsymbol{\mathcal{J}}^{C}_{rj} d\boldsymbol{r}_j, \tag{41}$$

using that $D_{ss} = p_{ss} r_{ss}$.

Linearizing firm equity returns gives

$$d\boldsymbol{r}_{\boldsymbol{p}} = \boldsymbol{\mathcal{J}}^{rp}_{p} d\boldsymbol{p} + \tilde{\boldsymbol{\mathcal{J}}}^{rp}_{D} d\boldsymbol{D}, \tag{42}$$

where

$$\boldsymbol{\mathcal{J}}^{rp}_{p} \equiv \frac{1}{p_{ss}}\left(\boldsymbol{I} - \frac{p_{ss} + D_{ss}}{p_{ss}}\boldsymbol{L}\right), \quad \tilde{\boldsymbol{\mathcal{J}}}^{rp}_{D} \equiv \frac{1}{p_{ss}}\boldsymbol{I}.$$

The real end-of-period value of firm equity is

$$p_t = \frac{p_{t+1} + D_{t+1}}{1 + r_t}.$$

Linearizing this yields

$$dp_t = \frac{dp_{t+1} + dD_{t+1}}{1 + r_{ss}} - \frac{p_{ss} + D_{ss}}{(1 + r_{ss})^2} dr_t.$$

Using that $p_{ss} + D_{ss} = (1 + r_{ss}) p_{ss}$ then yields

$$dp_t = \frac{dp_{t+1} + dD_{t+1}}{1 + r_{ss}} - \frac{p_{ss}}{1 + r_{ss}} dr_t.$$

Iterating this equation forward yields

$$dp_t = \sum_{s=1}^{\infty} \frac{dD_{t+s} - dr_{t+s-1}}{(1 + r_{ss})^s}.$$

Written this in the sequence space then gives

$$d\boldsymbol{p} = \boldsymbol{\mathcal{J}}_{\boldsymbol{D}}^{\boldsymbol{p}} d\boldsymbol{D} + \boldsymbol{\mathcal{J}}_{\boldsymbol{r}}^{\boldsymbol{p}} d\boldsymbol{r},$$

where

$$\boldsymbol{\mathcal{J}}_{\boldsymbol{D}}^{\boldsymbol{p}} \equiv \begin{pmatrix} 0 & (1+r_{ss})^{-1} & (1+r_{ss})^{-2} & \dots \\ 0 & 0 & (1+r_{ss})^{-1} & \dots \\ \vdots & \vdots & & \ddots \end{pmatrix},$$
$$\boldsymbol{\mathcal{J}}_{\boldsymbol{r}}^{\boldsymbol{p}} \equiv - \begin{pmatrix} (1+r_{ss})^{-1} & (1+r_{ss})^{-2} & (1+r_{ss})^{-3} & \dots \\ 0 & (1+r_{ss})^{-1} & (1+r_{ss})^{-2} & \dots \\ & \vdots & \vdots & \end{pmatrix}$$

Inserting this in eq. (42) then gives that

$$d\boldsymbol{r_p} = \boldsymbol{\mathcal{J}}_{\boldsymbol{p}}^{\boldsymbol{rp}} \left(\boldsymbol{\mathcal{J}}_{\boldsymbol{D}}^{\boldsymbol{p}} d\boldsymbol{D} + \boldsymbol{\mathcal{J}}_{\boldsymbol{r}}^{\boldsymbol{p}} d\boldsymbol{r} \right) + \boldsymbol{\mathcal{J}}_{\boldsymbol{D}}^{\boldsymbol{rp}} d\boldsymbol{D}.$$

Collecting terms gives

$$d\boldsymbol{r_p} = \boldsymbol{\mathcal{J}}_{\boldsymbol{D}}^{\boldsymbol{rp}} d\boldsymbol{D} + \boldsymbol{\mathcal{J}}_{\boldsymbol{r}}^{\boldsymbol{rp}} d\boldsymbol{r}, \tag{43}$$

where

$$\mathcal{J}_{D}^{rp} \equiv \mathcal{J}_{p}^{rp}\mathcal{J}_{D}^{p} + \tilde{\mathcal{J}}_{D}^{rp}, \quad \mathcal{J}_{r}^{rp} \equiv \mathcal{J}_{p}^{rp}\mathcal{J}_{r}^{p}.$$

