The International Spillovers of Synchronous Monetary Tightening

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Abstract

We use historical data and a calibrated model of the world economy to study how a synchronous monetary tightening can amplify cross-border transmission of monetary policy. The empirical analysis shows that historical episodes of synchronous tightening are associated with tighter financial conditions and larger effects on economic activity than asynchronous ones. In the model, a sufficiently large synchronous tightening can disrupt intermediation of credit by global financial intermediaries causing large output losses and an increase in sacrifice ratios, that is, output lost for a given reduction in inflation. We use this framework to show that there are gains from coordination of international monetary policy.

KEYWORDS: Monetary Policy; Inflation; International Spillovers; Financial Frictions; Open Economy Macroeconomics; Panel Data Estimation.

JEL CLASSIFICATION: C33. E32. E44. F42.

1 Introduction

Starting in 2022, central banks around the world have tightened monetary policy at an unprecedented pace to contain the rise in global inflation that began in 2021. The synchronous nature of this global monetary tightening has raised concerns that interest rate hikes could mutually compound and lead to significant cross-border spillovers, resulting in a deep global downturn. Accordingly, some commentators have called on central banks to coordinate their fight against inflation to avoid driving the world economy into an unnecessarily harsh contraction (Obstfeld, 2022).

In this paper, we first show that, in the data, international spillovers of monetary policies are large and mutually reinforcing. Episodes of global tightening are associated with larger economic downturns, worse financial conditions, and a relatively muted decline in inflation, resulting in effects on activity that are larger than the sum of the effects of asynchronous tightening events. We then develop a model that is consistent with our findings. In the model, the amplification of synchronous tightening works through its effects on the balance sheets of global financial intermediaries that face occasionally binding leverage constraints. The nonlinear financial amplification of global tightening episodes is greater on output than on inflation, thus worsening monetary policy trade-offs. Finally, we investigate the optimal policy prescriptions of our model. When global adverse shocks are small and the financial channel is not active, we find that the optimal policy from an individual country perspective is not materially affected by foreign policy choices. However, when adverse shocks are significant and credit intermediation by global intermediaries is impaired, global strategic considerations become relevant for the conduct of monetary policy and countries can gain from coordinating their monetary policy actions.

Section 2 presents the empirical facts that support and motivate our model. We proceed in two steps. First, we show—using predictive regressions—that tighter monetary policy actions in one country lower GDP both at home and abroad, and these effects are amplified when the tightening episodes are synchronous and when GDP growth—used as an indicator of the overall health of the economy—is relatively low. Second, using event study regressions, we document that tightening episodes in one country are associated with a larger deterioration in economic and financial conditions when they occur during periods of global monetary tightening. The amplification is substantial for GDP, unemployment, credit spreads, and the equity price of global banks.[1] In contrast, the additional effects on inflation are muted, so that monetary policy trade-offs appear to worsen significantly during episodes of global monetary tightening.

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[1] These findings are in line with other existing literature that studies the transmission of monetary policy shocks both domestically and across countries. Gertler and Karadi (2015) and Caldara and Herbst (2019) are examples of paper documenting that a monetary policy tightening raises spreads on corporate credit.

Motivated by the empirical results, in Section 3 we present a two-country new-Keynesian model that is consistent with the evidence. Central to our model is the presence of leveraged global financial intermediaries (GFIs) that raise funds both domestically and abroad and face occasionally binding leverage constraints. We assume that GFIs ability to intermediate assets depends on their net worth, due to an agency problem similar to the one proposed by Gertler and Kiyotaki (2010). When net worth is high, global intermediaries absorb losses by raising more debt, guaranteeing a smooth functioning of international credit markets. When net worth is low, for instance due to a decline in asset prices caused by higher interest rates, financial intermediaries are limited in their ability to issue new debt and are forced to sell assets. Assets are absorbed by less specialized buyers at a discount and, as a result, global credit spreads rise rapidly.

In Section 4 we illustrate how the nonlinear amplification of global tightening shocks arises from the interaction between the "financial accelerator" mechanism and the global exposure of financial intermediaries. When only one central bank hikes, the geographic diversification of their portfolios implies that global financial intermediaries suffer losses only on a portion of their assets. As a result, equity losses are contained and intermediaries' ability to issue debt is not impaired. In this case, debt issuance makes up for net worth losses, credit intermediation remains efficient, and monetary spillovers, that work through traditional trade channels, are small. However, when both central banks hike, capital losses occur on many assets at the same time and cause intermediaries' equity to decline more. If the synchronous tightening is large enough, the global economy can reach a tipping point beyond which the effects of higher interest rates are greatly amplified. In this region, the financial accelerator channel is activated, and credit spreads rise rapidly across countries causing large financial spillovers.

In Section 5 we show that, in line with the empirical evidence on the effects of global tightening episodes, in the model financial amplification of global policy shocks is larger for output than for inflation—thus increasing sacrifice ratios, measured as the output lost to achieve a given reduction in inflation.[2] The reason is that financial constraints in our model act primarily to restrict demand for investment. The additional drop in output due to financial amplification is therefore associated with muted effects both on rental rates—because of lower capital accumulation—and on wages—because by weighing more on investment than on consumption, financial amplification is associated with smaller wealth effects on labor supply. The upshot is that when the financial channel is active, policy spillovers are larger and policy trade-offs worsen globally, which affects strategic interdependence of global monetary policy.

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[2] Schularick and Taylor (2012) also find that banking crises in the post World War II period have been associated with large declines in activity but muted response of inflation. Christiano, Eichenbaum, and Trabandt (2015), Del Negro, Giannoni, and Schorfheide (2015), and Gilchrist et al. (2017) argue that financial factors can help explain the surprisingly contained decline in U.S. inflation during the Global Financial Crisis.

In Section 6 we study how financial spillovers affect optimal monetary policy in response to shocks that cause an increase in global inflation, i.e. a global markup shock. We first show that when the inflationary shocks are small, credit spreads do not rise, financial spillovers are muted, and the model suggests that the optimal monetary policy from an individual country's perspective remains nearly optimal from a global perspective. This case of strategic independence confirms, within our model, a result established in related literature that finds that spillovers through traditional trade channels are quantitatively small and do not materially alter optimal monetary policy prescriptions from closed economy analyses. We then show that when the inflationary shocks are large enough, financial frictions become active, credit spreads rise, and macroeconomic spillovers become large. When this happens, strategic considerations become relevant for the conduct of monetary policy. The optimal policy in one country depends on the policy stance in the other country, with policy actions being strategic substitutes: a more aggressive foreign response to the rise in inflation is met with a more accommodative response at home. The reason is that a more-aggressive response to inflation by the foreign central bank, pushes global intermediaries further into the leverage constraint and significantly worsens policy trade-offs at home.

We also document that state-dependent monetary policy trade-offs are a key motive underlying international policy coordination. In our model, a wide range of policies can lead to improved global outcomes by containing the increase in spreads associated with the Nash equilibrium. The policy arrangement that achieves the best global outcome involves a reduction in spreads through a less aggressive response to inflation in the home country, capturing the U.S., compared to the Nash equilibrium. This helps mitigate financial spillovers, resulting in improved policy trade-offs for the foreign economy. Consequently, the foreign central bank can adopt a more aggressive stance towards inflation compared to the Nash equilibrium. This policy configuration capitalizes on a key model asymmetry, namely that the U.S. economy exerts a disproportionately significant influence on global financial conditions.[3] However, under this policy arrangement, the U.S. experiences a worse outcome compared to the Nash equilibrium, as the more accommodative response leads to a greater increase in inflation. In contrast, the foreign economy benefits from leveraging the U.S.'s accommodative response to achieve better outcomes in both inflation and output.

Since the optimal global outcome is attained through a policy configuration that does not attain a Pareto improvement, we also explore the possibility of achieving Pareto improvements within our model. We find that there is a range of policies that make both countries better off relative to the Nash equilibrium. Under these policies, both countries contribute to easing financial conditions by accepting slightly higher inflation in exchange for substantially lower output losses.

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[3] This asymmetry is in line with the role of U.S. monetary policy in driving the global financial cycle, as described by Miranda-Agrippino and Rey (2020).

Related Literature

Our paper is related to three broad streams of research: literature on the foreign spillovers of monetary policy shocks; literature on banking and financial frictions in international business cycle models; and literature on international monetary policy coordination.

Our empirical analysis of monetary spillovers follows a large body of literature that has looked at the cross-border effects of monetary policy and financial shocks. Recent examples include Iacoviello and Navarro (2019), who find that international spillovers of higher U.S. interest rates are stronger for countries that are more financially vulnerable.[4]. Our novel contribution is to highlight the interaction between domestic and global monetary shocks, and the nonlinear and state-dependent nature of their effects.

Our modeling approach focuses on the prominent role played by global financial intermediaries in allocating funds across countries, and builds on the idea that financial integration can act as an important channel of financial contagion. Examples include Gabaix and Maggiori (2015), Maggiori (2017), Morelli, Ottonello, and Perez (2022), Devereux and Yetman (2010), Cetorelli and Goldberg (2012), and Bruno and Shin (2015), who study the role of global financial intermediaries in asset pricing, international lending, and in the transmission of real and financial shocks across borders. Our contribution is to show how the stance of global monetary policy is a key determinant of how financial intermediation matters for economic outcomes.[5]

Finally, our paper contributes to the literature that studies the gains from policy coordination. The seminal work of Obstfeld and Rogoff (2002) shows, using a canonical open-economy new-keynesian model, that the gains associated to optimal departures from domestically oriented policies are negligible. Corsetti and Pesenti (2005), Devereux and Engel (2003), and Taylor (2013) confirm this result in quantitative international macro models in which, however, policy spillovers only work through traditional trade channels. Recent contributions have analyzed departures from the canonical framework that can yield significant gains from cooperation: recent examples include Dedola, Karadi, and Lombardo (2013), who focus on unconventional monetary policies, Bodenstein, Corsetti, and Guerrieri (2020), who study the how incentives to manipulate terms of trade can vary when net foreign asset positions are large, and Fornaro and Romei (2022), who study gains from coordination in response to large sectoral shocks. Our contribution is to highlight the role of financial frictions and cross-border financial integration as potential sources of state-dependent

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[4] See also Dedola, Rivolta, and Stracca (2017), Degasperi, Hong, and Ricco (2020), Albrizio et al. (2020), and di Giovanni and Shambaugh (2008).

[5] Our work is also related to Devereux and Yu (2020) who show how financial integration can act as an important source of financial contagion. See also Akinci and Queralto (2023) and Ferrante and Gornemann (2022) for models studying cross-border spillovers of monetary shocks through financial channels.

gains from cooperation.

2 Empirical background

In the empirical section, we present two sets of results that motivate our model and that are consistent with its predictions. Our analysis is unified by the theme that simultaneous changes in monetary policy stances across countries can yield effects greater than the sum of their individual impacts. This phenomenon is particularly noticeable during periods of either weak country-level growth or tight global financial conditions.

First, using predictive regressions, we show that contractionary monetary policy shocks in one country lower GDP both at home and abroad, and these effects are amplified when the policy shocks are contractionary on average in the rest of the world and when growth is relatively low. Second, using event study regressions, we focus on the state dependent responses of a larger set of economic and financial variables to domestic contractionary policy shocks, allowing for the responses to vary depending on whether the monetary shock happens during historical periods of global tightening. Our findings confirm that contractionary monetary policy shocks are associated with a more significant deterioration in economic and financial conditions when they occur during periods of global monetary tightening. Conversely, the impact on inflation remains relatively muted.

2.1 The data

Our baseline analysis uses quarterly data from 1980 through 2019 for 21 advanced economies.[6] In line with the scope of our analysis, our dataset includes measures of interest rates, GDP and its private components—consumption, investment, and net exports—, unemployment, inflation, the real exchange rate, credit spreads, and bank equity. We report details of the data collection in Appendix A. Data coverage, which varies across countries and variables, is listed in Table A.1.

We measure interest rates with the policy rate set by the national central bank, or, if unavailable, with the yields on short-term government bonds. Inflation is measured using the four-quarter change in the core CPI index. The real exchange rate is the effective measure described in Darvas (2012). Credit spreads, which are available for a subset of countries, are given by the difference between 5 or 10-year yields on BBB corporate bonds relative to government bonds of the same maturity. Finally, for bank equity we use the list of global banks from Acalin (2022), which contains

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[6] The economies in the sample are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

20 banks across eight advanced economies, and construct a weighted stock price index of global banks operating in each country.

2.2 Identification of tight monetary policy episodes

Our empirical analysis aims to assess whether an increase in policy rates in one country spills over to others and whether these effects are amplified during periods of economic or financial tightness. To achieve this, we require plausibly exogenous measures of tight monetary policy for numerous countries and over an extended sample period. A lot of progress has been made in constructing measures of exogenous monetary shocks identified using large sets of data, narrative records, or high-frequency information from financial markets. However, these measures are typically available only for a limited number of countries and for shorter sample periods, which limits their utility for studying the effects of monetary tightening across countries and various stages of the business cycle.

To identify episodes of tight monetary policy, we proceed in two steps. In the first step, we identify monetary policy shocks by regressing country-by-country policy rates on a set of macroeconomic controls as follows:

$$R_{i,t} = \alpha_i + \boldsymbol{\beta}_i \mathbf{Z}_{i,t} + u_{i,t}, \tag{1}$$

where the set of controls $\mathbf{Z}_{i,t}$ includes linear and quadratic time trends, two lags of interest rates, two lags of inflation, two lags of unemployment, two lags of the real exchange rate, and two lags of oil price inflation. This first step follows the tradition of identifying monetary policy shocks using vector autoregressive models, with the interest rate placed first in a recursive ordering.[7]

In the second step, we convert the shocks $u_{i,t}$ estimated above into dummy variables that capture episodes of tight monetary policy. Dummy variables are best suited to measure the typical effects of shifts in monetary policy in a long sample including changes in central banks practices and regimes across heterogeneous countries. A downside of this approach is that it does not allow to capture the intensity of the tightening.

Specifically, the dummy $\mathbb{D}_{i,t}$ is set to one in the event of a domestic exogenous tightening in country i, corresponding to quarters in which domestic monetary policy shocks are greater than zero, i.e. $\mathbb{D}_{i,t} = \mathbb{I}_{\{u_{it}>0\}}$. The dummy $\mathbb{F}_{i,t}$ is set to one in the event of an exogenous foreign tightening,

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corresponding to quarters in which the GDP-weighted average of other countries' monetary policy shock is greater than zero, i.e. $\mathbb{F}_{i,t} = \mathbb{I}_{\{\sum_{j \neq i} w_j u_{jt} > 0\}}$ where w_j is the GDP weight of country j. With these dummies, we investigate in Section 2.3 whether joint domestic and foreign tightening actions produce effects that exceed the sum of their individual impacts. The dummy $\mathbb{D}_{i,t}^{NAR}$ identifies a narrower subset of episodes and is set to one in the event of a *large* domestic exogenous tightening, corresponding to quarters in which a country monetary policy shock is greater than a threshold of 25 basis points, i.e. $\mathbb{D}_{i,t}^{NAR} = \mathbb{I}_{\{u_{it} > 25bps\}}$. With this dummy, we examine in Section 2.4 whether individual country tightening actions yield larger effects when they occur during a global tightening period.

2.3 State-dependent policy spillovers: predictive regressions

Our analysis builds on the idea that domestic and foreign tightening episodes weaken domestic economic activity, and that the effects of tighter policy are amplified by the tightening actions of other countries, particularly when economic fundamentals are weak. To test this idea, we estimate a simple panel regression of the form:

$$\Delta y_{i,t+8} = \beta_D \mathbb{D}_{i,t} + \beta_F \mathbb{F}_{i,t} + \beta_H \mathbb{DF}_{i,t} \times \mathbb{YHI}_{i,t} + \beta_L \mathbb{DF}_{i,t} \times \mathbb{YLO}_{i,t} + \alpha_i + \varepsilon_{i,t}, \qquad (2)$$

where $\Delta y_{i,t+8}$ is country i's log GDP level eight quarters ahead minus log GDP at time t; $\mathbb{D}_{i,t}$ is the dummy capturing exogenous domestic tightening; $\mathbb{F}_{i,t}$ is the dummy capturing exogenous foreign tightening; $\mathbb{DF}_{i,t}$ is an interaction effect ($\mathbb{DF}_{i,t} := \mathbb{D}_{i,t} \times \mathbb{F}_{i,t}$) denoting the simultaneous occurrence of domestic and foreign tightening; and $\mathbb{YHI}_{i,t}$ and $\mathbb{YLO}_{i,t}$ are mutually exclusive dummies equal to 1 if a country is in a period of high or low growth, respectively. A high-growth period is defined as a period of annual GDP growth (Q4/Q4) above each country's median.

The regression in equation (2) embeds the possibility of two, distinct nonlinearities. The first nonlinearity allows for joint monetary actions to exert effects that are larger than the sum of their individual parts. The second nonlinearity allows for monetary actions to have larger effects depending on a country's own business cycle.