Inserting $P_{f,t} = \mu W_t$ into the definition of real dividends gives

$$D_t = \frac{\mu - 1}{\mu}\frac{P_{f,t}}{P_t}Y_t + r_{u,t}A_u^F.$$

Linearizing this then gives

$$dD_t = \frac{\mu - 1}{\mu}Y_{ss}d\left(\frac{P_{f,t}}{P_t}\right) + \frac{\mu - 1}{\mu}dY_t + A_u^F dr_{u,t}.$$

Inserting eq. (30) into this yields

$$dD_t = \frac{\mu - 1}{\mu}dY_t - \frac{\mu - 1}{\mu}\frac{\alpha_u}{\alpha_f}dQ_t + A_u^F dr_{u,t}.$$

This can be written in the sequence space as

$$d\boldsymbol{D} = \mathcal{J}_{Y}^{D}d\boldsymbol{Y} + \mathcal{J}_{Q}^{D}d\boldsymbol{Q} + A_u^F d\boldsymbol{r_u},$$

where

$$\mathcal{J}_{Y}^{D} \equiv \frac{\mu - 1}{\mu}\boldsymbol{I}, \quad \mathcal{J}_{Q}^{D} \equiv -\frac{\mu - 1}{\mu}\frac{\alpha_u}{\alpha_f}\boldsymbol{I}.$$

Inserting this in eq. (43) then gives

$$d\boldsymbol{r_p} = \frac{\mu - 1}{\mu}\mathcal{J}_{D}^{rp}\left(d\boldsymbol{Y} - \frac{\alpha_u}{\alpha_f}d\boldsymbol{Q}\right) + A_u^F \mathcal{J}_{D}^{rp}d\boldsymbol{r_u} + \mathcal{J}_{r}^{rp}d\boldsymbol{r}.$$

Inserting this into eq. (41), I get that

$$d\boldsymbol{C} = \boldsymbol{M}d\boldsymbol{Y} - \boldsymbol{M^T}d\boldsymbol{T} - \frac{\alpha_u}{\alpha_f}\boldsymbol{M}d\boldsymbol{Q} + \boldsymbol{M^r}d\boldsymbol{r} + \boldsymbol{M^{rb}}d\boldsymbol{r_b} + \boldsymbol{M^{ru}}d\boldsymbol{r_u} + \boldsymbol{M^{rr}}d\boldsymbol{r_r} \quad (44)$$

where

$$
\begin{aligned}
\boldsymbol{M} &\equiv \frac{1}{\mu}\mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{Z}} + w_p \frac{\mu-1}{\mu}\mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{rp}}\mathcal{J}^{\boldsymbol{rp}}_{\boldsymbol{D}}, \\
\boldsymbol{M^T} &\equiv \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{Z}}, \\
\boldsymbol{M^r} &\equiv \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{rp}}\mathcal{J}^{\boldsymbol{rp}}_{\boldsymbol{r}}, \\
\boldsymbol{M^{rb}} &\equiv \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{rb}}, \\
\boldsymbol{M^{ru}} &\equiv \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{ru}} + A^F_u \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{rp}}\mathcal{J}^{\boldsymbol{rp}}_{\boldsymbol{D}}, \\
\boldsymbol{M^{rr}} &\equiv \mathcal{J}^{\boldsymbol{C}}_{\boldsymbol{rr}}.
\end{aligned}
$$

B.3.5 Main Proof

Define $\boldsymbol{q} = (1, (1+r_{ss})^{-1}, (1+r_{ss})^{-2}), \dots)'$. I then use that a standard transversality condition and the households' budget constraint implies that the present-value MPC is one (see Auclert et al. 2024), such that

$$
\begin{aligned}
\boldsymbol{q}'\boldsymbol{M} &= \boldsymbol{q}', \\
\boldsymbol{q}'\boldsymbol{M^T} &= \boldsymbol{q}', \\
\boldsymbol{q}'\boldsymbol{M^r} &= \boldsymbol{0}, \\
\boldsymbol{q}'\boldsymbol{M^{rb}} &= B_{ss}\boldsymbol{q}', \\
\boldsymbol{q}'\boldsymbol{M^{ru}} &= (A_{u,ss} + A^F_u)\boldsymbol{q}', \\
\boldsymbol{q}'\boldsymbol{M^{rr}} &= A_{r,ss}\boldsymbol{q}'.
\end{aligned}
$$

Thus, multiplying q' onto dC in eq. (44) yields

$$
\boldsymbol{q}'d\boldsymbol{C} = \boldsymbol{q}'(d\boldsymbol{Y} - d\boldsymbol{T}) - \frac{\alpha_u}{\alpha_f}\boldsymbol{q}'d\boldsymbol{Q} + B_{ss}\boldsymbol{q}'d\boldsymbol{r_b} + (A_{u,ss} + A^F_u)\boldsymbol{q}'d\boldsymbol{r_u} + A_{r,ss}\boldsymbol{q}'d\boldsymbol{r_r}.
$$

Similarly, multiplying q' onto dY in eq. (39) yields

$$
\boldsymbol{q}'d\boldsymbol{Y} = \alpha_f\boldsymbol{q}'d\boldsymbol{C} + (1-\alpha_f)\boldsymbol{q}'(d\boldsymbol{Y_u} + d\boldsymbol{Y_r}) + \zeta\boldsymbol{q}'d\boldsymbol{Q}.
$$

Inserting the latter into the former yields

$$
\begin{aligned}
\boldsymbol{q}'d\boldsymbol{Y} = \alpha_f &\left[\boldsymbol{q}'(d\boldsymbol{Y} - d\boldsymbol{T}) - \frac{\alpha_u}{\alpha_f}\boldsymbol{q}'d\boldsymbol{Q} + B_{ss}\boldsymbol{q}'d\boldsymbol{r_b} + (A_{u,ss} + A^F_u)\boldsymbol{q}'d\boldsymbol{r_u} + F_{ss}\boldsymbol{q}'dr_r\right] \\
&+ (1-\alpha_f)\boldsymbol{q}'(d\boldsymbol{Y_u} + d\boldsymbol{Y^f}) + \zeta\boldsymbol{q}'d\boldsymbol{Q}.
\end{aligned}
$$

Solving for $\boldsymbol{q}'d\boldsymbol{Y}$ yields

$$\boldsymbol{q}'d\boldsymbol{Y} = \boldsymbol{q}'(d\boldsymbol{Y_u} + d\boldsymbol{Y_r}) + \frac{\alpha_f}{1-\alpha_f}(B_{ss}\boldsymbol{q}'d\boldsymbol{r_b} + (A_{u,ss} + A_u^F)\boldsymbol{q}'d\boldsymbol{r_u} - \boldsymbol{q}'d\boldsymbol{T}) \\ + \frac{1}{1-\alpha_f}(\zeta - \alpha_u)\boldsymbol{q}'d\boldsymbol{Q}.$$

Focus on the government. Iterating on its budget constraint and using a standard condition of $\lim_{t\to\infty} B_t/(1+r)^t = 0$ yields

$$\sum_{t=0}^{\infty} q_t \mathrm{PD}_t + (1+r)B_{ss} = 0,$$

where

$$\mathrm{PD}_t = \frac{P_{F,t}}{P_t}G_t - T_t - r_{u,t}A_u^G,$$

and

$$q_t = (1+r_0)^{-1}(1+r_1)^{-1}\ldots(1+r_{t-1})^{-1}, \quad \text{for } t = 1,2,\ldots, \\ q_0 \equiv 1.$$

Taking a first-order approximation yields

$$\mathrm{PD}_{ss}\sum_{t=0}^{\infty} dq_t + \sum_{t=0}^{\infty}\frac{d\mathrm{PD}_t}{(1+r)^t} = 0.$$

Insert the definition of PD_t and write in the sequence space:

$$\boldsymbol{q}'d\boldsymbol{T} = \mathrm{PD}_{ss}\sum_{t=0}^{\infty} dq_t + G_{ss}\boldsymbol{q}'(d\boldsymbol{P}_F - d\boldsymbol{P}) - A_u^G\boldsymbol{q}'d\boldsymbol{r_u}.$$