The first column of Table 1 tabulates the estimated coefficients from regression (2), when the nonlinearities are turned off. Two years after a domestic tightening episode, the level of GDP is 1 percent lower than otherwise.[8] The effects of a foreign tightening are of similar magnitude: a foreign tightening lowers the level of GDP by nearly 0.9 percent. Thus, the spillovers from foreign

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[8] On average, a domestic tightening results in policy rates that are 70 basis points higher than otherwise. The average domestic tightening raises rates by 35 basis points. The average domestic easing lowers rates by 35 basis points.

monetary policy tightening are sizeable.[9]

The second and third column of Table 1 show the results allowing for nonlinearities. In the second column, we allow for the effects of the joint monetary policy tightening to be larger than the sum of their two parts, but restricting $\beta_H = \beta_L$. The estimated coefficient on the interaction term is negative: that is, the negative effects of domestic and foreign tightening episodes are amplified when they occur simultaneously, resulting in an additional 0.9 percentage point decline in GDP. In the third column, we allow for both nonlinearities. The coefficient β_L is more negative than β_H, and only β_L is statistically different from zero at conventional significance levels: in words, joint tightening events produce effects that are larger than the sum of their parts, particularly during periods of low growth. Figure A.1 in the Appendix provides a visual interpretation of the size of the effects. If the marginal effects of tighter domestic or foreign policies were linear, the four lines plotted in the figure would be parallel.

2.4 State dependent policy spillovers: an event study analysis

We now examine the dynamic effects of tighter monetary policy using event study regressions. Specifically, we compare the aftermath of country-specific monetary policy shocks during two different sets of episodes, classified according to the behavior of global interest rates.[10]

Global tightening windows

Over the past half-century, central banks have synchronously tightened their monetary policy stance on several occasions. We illustrate this fact in Figure 1, which shows the time-series behavior of global policy interest rates between 1980 and 2022, constructed as the GDP-weighted average of each country's interest rate. The top panel shows that there are several periods in history in which global interest rates rise persistently. The bottom panel shows that episodes of rising global interest rates have resulted from synchronous actions of central banks, with the share of central banks tightening exhibiting large increases over very short periods of time.

We select global tightening windows using quantitative criteria. Specifically, we assume that the tightening windows last two years and that they begin in a quarter t^* that satisfies two criteria: (a) global interest rates are higher by more than 25 basis points than four quarters before; (b) global interest rates are higher than six quarters later. If the criteria are satisfied more than once in a

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[9] On average, a foreign tightening results in foreign policy rates that are 40 basis points higher than otherwise. The average foreign tightening raises rates by 20 basis points; the average foreign easing lowers them by 20.

[10] We do not consider emerging market economies in our baseline specification due to the lack of consistent data on financial conditions. We present robustness exercises—including the addition of emerging market economies to sample—in the Appendix.

four-quarter window, we select the first quarter in which they are met. As denoted by the gray areas in Figure 1, this approach results in 8 global tightening windows starting in 1981Q1, 1984Q1, 1989Q2, 1994Q4, 2000Q1, 2006Q3, 2011Q1, and 2018Q2. As illustrated by the Figure, each window includes the build-up period, the peak, and the immediate aftermath of each tightening cycle.

Amplification during synchronous tightening events: Empirical Evidence

We employ event study panel regressions where the response to a country-level tightening episode is allowed to differ across synchronous and asynchronous events. Formally, we estimate:

$$y_{i,t} = \gamma_i + \sum_{\tau=-2}^{10} \sigma_\tau \mathbb{S}_{i,t-\tau} + \sum_{\tau=-2}^{10} \alpha_\tau \mathbb{A}_{i,t-\tau} + \varepsilon_{i,t}, \tag{3}$$

where $y_{i,t}$ is an outcome variable; the dummy $\mathbb{S}_{i,t}$ is set to one in the event of a synchronous tightening in country i at quarter t; the dummy $\mathbb{A}_{i,t}$ is set to one in the event of an asynchronous tightening in country i at quarter t. Specifically, a synchronous tightening occurs if a large domestic exogenous tightening—measured by $\mathbb{D}_{i,t}^{NAR}$—takes place during a global tightening window; an asynchronous tightening occurs if a large domestic exogenous tightening takes place outside of a global tightening window. Using this criterion, we find 143 synchronous and 162 asynchronous tightening events.

Figure 2 plots how macroeconomic variables respond in the aftermath of a monetary tightening. Following standard practice in event study analysis, we plot the sequence of regression coefficients σ_τ and α_τ—expressed in deviation from their estimated values σ_{-1} and α_{-1} in period $t-1$, respectively.[11]

During both synchronous and asynchronous tightening events, interest rates increase for one year and start declining thereafter. Asynchronous tightening episodes result in small declines in GDP and limited increases in unemployment relative to their jump-off points; corporate spreads and bank equity prices react very little. By contrast, synchronous tightening episodes are associated with larger economic costs, with GDP declining more than 2 percent and unemployment rising more than 1 percentage point after two years. Of note, inflation declines modestly about two years after shock across both synchronous and asynchronous events. Synchronous tightening episodes are associated with a greater deterioration in financial conditions, with corporate spreads rising by about 50 basis points and bank equity prices falling by a larger amount.

The response of consumption and net exports is similar across synchronous and asynchronous

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[11] See Freyaldenhoven et al. (2021) for the suggestion of normalizing the regression coefficients relative to period $\tau = -1$. We depart from these authors' approach in that we do not plot the cumulative effects of the policy, since the variables in $y_{i,t}$ are expressed in levels or log levels.

tightening events. By contrast, the majority of the additional decline in GDP during synchronous tightening events is accounted for by a larger decline in investment, which aligns with the more pronounced deterioration in financial conditions. There is little disparity in the behavior of the exchange rate—which appreciates—and the trade balance—which moves little—across synchronous and asynchronous events. However, synchronous events are associated with a substantial decline in trade relative to economic activity.

To further explore the response of trade, we follow Alessandria and Choi (2021), and in the last two panels of the figure we decompose the response of net exports into one term reflecting demand substitution (net exports to trade ratio) and another term reflecting the intensity of trade (trade to trend GDP ratio). Synchronous and asynchronous tightening events weigh roughly equally on exports and imports. However, synchronous monetary tightening events lead to a larger decline in both imports and exports.[12]

The Appendix presents robustness analysis. We show that our results are qualitatively similar when we use an alternative window that selects global tightening events based on whether HP-filtered global interest rates are above or below 50 basis points relative to trend—see Figure A.2. We also show that our results are largely unchanged when we include emerging economies in our sample, as shown in Figure A.3.

One possible concern is that global tightening events may be partly caused by large adverse global supply shocks, so that the monetary shocks extracted during these events are themselves a combination of endogenous responses to global supply shocks and pure deviations from the rule. In that case, the contractionary monetary shocks that we extract across the two episodes may be different in magnitude too, and the large adverse responses to synchronous tightening events may reflect the effects of shocks other than pure monetary policy shocks. We allay this concern in two ways. First, we compare the distributions of the estimated monetary shocks across asynchronous and synchronous episodes (see Figure A.4). Synchronous tightening shocks are a touch larger, on average, than asynchronous ones, but the difference between the two distributions is small. A Kolmogorov-Smirnov test of equality does not reject the null hypothesis that the two shocks distributions are equal at the 10 percent level (the p-value of the Kolmogorov-Smirnov test is 0.106). Second, we re-estimate the country-specific monetary shocks by including additional global controls in the specification of Equation (1). Specifically, we add two lags of global unemployment, two lags of global inflation, and two lags of global interest rates. As shown in Figure A.5, our results are similar to those of the baseline specification.

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[12] The delayed appreciation of the exchange rate following a monetary shock is somewhat puzzling in light of the uncovered interest rate parity, but is a recurring result in VAR-based studies of the effects of monetary shocks—see for instance the discussion Engel (2014). Monetary VARs also document a reduction of similar size in both imports and exports following a contractionary monetary policy shock. See for instance Miranda-Agrippino and Ricco (2021).

In sum, spillovers from foreign monetary policy tightening on individual countries are large, negative, and significant. Furthermore, these spillovers are amplified when tightening events happen simultaneously and during periods of low growth.

We conclude this section by highlighting key empirical findings from our analysis that are consistent with our model and the insights of the optimal monetary policy exercise. First, during global tightening episodes, the effects of contractionary monetary policy shocks are amplified by financial factors. Second, while financial factors amplify the response of GDP and unemployment, the additional effects on inflation are more muted. Accordingly, policy trade-offs worsen significantly.

3 A Model of international financial spillovers

3.1 Model overview

We study a medium scale international New-Keynesian DSGE model that includes a home (H) bloc, calibrated to represent the United States, and a "foreign" (F) bloc. The model features nominal and real rigidities that are standard in quantitative macro models following Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007), and embeds them into an open-economy DSGE model following Clarida, Galı, and Gertler (2002), Kollmann (2001), Corsetti and Pesenti (2005), and Erceg, Guerrieri, and Gust (2005). The model's key non-standard feature is the presence of global financial intermediaries (GFIs) specialized in holding assets from both countries and subject to occasionally binding leverage constraints that limit their ability to raise external funds. Our definition of financial intermediaries is broad and and includes banks and non-banks financial institutions.