Insert eq. (30):

$$\boldsymbol{q}'d\boldsymbol{T} = \mathrm{PD}_{ss}\sum_{t=0}^{\infty} dq_t - G_{ss}\boldsymbol{q}'\left(\frac{\alpha_u}{\alpha_f}dQ_t + \frac{\alpha_r}{\alpha_f}dQ_{r,t}\right) - A_u^G\boldsymbol{q}'d\boldsymbol{r_u}.$$

Note then that

$$\mathrm{PD}_{ss}\sum_{t=0}^{\infty} dq_t = r(B_{ss} - A_u^G)\frac{1}{r(1+r)}\boldsymbol{q}'d\boldsymbol{r} = \frac{B_{ss} - A_u^G}{1+r}\boldsymbol{q}'d\boldsymbol{r}.$$

Thus,

$$\boldsymbol{q}'d\boldsymbol{T} = \frac{B_{ss} - A_u^G}{1+r}\boldsymbol{q}'d\boldsymbol{r} - G_{ss}\boldsymbol{q}'\left(\frac{\alpha_u}{\alpha_f}dQ_t + \frac{\alpha_r}{\alpha_f}dQ_{r,t}\right) - A_u^G\boldsymbol{q}'d\boldsymbol{r_u}.$$

Inserting this gives

$$\begin{aligned}\boldsymbol{q}'d\boldsymbol{Y} &= \boldsymbol{q}'(d\boldsymbol{Y_u} + d\boldsymbol{Y_r}) + \frac{1}{1-\alpha_f}(\zeta - \alpha_u)\boldsymbol{q}'d\boldsymbol{Q} \\ &+ \frac{\alpha_f}{1-\alpha_f}\left\{B_{ss}\boldsymbol{q}'d\boldsymbol{r_b} + \text{NWFU}\boldsymbol{q}'d\boldsymbol{r_u} - \frac{B_{ss} - A_u^G}{1+r}\boldsymbol{q}'d\boldsymbol{r} + G_{ss}\frac{\alpha_u}{\alpha_f}\boldsymbol{q}'dQ\right\}.\end{aligned}$$

where I used $dQ_{r,t} = 0$. Note that $\boldsymbol{q}'d\boldsymbol{r_b} = \boldsymbol{q}'d\boldsymbol{r}/(1+r)$:

$$\begin{aligned}\boldsymbol{q}'d\boldsymbol{Y} &= \boldsymbol{q}'(d\boldsymbol{Y_u} + d\boldsymbol{Y_r}) + \frac{1}{1-\alpha_f}(\zeta - \alpha_u)\boldsymbol{q}'d\boldsymbol{Q} \\ &+ \frac{\alpha_f}{1-\alpha_f}\left\{\text{NWFU}\boldsymbol{q}'d\boldsymbol{r_u} + \frac{A_u^G}{1+r}\boldsymbol{q}'d\boldsymbol{r} + G_{ss}\frac{\alpha_u}{\alpha_f}\boldsymbol{q}'dQ\right\}.\end{aligned}$$

To write as a semi-elasticity, I divide by $\boldsymbol{q}'d\boldsymbol{i_u}$ and use $d\boldsymbol{r} = 0$:

$$\frac{\boldsymbol{q}'d\boldsymbol{Y}}{\boldsymbol{q}'d\boldsymbol{i_u}} = \frac{\boldsymbol{q}'d\boldsymbol{Y_u}}{\boldsymbol{q}'d\boldsymbol{i_u}} + \frac{\boldsymbol{q}'d\boldsymbol{Y_r}}{\boldsymbol{q}'d\boldsymbol{i_u}} + \text{NWFU}\frac{\alpha_f}{1-\alpha_f}\frac{\boldsymbol{q}'d\boldsymbol{r_u}}{\boldsymbol{q}'d\boldsymbol{i_u}} + \frac{1}{1-\alpha_f}(\zeta + (G_{ss}-1)\alpha_u)\frac{\boldsymbol{q}'d\boldsymbol{Q}}{\boldsymbol{q}'d\boldsymbol{i_u}}.$$

Note now that $Y_{ss} = Q_{ss} = 1$. By dividing and multiplying by $Y_{u,ss}$ and $Y_{r,ss}$ in the first two terms, respectively, I arrive at

$$\epsilon_Y = Y_{u,ss}\epsilon_{Yu} + Y_{r,ss}\epsilon_{Yr} + \text{NWFU}\frac{\alpha_f}{1-\alpha_f}\tilde{\epsilon}_{ru} + \frac{1}{1-\alpha_f}(\zeta - \alpha_u C_{ss})\epsilon_{Qu},$$

where I used the definitions of semi-elasticities and slopes. The result is the main text uses $C_{ss} = 1$ since $G_{ss} = 0$.