In this section, we characterize the key features of the model. We first discuss global financial flows. We then present the equations describing the six types of agents present in the model: global financial intermediaries, households, final good retailers, intermediate good producers, final good producers, and central banks.

3.2 Model details

3.2.1 Global financial flows

Figure 3 provides a visual representation of global financial flows in our model. GFIs issue dollar-denominated liabilities to home and foreign residents, and combine liabilities and their net worth to finance investment both in the U.S. and abroad. Funds can flow from households to productive assets either through direct financial claims issued by firms to domestic households, or through

bank intermediation. Let $K_{i,t}^h$ be the amount of households' direct finance, and $K_{i,t}^b$ the capital intermediated by GFIs in country i. Then we have that total capital in country i is given by

$$K_{i,t} = K_{i,t}^h + K_{i,t}^b. \tag{4}$$

Households' direct finance is relatively inefficient, an assumption similar to Gertler and Kiyotaki (2015). In particular, we assume that households incur quadratic costs of holding capital directly. These costs depend on the share of capital intermediated by households and take the form:

$$\zeta_i\left(K_{i,t}^h, K_{i,t}\right) = \frac{\chi}{2}\left(\frac{K_{i,t}^h}{K_{i,t}} - \gamma_i\right)^2 K_{i,t}, \tag{5}$$

where the parameter γ_i is the share of capital that households can hold without incurring costs.

Global financial intermediaries are specialized in intermediating assets globally, and their holdings do not involve resource costs. Their economic function is to adjust their global asset holdings in order to ensure that the allocation of capital is efficient. That is, absent financial frictions, they adjust $K_{H,t}^b$ and $K_{F,t}^b$ in order to ensure that no costs from direct households finance are incurred, so that $\frac{K_{i,t}^h}{K_{i,t}} = \gamma_i$.[13] However, when financial intermediaries suffer large losses on their balance sheets, their leverage constraints become binding, their ability to issue new debt is limited, and they are forced to sell assets to households. As the fraction of direct finance rises, i.e. $\frac{K_{i,t}^h}{K_{i,t}} > \gamma_i$, the returns on holding capital must increase to compensate households for the associated costs. As a result, the spread between the return on capital and the return on safe assets rises both at home and abroad.

3.2.2 Global financial intermediaries

In country H there is a continuum of families of measure $\mathcal{N}_H$, each consisting of a continuum of members. At each point in time, a fraction f of family members manages a GFI—the bankers—,while the remaining fraction $1-f$ supplies work to non-financial firms. At the beginning of each period, a fraction $1-\sigma$ of bankers turn into workers, and a fraction $(1-\sigma)\frac{f}{1-f}$ of workers start a new bank, so that the relative proportion of bankers and workers remains constant. New bankers enter with some startup funds from the family, as discussed below. This is a standard approach to introduce financial intermediation while keeping the tractability of the representative family framework (see Gertler and Kiyotaki, 2010).

We now focus on the problem of a banker. A GFI raises dollar deposits (d_t) globally, and uses

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[13] Technically, this is true under our approximation of the true policy functions. In general some small costs are always incurred even when bankers are arbitraging away excess returns since their stochastic discount factor is more countercyclical than households, see equations (14)-(17) below.

these deposits together with its own net worth (n_t) to finance investment in domestic and foreign capital. We assume that a GFI can directly hold capital at home, but needs to establish a foreign subsidiary in order to hold foreign capital. The flow budget constraint for a GFI is given by:

$$Q_t k_{H,t}^b + s_{F,t} \leq n_t + d_t, \tag{6}$$

where $Q_{H,t}$ is the price of capital at home, $k_{H,t}^b$ are the GFI's holdings of capital at home, and $s_{F,t}$ are the GFI's holdings in the foreign subsidiary.

Let $R_{H,t+1}^k$ denote the real dollar return on domestic capital investment, and $R_{F,t+1}^s$ the real dollar return on investment in the foreign subsidiary. These returns are determined in equilibrium as described below in equations (24) and (28). Also, let $R_{H,t}^d$ denote the time-t determined, real dollar return on riskless deposits held from t to $t + 1$. The evolution of net worth is given by the returns on investments minus the costs of deposits:

$$n_{t+1} = R_{H,t+1}^k Q_t k_{H,t}^b + R_{F,t+1}^s s_{F,t} - d_t R_{H,t}^d. \tag{7}$$

Equations (6) and (7) reflect our assumption, common in the literature, of no new equity issuance.

We can express the objective of the banker recursively as follows:

$$V_t = \beta E_t \Lambda_{H,t+1}[(1 - \sigma)n_{t+1} + \sigma V_{t+1}] \tag{8}$$

where $\Lambda_{H,t+1}$ is the stochastic discount factor of the representative U.S. household between t and $t + 1$, and, as discussed above, $(1 - \sigma)$ is the probability of exiting in each period.[14]

The final ingredient of the banker's problem is the presence of an agency friction between the GFI and its depositors, which gives rise to an endogenous leverage constraint. In particular, we assume that the banker can divert a proportion θ_H of home assets and a proportion θ_F of assets held in the foreign subsidiary, where $\theta_F > \theta_H$.[15] Given this agency problem, rational depositors will limit the amount of lending to the bank to ensure that the banker does not have an incentive to divert the funds. The resulting incentive constraint is:

$$V_t \geq \theta_H Q_{H,t} k_{H,t}^b + \theta_F s_{F,t}. \tag{9}$$

The problem of the banker is to choose assets $k_{H,t}^b$ and $s_{F,t}$, deposits d_t, and net worth n_{t+1}, in

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[14] The objective in equation (8) implicitly uses the fact that the banker will not want to payout dividends to the family until exit. This is true given that the banker will occasionally make excess returns on investments so that the marginal value of wealth inside the bank is higher than the household's marginal value of wealth.

[15] We allow these parameters to be different to capture that it is more difficult for investors to recover foreign assets if the banker were to abscond with them. Accordingly, in our calibration $\theta_F > \theta_H$ as discussed below.

order optimize the objective in equation (8), subject to the constraints in (6), (7) and (9). Given the linearity of the objective function and of all constraints, the optimal value V_t^* of operating a bank with net worth n_t is given by

$$V_t^* = \psi_t^* n_t. \tag{10}$$

The variable ψ_t^* is the bank's franchise value: the ratio between the marginal value of wealth inside the bank and the marginal value of wealth to the household.

To describe the optimal choices of the banker it is useful to define the leverage multiples, $\phi_{H,t} = \frac{Q_{H,t} k_{H,t}^b}{n_t}$ and $\phi_{F,t} = \frac{s_{F,t}}{n_t}$. Using these to substitute for $k_{H,t}^b$ and $s_{F,t}$ in (6) and (7), the evolution of net worth can be written as:

$$n_{t+1} = n_t[(R_{H,t+1}^k - R_t^d)\phi_{H,t} + (R_{F,t+1}^s - R_t^d)\phi_{F,t} + R_t^d]. \tag{11}$$

Using equations (11) and $V_{t+1} = \psi_{t+1}^* n_{t+1}$ to substitute for n_{t+1} and V_{t+1} in equation (8), the bankers problem simplifies to:

$$\max_{\phi_{H,t},\phi_{F,t}} \mu_{H,t}\phi_{H,t} + \mu_{F,t}\phi_{F,t} + \nu_t \tag{12}$$

$$s.t.$$

$$\mu_{H,t}\phi_{H,t} + \mu_{F,t}\phi_{F,t} + \nu_t \geq \theta_H \phi_{H,t} + \theta_F \phi_{F,t} \tag{13}$$

where $\mu_{H,t}$ and $\mu_{F,t}$ are the excess returns on investments in U.S. capital and in the foreign subsidiary, discounted with the marginal value of banker's wealth:

$$\mu_{H,t} = \beta E_t \Lambda_{H,t+1} \left[1 - \sigma + \sigma \psi_{t+1}^*\right] \left(R_{H,t+1}^k - R_t^d\right) \tag{14}$$

$$\mu_{F,t} = \beta E_t \Lambda_{H,t+1} \left[1 - \sigma + \sigma \psi_{t+1}^*\right] \left(R_{Ft+t}^s - R_t^d\right). \tag{15}$$

and ν_t is the present discounted cost of a unit of deposit

$$\nu_t = \beta E_t \Lambda_{H,t+1} \left[1 - \sigma + \sigma \psi_{t+1}^*\right] R_t^d. \tag{16}$$

Notice that the individual banker's net worth n_t does not appear in equations (12) and (13). This implies that optimal leverage is constant across bankers, $\phi_{H,t} = \Phi_{H,t}$ and $\phi_{F,t} = \Phi_{F,t}$.

To characterize the solution to the banker's problem, we distinguish two cases. If the incentive constraint in equation (13) does not bind, then excess returns must be zero and the banker is indifferent about any leverage choice:

$$\mu_{H,t} = \mu_{F,t} = 0. \tag{17}$$

Alternatively, when $\mu_{H,t}$ and $\mu_{F,t}$ are positive, the incentive constraint binds and the optimality conditions are given by the incentive constraint at equality,

$$\mu_{H,t}\phi_{H,t} + \mu_{F,t}\phi_{F,t} + \nu_t = \theta_H\phi_{H,t} + \theta_F\phi_{F,t}, \tag{18}$$

and a condition that equates the ratio of excess returns to the ratio of their incentive costs

$$\frac{\mu_{H,t}}{\mu_{F,t}} = \frac{\theta_H}{\theta_F}. \tag{19}$$

To get the intuition behind equation (19), it is useful to suppose that, for instance, excess returns on home capital are relatively higher than excess returns on foreign investments, i.e. $\mu_{H,t} > \frac{\theta_H}{\theta_F}\mu_{F,t}$. Then, consider a trade in which the banker sells $\frac{\theta_H}{\theta_F}$ units of the foreign asset and buys one unit of U.S. capital. This trade is both profitable, since $\mu_{H,t} - \frac{\theta_H}{\theta_F}\mu_{F,t} > 0$, and feasible, since it keeps the right hand side of equation (13) constant while increasing the left hand side. With all bankers engaging in this trade, $\mu_{H,t}$ falls and $\mu_{F,t}$ rises until equation (19) is satisfied.

The tight link between excess returns on U.S. and foreign assets implied by equation (19) is a key feature for our analysis of spillovers. Irrespective of whether losses originate on holdings at home or abroad, once GFIs become constrained, equation (19) implies that spreads must rise simultaneously in both countries. The global exposure of banks implies that their balance sheet can become a conduit for financial transmission of shocks across countries.

3.2.3 Foreign subsidiaries

Foreign subsidiaries of GFIs are one-period-lived entities that invest in foreign capital and finance these investments with equity injections from GFIs, $s_{F,t}$, and local deposits $b_{F,t}$. The flow of funds constraint of the foreign subsidiary is given by

$$Q_{F,t}k_{F,t}^b = s_{F,t} + b_{F,t}. \tag{20}$$

We assume a simple leverage constraint on foreign subsidiaries of the form:

$$s_{F,t} \geq (1 - \lambda)Q_{F,t}k_{F,t}^b. \tag{21}$$

Let $X_{FH,t}$ be the real exchange rate value of the foreign consumption good in terms of the home

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consumption good, and $R^d_{F,t}$ the interest rate on foreign deposits. The return on GFIs' investment in its foreign subsidiary is given by

$$r^s_{F,t+1} = \frac{X_{FH,t+1}}{X_{FH,t}} \left[R^k_{F,t+1} Q_{F,t} k^b_{F,t} - R^d_{F,t} b_{F,t}(1-\tau) \right],$$ (22)

where we introduce a tax advantage on deposits τ to ensure that the foreign subsidiary always wants to increase its leverage up to the constraint even when the GFIs constraint is not binding.[16]

The foreign subsidiary chooses $k^b_{F,t}$ and $b_{F,t}$ to maximize

$$E_t \beta \Lambda_{H,t+1} [1 - \sigma + \sigma \psi^*_{t+1}] r^s_{F,t+1}$$

subject to equations (20) and (21). The solution to this problem is given by the leverage constraint at equality, which we can rewrite as

$$Q_{F,t} k^b_{F,t} = \frac{1}{1-\lambda} s_{F,t}$$ (23)

together with the flow of fund constraint (20). Using equations (20), (23) and (22), we get an expression for the return on GFIs' investments in their foreign subsidiaries given by:

$$R^s_{F,t+1} = \frac{X_{FH,t+1}}{X_{FH,t}} \left[\frac{R^k_{F,t+1} - R^d_{F,t}(1-\tau)}{1-\lambda} + R^d_{F,t}(1-\tau) \right].$$ (24)

Equation (24) shows that the return on GFIs investment in foreign subsidiaries is a leveraged return on foreign capital. The leverage of foreign subsidiaries, $\frac{1}{1-\lambda}$ amplifies the sensitivity of GFIs balance sheet to fluctuations in returns on foreign capital. This sensitivity is key for the quantitative transmission of a foreign tightening. To illustrate, if we assume that foreign subsidiaries are pass-through entities with no leverage, i.e. $\lambda = 0$, the GFI would be directly investing in foreign capital, just as it invests in domestic capital. The return on the investment in the foreign subsidiary would then be given by $R^s_{F,t+1} = \frac{X_{FH,t+1}}{X_{FH,t}} R^k_{F,t+1}$. In this case, a foreign tightening would still cause the foreign currency returns on foreign capital, $R^k_{F,t+1}$, to decline. This effect, however, would be largely offset by an appreciation of the foreign currency, i.e. an increase in $X_{FH,t+1}$. The presence of leverage amplifies the capital losses on foreign subsidiaries associated to any given decline in $R^k_{F,t+1}$ by a multiple of $\frac{1}{1-\lambda}$ and hence increases the sensitivity of GFIs balance sheets to foreign policy tightening actions. [17]

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[16] In practice given our solution is piecewise linear, an infinitesimally small value of τ suffices.

[17] Notice that it is also important that foreign subsidiaries borrow in foreign currency, as this mutes any effect of foreign currency appreciation on the subsidiary's debt. All these assumptions are made for simplicity. If we assume that GFIs loans were denominated in dollars, as is mostly the case in practice, the offsetting effect of the

3.2.4 Households

The representative family in country i maximizes a utility function that depends on consumption of a bundle of goods $C_{i,t}$ and on the amount of labor supplied to non-financial firms $L_{i,t}$:

$$E_t \sum_{s \geq t} \beta^{s-t} \left[\frac{(C_{i,s} - \iota C_{i,s-1})^{1-\rho}}{1-\rho} - \psi \frac{L_{i,s}^{1+\varphi}}{1+\varphi} \right]$$

Households can save in GFIs dollar deposits, $D_{i,t}$, in government bonds, $G_{i,t}$, whose nominal riskless interest rate, R_{it}^g is set by the central bank, or in local capital, $K_{i,t}^h$, subject to the cost, $\zeta_i \left(K_{i,t}^h, K_{i,t} \right)$, in equation (5). Their budget constraint in real terms is given by

$$C_{i,t} + X_{Hi,t} D_{i,t} + g_{i,t} + Q_{i,t} K_{i,t}^h + \zeta_i \left(K_{i,t}^h, K_{i,t} \right) =$$
$$w_{i,t} L_{i,t} + X_{Hi,t} D_{i,t-1} R_{t-1}^d + g_{i,t-1} \frac{R_{it-1}^g}{\pi_{it}} + K_{i,t-1}^h (z_{i,t} + (1-\delta) Q_{i,t}) + T_{i,t} \quad (25)$$

where $X_{ij,t}$ is the real exchange rate of goods from country i to country j (so that $X_{ii} = X_{jj} = 1$ and $X_{ij} = \frac{1}{X_{ji}}$), $g_{i,t}$ are real holdings of government bonds, $w_{i,t}$ is the real wage, $z_{i,t}$ is the rental rate of capital, π_{it} is inflation, and $T_{i,t}$ are profits from firms plus net transfers from bankers.

Optimality conditions for labor, deposits and government bonds, and capital are

$$\psi L_{i,t}^{\varphi} = U_{ci,t} w_{i,t}, \quad (26)$$

$$1 = \beta E_t \Lambda_{i,t+1} \frac{X_{Hi,t+1}}{X_{Hi,t}} R_t^d = \beta E_t \Lambda_{i,t+1} \frac{R_{it+1}^g}{\pi_{it+1}}, \quad (27)$$

$$1 + \frac{\partial \zeta_i}{\partial K_{i,t}^h} \frac{1}{Q_{i,t}} = E_t \Lambda_{i,t+1} \frac{(z_{i,t+1} + (1-\delta) Q_{i,t+1})}{Q_{i,t}} = E_t \Lambda_{i,t+1} R_{i,t+1}^k, \quad (28)$$

where $U_{ci,t} = (C_{i,t} - \iota C_{i,t-1})^{-\rho} - \beta \iota E_t (C_{i,t+1} - \iota C_{i,t})^{-\rho}$ and $\Lambda_{i,t+1} = \frac{U_{ci,t+1}}{U_{ci,t}}$.