B.4 US Returns In the Sequence Space

Linearizing $r_{u,t}$ yields

$$dr_{u,t} = \frac{\delta}{q_{ss}}dq_t - \frac{1+\delta q_{ss}}{q_{ss}^2}dq_{t-1} + (1+r_{ss})(dQ_t - dQ_{t-1}).$$

In the sequence space

$$d\boldsymbol{r_u} = \frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{q}} d\boldsymbol{q} + \frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{Q}} d\boldsymbol{Q},$$

where

$$\frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{q}} = \begin{pmatrix} \frac{\delta}{q_{ss}} & 0 & 0 & \cdots \\ -\frac{1+\delta q_{ss}}{q_{ss}^2} & \frac{\delta}{q_{ss}} & 0 & \cdots \\ 0 & -\frac{1+\delta q_{ss}}{q_{ss}^2} & \frac{\delta}{q_{ss}} & \\ \vdots & & & \ddots \end{pmatrix},$$

$$\frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{Q}} = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots \\ -1 & 1 & 0 & 0 & \cdots \\ 0 & -1 & 1 & 0 & \\ & & \ddots & \ddots & \end{pmatrix} = \boldsymbol{I} - \boldsymbol{L},$$

where $\boldsymbol{L}$ is the lag operator. Linearizing q_t yields

$$dq_t = \frac{\delta}{1+r_{ss}} dq_{t+1} - \frac{q_{ss}}{1+r_{ss}} di_{u,t}.$$

Iterating forwards yields

$$dq_t = -\frac{q_{ss}}{1+r_{ss}} i_{u,t} - \frac{\delta q_{ss}}{(1+r_{ss})^2} i_{u,t+1} - \frac{\delta^2 q_{ss}}{(1+r_{ss})^3} i_{u,t+2} - \ldots$$

In the sequence space,

$$d\boldsymbol{q} = \frac{\partial \boldsymbol{q}}{\partial \boldsymbol{i_u}} d\boldsymbol{i_u},$$

where

$$\frac{\partial \boldsymbol{q}}{\partial \boldsymbol{i_u}} = \begin{pmatrix} 1 & \frac{\delta}{1+r_{ss}} & \frac{\delta^2}{(1+r_{ss})^2} & \cdots \\ 0 & 1 & \frac{\delta}{1+r_{ss}} & \\ 0 & 0 & 1 & \\ \vdots & & \ddots & \ddots \end{pmatrix}.$$

Combining yields

$$d\boldsymbol{r_u} = \frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{q}} \frac{\partial \boldsymbol{q}}{\partial \boldsymbol{i_u}} d\boldsymbol{i_u} + (\boldsymbol{I} - \boldsymbol{L}) d\boldsymbol{Q}.$$

Defining $\boldsymbol{\Theta} \equiv \frac{\partial \boldsymbol{r_u}}{\partial \boldsymbol{q}} \frac{\partial \boldsymbol{q}}{\partial \boldsymbol{i_u}}$, this can be also be written as

$$d\boldsymbol{r_u} = \boldsymbol{\Theta} d\boldsymbol{i_u} + (\boldsymbol{I} - \boldsymbol{L}) d\boldsymbol{Q}.$$

Note that both matrices in the product defining $\boldsymbol{\Theta}$ depend only on r_{ss}, δ, and q_{ss}. Note further that eq. (20) evaluated in the steady state implies that

$$q_{ss} = \frac{1}{1 + r_{ss} - \delta}.$$

Thus, $\boldsymbol{\Theta}$ depends only on r and δ. Making this dependence explicit, I write that

$$d\boldsymbol{r_u} = \boldsymbol{\Theta}(r, \delta) d\boldsymbol{i_u} + (\boldsymbol{I} - \boldsymbol{L}) d\boldsymbol{Q}.$$