As we discuss below, equation (28) implies that households are only willing to buy assets from bankers at a discount, given that direct intermediation is inefficient at the margin.

3.2.5 Final goods retailers

Retailers of final goods in country i buy intermediate goods from domestic producers $Y_{ii}(s)$ and foreign producers $Y_{ji}(s)$ and bundle them with a CES aggregator:

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appreciation of the foreign currency would disappear. However our simple modeling of banks following the Gertler and Kiyotaki (2010) approach, implies that banks loans must bear the exchange rate risk. An interesting alternative would be to introduce long-term defaultable dollar bonds issued by foreign firms. As in the Gertler and Kiyotaki (2010) framework, our approach has the advantage of being more tractable.

$$Y_{i,t} = \left[\omega_i^{\frac{1}{\theta}} Y_{ii,t}^{\frac{\theta-1}{\theta}} + (1 - \omega_i)^{\frac{1}{\theta}} Y_{ji,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{29}$$

where ω_i is the home bias parameter, θ is the trade elasticity, and $Y_{ii,t}$ and $Y_{ij,t}$ are bundles of domestically produced inputs and imported inputs respectively:

$$Y_{ii,t} = \left[\int (Y_{ii,t}(s))^{\frac{1}{\mu_t}} \right]^{\mu_t} \tag{30} \qquad\qquad Y_{ij,t} = \left[\int (Y_{ij,t}(s))^{\frac{1}{\mu_t}} \right]^{\mu_t} \tag{31}$$

The time-varying desired markup $\mu_t = \mu exp(u_t)$ will serve as a global inflationary shock in our experiments.

Optimality implies familiar demand schedules for imported and domestically produced goods, $Y_{ii,t} = p_{ii,t}^{-\theta} \omega_i Y_{i,t}$ and $Y_{ji,t} = p_{ji,t}^{-\theta} (1 - \omega_i) Y_{i,t}$, where $p_{ii,t} = P_{ii,t}/P_{i,t}$ and $p_{ji,t} = P_{ji,t}/P_{i,t}$ are real prices, and for firm-specific varieties, $Y_{ii,t} \left(\frac{P_{ii,t}(s)}{P_{ii,t}} \right)^{-\frac{\mu_t}{\mu_t-1}} = Y_{ii,t}(s)$ and $Y_{ji,t} \left(\frac{P_{ji,t}(s)}{P_{ji,t}} \right)^{-\frac{\mu_t}{\mu_t-1}} = Y_{ji,t}(s)$.

3.2.6 Intermediate goods production

Monopolistically competitive intermediate goods firm f produces output,$\bar{Y}_{i,t}(f)$, that is sold either domestically $Y_{ii}(f)$ or abroad $Y_{ij}(f)$, with a Cobb-Douglas function in capital and labor:

$$\bar{Y}_{i,t}(f) = Y_{ii}(f) + Y_{ij}(f) = l_t(f)^{1-\alpha} k_{t-1}(f)^{\alpha} \tag{32}$$

We assume that *local currency pricing* (LCP) holds, implying that firms set prices in the currency of the destination market for their products. The optimal pricing conditions for domestic and export prices yield two Phillips curves:

$$(\pi_{ii,t} - 1) \pi_{ii,t} = s_t [mc_{i,t} \mu_t - p_{ii,t}] + \beta E_t \Lambda_{H,t+1} (\pi_{iit+1} - 1) \pi_{iit+1} \frac{Y_{iit+1}}{Y_{ii,t}} \tag{33}$$

$$(\pi_{ij,t} - 1) \pi_{ij,t} = s_t [mc_{i,t} \mu_t - X_{ji,t} p_{ij,t}] + \beta E_t \Lambda_{t+1} (\pi_{ijt+1} - 1) \pi_{ijt+1} \frac{Y_{ijt+1}}{Y_{ij,t}} \tag{34}$$

where $\pi_{ii,t} = \frac{P_{ii,t}}{P_{iit-1}}$ and $\pi_{ij,t} = \frac{P_{ij,t}}{P_{ijt-1}}$, are the inflation rates of domestic and foreign sales respectively, $s_t = \frac{1}{\kappa(\mu_t-1)}$ is the slope of the Phillips curve, and marginal costs are given by:

$$mc_{i,t} = \left(\frac{w_{i,t}}{1 - \alpha} \right)^{1-\alpha} \left(\frac{z_{i,t}}{\alpha} \right)^{\alpha}. \tag{35}$$

3.2.7 Capital goods production

Capital producers sell capital at price Q_i and face convex adjustment costs. They solve:

$$\max E_t \Lambda_{t,t+i} \left[Q_{i,t+i} I_{i,t+i} - I_{i,t+i} - \frac{\gamma_k}{2} \left(\frac{I_{t+i}}{I_{t+i-1}} - 1 \right)^2 I_{t+i} \right].$$

Optimality implies the following relation between the price of capital and investment:

$$Q_{i,t} = 1 + \frac{\gamma_k}{2} \left(\frac{I_{i,t}}{I_{i,t-1}} - 1 \right)^2 + \gamma_k \frac{I_{i,t}}{I_{i,t-1}} \left(\frac{I_{i,t}}{I_{i,t-1}} - 1 \right) - \beta \Lambda_{i,t+1} \gamma_k \left(\frac{I_{i,t+1}}{I_{i,t}} \right)^2 \left(\frac{I_{i,t+1}}{I_{i,t}} - 1 \right) \qquad (36)$$

3.2.8 Monetary policy, shocks, and market clearing

In both countries, monetary policy follows a simple Taylor rule that responds to inflation of domestic goods:

$$\log \left(R_{i,t}^g \right) = (1 - \rho_r) R_{SS} + \rho_r \log \left(R_{i,t-1}^g \right) + \varphi_i \log \left(\pi_{ii,t} \right) + \varepsilon_{i,t}^m. \qquad (37)$$

We assume that $\varepsilon_{i,t}^m$ is a random shock $\varepsilon_{i,t}^m \sim N(0, \sigma^m)$. We also assume that the global markup is given by $\mu_t = \mu \exp(u_t)$, where u_t follows an AR(1) process:

$$u_t = \rho_\mu u_{t-1} + \varepsilon_t^\mu. \qquad (38)$$

Market clearing in the goods and investment market requires

$$\bar{Y}_{i,t} = Y_{ii,t} + \frac{\mathcal{N}_j}{\mathcal{N}_i} Y_{ij,t} \quad \text{for} \quad i \in \{H, F\} \qquad (39)$$

$$K_{it} = (1 - \delta) K_{it-1} + I_{it} \qquad (40)$$

where δ represents capital's depreciation rate. Market clearing for capital GFI deposits, and bonds require

$$K_{i,t} = K_{i,t}^h + K_{i,t}^b \quad \text{for} \quad i \in \{h, f\} \qquad (41)$$

$$D_t = D_{H,t} + D_{F,t} \qquad (42)$$

and a balance of payment equation:

$$C_{H,t} + I_{H,t} = p_{HH,t} \bar{Y}_{H,t} + \left(D_{F,t} - D_{F,t-1} R_t^d \right) + \left(R_{F,t}^s S_{F,t-1}^b - S_{F,t}^b \right). \qquad (43)$$

3.3 Calibration and solution

We calibrate the model so that in the steady state the leverage constraint on global banks is not binding. We solve the model using the OccBin toolkit to capture the nonlinearities in the decision rules which arise from the occasionally binding leverage constraint (Guerrieri and Iacoviello, 2015). In Appendix B.2, we augment the model to include a large set of shocks, and we show that under our calibration it produces business cycle moments for key variables that align with the data.

Table 2 reports our baseline calibration. We set the population shares so that the home country, assumed to be the United States, accounts for 25 percent of world GDP. For preferences, we assume log utility with habit and calibrate the discount factor β to obtain a world annualized real interest rate of 1 percent in steady state. The consumption habit parameter, ι, is set at 0.8 in line with, for instance, Justiniano, Primiceri, and Tambalotti (2010). We set both the Frisch and the trade elasticity to unity. The home bias parameter in the U.S., ω_H, is set to target an import share of 15 percent, and ω_F and D_F are adjusted to ensure that trade is balanced in steady state with the exchange rate normalized to unity. The Rotemberg adjustment cost parameter delivers a slope of the Phillips curve in line with a Calvo-style probability of not resetting prices of approximately 0.8, as in, for instance, Galí and Monacelli (2016).[18] The parameter governing the elasticity of the price of capital to investment is in the range of existing estimates, for example Justiniano, Primiceri, and Tambalotti (2010) estimate a value around 2.5.

The remaining parameters are specific to our model and are related to the global financial sector. We set $\gamma_H = 0.67$ so that global banks intermediate one-third of U.S. capital, as discussed in Gertler, Kiyotaki, and Prestipino (2020). A key element of our calibration is the foreign share of GFIs assets, which determines global banks exposure to a foreign monetary tightening. We set γ_F so that the steady state ratio of foreign assets to total assets is equal to 25 percent, which is in line with the average ratio of foreign exposure to total assets of U.S.-headquartered banks as reported in the BIS locational banking statistics. The bank survival rate σ_b implies a 5 percent dividend payout ratio as in Gertler and Kiyotaki (2015). We assume that $\lambda = 0.66$, which implies a conservative value of 3 for the leverage of GFIs foreign subsidiaries. The parameters χ, ξ, θ_H, θ_F are jointly calibrated to hit the following targets. First, an increase in global spreads of about 60 basis points during a synchronous tightening of 150 basis points (relative to an asynchronous one), in line with the evidence shown in Figure 2. Second, an average increase in foreign spreads equal to about one and half times the increase in U.S. spreads when the leverage constraint binds,

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[18] Here we are referring to the Phillips curve loosely as the relation between inflation and marginal costs arising from the optimal pricing conditions (33) (34). Our assumption of wage flexibility amplifies the implied sensitivity of inflation to output with respect to models using similar degrees of price rigidity but also assuming rigid wages. As we show in Appendix B.2 these features combine to deliver a relatively large inflation response to shocks.

in line with the relative movements of U.S. and foreign spreads during the Great Recession. Third, a steady state leverage ratio of GFIs of 4.75, i.e. $\phi = \phi_H + \phi_F = 4.75$, in line with the estimate of 4.8 computed by Morelli, Ottonello, and Perez (2022) for global banks.[19] Fourth, a steady state level of GFIs net worth that is 5 percent in excess of what required by the leverage constraint.[20]

4   Monetary policy transmission through the occasionally binding constraint

The novel channel of transmission of global monetary policy shocks in our framework works through the interaction of monetary policy, GFIs' net worth, and global excess returns. Three ingredients deliver nonlinear financial amplification of monetary policy spillovers in our model.

First, GFIs' exposure to assets both in the Home and Foreign country implies that a policy tightening in either bloc causes a decline in GFIs net worth by lowering asset valuations. Letting $E_t = \xi Q_{H,t-1} K_{H,t-1}^b$ denote new bankers' net worth, aggregate GFIs net worth is given by:

$$N_t = \sigma[Q_{H,t-1} K_{H,t-1}^b R_{H,t}^k + S_{F,t-1} R_{F,t}^s - D_{t-1} R_{t-1}^d] + E_t, \tag{44}$$

A policy tightening in country H (F) lowers asset valuations $Q_{H,t}$ ($Q_{F,t}$), and hence causes a decline in R_{Ht}^k (R_{Ft}^s) and in GFIs' net worth.

Second, the leverage constraint on GFIs introduces a tight link between GFIs' aggregate net worth and their ability to intermediate assets. When net worth drops below a certain threshold, the leverage constraint becomes binding and GFIs' ability to intermediate assets is limited.

To illustrate why a large enough drop in N_t can trigger the leverage constraint, suppose that at time t the constraint is not binding and excess returns are arbitraged away, i.e. $\mu_{H,t} = \mu_{F,t} = 0$. Let $\Phi_{H,t} = \frac{Q_{H,t} K_{H,t}^b}{N_t}$ and $\Phi_{F,t} = \frac{S_t^f}{N_t}$ be the GFIs' leverage multiples. Since the constraint is not binding, $\Phi_{H,t}$ and $\Phi_{F,t}$ satisfy the incentive constraint (13) with strict inequality (and with $\mu_{H,t} = \mu_{F,t} = 0$):

$$\nu_t > \theta_H \Phi_{H,t} + \theta_F \Phi_{F,t}.$$

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[19] As discussed by Morelli, Ottonello, and Perez (2022), this value should be considered an average of the leverage ratio of several types of financial institutions that operate internationally, for instance broker dealers, hedge funds, and money market funds.

[20] The steady state value of net worth is key in determining the size of the shocks needed in order for the constraint to become binding. In the quantitative extension presented in Appendix B.2, we find that the our simulated economy enters a regime with constrained GFIs with a probability of about 3.5 percent. For comparison, using historical data from Schularick and Taylor (2012), Boissay, Collard, and Smets (2016) estimate the frequency of "financial recessions" to be around 2.5 percent.

Now consider a sudden drop in net worth from N_t to $\hat{N}_t$, for instance because of a decline in E_t. For asset prices to remain constant and excess returns to remain at zero, GFIs' asset holdings $K^b_{H,t}$ and S^f_t must be unaffected. But with lower net worth this requires higher leverage $\hat{\Phi}^h_t = \frac{Q_{H,t}K^b_{H,t}}{\hat{N}_t}$ and $\hat{\Phi}^s_t = \frac{S^f_t}{\hat{N}_t}$. If the drop in net worth is large enough, the incentive constraint is violated, i.e.

$$\nu_t < \theta_H \hat{\Phi}_{H,t} + \theta_F \hat{\Phi}_{F,t}$$

and so GFIs are forced to sell assets globally.

Third, GFIs are more efficient than households, at the margin, in intermediating global assets. As a result, when the binding leverage constraint forces GFIs to sell assets to households, global excess returns increase. Equations (27) and (28) can be combined to express excess returns in country i as a function of the share of capital that households intermediate, as follows:

$$\chi \left(\frac{K^h_{i,t}}{K_{i,t}} - \gamma_i \right) \frac{1}{Q_{i,t}} = E_t \Lambda_{i,t+1} \left(R^k_{i,t+1} - \frac{R^g_{it+1}}{\pi_{it+1}} \right). \tag{45}$$

When the constraint is binding, households absorb assets from GFIs, the share $\frac{K^h_{i,t}}{K_{i,t}}$ rises above γ_i, the level that households can intermediate at no cost, and global spreads rise.[21]

The interaction of these three ingredients determines the overall transmission of policy shocks through GFIs. The relative exposure of GFIs to domestic asssets, K_H, and foreign assets, S_F—which is largely controlled by the parameters γ_H and γ_F—affects the relative size of cross country spillovers from policy shocks in the Home and Foreign country on GFIs net worth. The elasticity of GFIs' capital demand at home and abroad to changes in excess returns, governed by θ_H and θ_F, affects the magnitude of the contraction in GFIs credit intermediation when the constraint is binding. Finally, the marginal cost of household intermediation, governed by χ, controls the elasticity of excess returns to asset reallocation from GFIs to the households sector.

Figure 4 illustrates how these three ingredients deliver nonlinear financial amplification of policy spillovers, by showing the impact response of key variables to Home monetary policy shocks of different sizes. The solid lines illustrate the case in which the only shock is a surprise policy hike in the U.S. The dashed lines illustrate the marginal effect of the U.S. policy shock assuming a monetary policy shock of 150 basis points abroad.[22]

Absent shocks, the economy is in a steady state in which the bank leverage constraint is not

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[21] Our assumption that households can intermediate a proportion of assets directly at no cost follows Gertler, Kiyotaki, and Prestipino (2020). This assumption is critical to calibrate a realistic share of assets intermediated by GFIs. The transmission of shocks would be similar if households were completely excluded from capital financing, as in e.g. Gertler and Kiyotaki (2010).

[22] We assume that the system is in steady state at $t = -1$. For any variable v_t, the solid line plots the impact

binding. We consider the case of an asynchronous tightening first. When only the U.S. tightens, the increase in U.S. interest rates causes U.S. asset prices to decline. As long as U.S. policy shocks are below a certain threshold—125 basis points—the leverage constraint is not binding, the price of foreign capital remains unaffected, and the effect of a policy tightening are small. In particular, the response of asset prices, bank net worth, spreads, output and inflation to a monetary shock remains relatively contained.

To illustrate why, we linearize the GFIs' unconstrained optimality condition (equation 17) around the steady state. So long as the leverage constraint is not binding, the price of capital satisfies a standard pricing equation:

$$\tilde{q}_{i,0} = \sum_{t=0}^{\infty} (1-\delta)^t \left[\bar{z}\tilde{z}_{i,t+1} - r_{i,t} \right]. \tag{46}$$

This equation states that the price of capital in each country is the present discounted value of future rental rates, $\bar{z}\tilde{z}_{i,t}$, where $\bar{z}$ is the steady state rental rate and $\tilde{z}$ is the percent deviation of the rental rate from steady state.[23] Notice that a U.S. tightening directly affects $\tilde{q}_{H,0}$ by increasing future real rates $\sum_{t=0}^{\infty} (1-\delta)^t r_{H,t}$. By contrast, the effects of a U.S. tightening on foreign asset prices only work through the indirect effect of U.S. rates on foreign real rates and the foreign rental rate of capital. In particular, foreign real rates decline in response to lower U.S. demand while rental rates decline in response to lower foreign employment. These effects are small and offsetting, leaving essentially no imprint on $\tilde{q}_{F,0}$.

However, a large policy shock—above 125 basis points—can push GFIs against the leverage constraint, even if asynchronous. When the constraint is binding, the financial amplification channel gets activated: GFIs are forced sell assets to meet their leverage constraint and cannot keep their demand for assets at a level that is consistent with the standard asset pricing equation given by 46. In particular, GFIs sell both domestic and foreign assets, the price of domestic and foreign capital drops, and the deleveraging of banks triggers a rise in spreads (see equation 45), a relatively larger decline in economic activity, and a slightly larger decline in inflation.

Turning to the case of a synchronous tightening, the key observation is that the threshold above

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impulse response function computed as

$$\frac{dv_0}{\bar{v}}(\epsilon_{H,0}^m; \epsilon_{F,0}^m = 0)$$

whereas the dashed red line plots

$$\frac{dv_0}{\bar{v}}(\epsilon_{H,0}^m; \epsilon_{F,0}^m = 150bps) - \frac{dv_0}{\bar{v}}(\epsilon_{H,0}^m = 0; \epsilon_{F,0}^m = 150bps).$$

[23] Future rental rates are discounted with the country specific real interest rate, $r_{i,t} = r_{i,t}^n - \pi_{i,t+1}$.

which a U.S. tightening triggers the leverage constraint is much smaller when the foreign economy is also tightening. With a synchronous tightening, GFIs' net worth is much lower because of large valuation losses on both U.S. and foreign holdings. Accordingly, a U.S. policy shock of, say, 150 basis points, causes a trough in U.S. output which is nearly twice as large (1.25 vs 0.7 percent) relative to the asynchronous tightening case.

5 Model analysis

5.1 Nonlinear effects of synchronous tightening

Figures 5 and 6 illustrate the effects of contractionary monetary shocks in the model, and show how the financial amplification channel of global monetary policy shocks delivers non-linear policy spillovers that are in line with the empirical evidence.

Figures 5 reports the impulse responses to an interest rate hike of 150 basis points, occurring either at home or abroad. The size of the increase mirrors the average interest rate hike documented in the event study analysis of section 2.4. Following a rate hike in the U.S./home (solid lines), domestic GDP and inflation decline by about 0.8 percent and 1.5 percentage point respectively, as higher rates depress domestic aggregate demand. Given the large exposure of global banks to U.S. assets implied by our calibration, GFIs' net worth declines almost 15 percent, causing the leverage constraint to bind for a few quarters. As a result, global spreads rise, causing negative spillovers to foreign economies: foreign GDP declines by about 0.2 percent, and foreign inflation decline, albeit only modestly. A foreign rate hike (dashed lines) yields effects that are the mirror image of the U.S. effects. However, given the relatively small exposure of GFIs to foreign assets, their net worth declines only by 5 percent, without triggering a binding leverage constraint. As a result, global spreads do not rise, and the spillovers to the U.S./home are smaller.

Figure 6 shows the impulse responses to a joint tightening of 150 basis points occurring both at home and abroad. To illustrate the amplification, we compare the effects of the joint tightening (the solid lines) to the effects of the two shocks occurring either at home or abroad (the blue and green bars) depicted in Figure 5. The effect of a global tightening is larger than the sum of the individual rate hikes: the joint tightening pushes global banks into the region where the leverage constraint binds for an extended period, generating a sizeable amplification effect, as measured by the red bars. The financial accelerator channel causes banks' net worth to decline twice as much as in the case of asynchronous shocks. Global spreads rise significantly, and the U.S. and the foreign economy suffer an extra decline in GDP of about 0.5 and 0.75 percentage point, respectively.

As shown in Figure 6, the nonlinear amplification is mainly driven by a larger decline in

investment. As the leverage constraint becomes binding, GFIs reduce their holdings of U.S. and foreign capital, while households in both countries are unable to absorb completely these assets. As a result, the price of capital plummets—activating the financial accelerator channel—causing investment to decline sharply. The decline in consumption in both blocs is muted. The nonlinear amplification is positive for the first two years, as the collapse in investment causes domestic demand to shift towards consumption. The nonlinear amplification turns negative after two years, as consumption slowly reverts to steady state due to habits in preferences. Finally, the joint tightening results in negligible movements in the real exchange rate and in net exports.

Similar to the data, the additional decline in GDP resulting from a synchronous tightening primarily stems from a substantial decrease in investment, due to the increase in credit spreads that accompanies the decline in net worth of global financial intermediaries. By contrast, conventional trade channels play only a secondary role. The main reason is that in a two-country model of the U.S. and the rest of the world, trade shares are relatively small. Furthermore, under our assumption of LCP, the exchange rate pass-through to prices is muted. Figures B.2 and B.3 in the Appendix show that trade plays a secondary role also under alternative calibrations of the trade elasticity and pricing assumptions.[24]

We now turn to study how financial amplification affects monetary policy in the presence of shocks that create a trade-off between inflation and output stabilization.

5.2 The financial amplification channel and policy trade-offs

An important feature of our model is that the financial amplification of shocks is larger for output than for inflation. This property can be seen by returning to the case of a global monetary tightening. As illustrated in Figure 6, the extra output drop due to the nonlinear amplification is proportionally larger than the inflation drop. Two main forces contribute to this result. First, binding leverage constraints restrict the demand for investment, causing future rental rates to remain elevated because of lower capital accumulation. Second, financial amplification effects weigh more on investment than consumption, limiting wealth effects on labor supply and thus containing the decline in wages—and hence marginal costs—for a given drop in output. These are general properties of how financial amplification works in our model, and will therefore be operative irrespective of whether the source of the shock is a monetary policy shock or a global markup shock,

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[24] Specifically, we lower the trade elasticity from one as in the baseline calibration to 0.5. The alternative assumptions that firms' currency of invoice follows a producer currency pricing (PCP) or dominant currency pricing (DCP) protocol increases the degree of exchange rate pass-through. In our two-country model, DCP combines LCP for producers in the foreign economy and PCP for producers in the home economy. The quantitative impact of changing these assumptions is small.

as we describe below. An implication of this result is that when leverage constraints are binding, the inflation-output trade-offs induced by markup shocks worsen and monetary policies aimed at reducing inflation is more costly in terms of output.

To dig deeper in the relationship between financial amplification and policy trade-offs, we consider monetary and markup shocks of different sizes and calculate the present discounted value of squared output and inflation deviations from steady state for country i, defined as

$$\mathcal{L}_i^y = \sum_{t=0}^{T} \beta^t y_{i,t}^2 \ \ \text{and} \ \ \mathcal{L}_i^\pi = \sum_{t=0}^{T} \beta^t \pi_{i,t}^2, \tag{47}$$

where T is a large number. These two terms are standard components of ad-hoc loss functions used to compute optimal monetary policy in the literature and in central banks practice.[25]

Figure 7 plots $\mathcal{L}_i^y$ and $\mathcal{L}_i^\pi$ for the U.S., together with their ratio, for different configurations of monetary and markup shocks. The first row shows monetary shocks. As long as the leverage constraint on GFIs does not bind, output and inflation losses rise in lockstep as the size of policy shocks increases, and their ratio is constant, a direct consequence of the linearity of our approximation of the policy functions in this region. However, when the constraint binds, the effects of higher interest rates are larger on output than on inflation, as shown by the increasing ratio of the losses. The second row shows how output and inflation losses vary with the global markup shock. As with the case of monetary shock, trade-offs are invariant to the size of the shock as long as the constraint does not bind. When the shock becomes large enough, output-inflation trade-offs worsen.

Figure 8 shows the response to a large markup shock that occurs in the U.S. and abroad simultaneously. We size the markup shock so that it drives global inflation roughly 4 percentage points above steady state—similar to the rise in inflation in the U.S. observed in 2021 and 2022—and assume that the shock reverts back to steady state with an autoregressive coefficient of 0.5.[26] The inflationary shock and associated monetary tightening reduce output, creating trade-offs between output and inflation stabilization. As shown in the figure, the trade-offs are worse when financial frictions are present, as the GDP losses due to leverage constraints occur without a material moderation in the inflation surge. We illustrate this effect by comparing our baseline model with an alternative calibration in which financial frictions are turned off altogether: despite a GDP decline that is much smaller absent financial frictions, the response in inflation is roughly unchanged across

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[25] Specifically, $y_{i,t}$ denotes percent deviations of output from steady-state, and $\pi_{i,t}$ denotes annualized percentage point deviations of inflation.

[26] Because the effects of the shock on the U.S. and on the foreign economy are similar, we show only the U.S. in Figure 8, while B.1 in the Appendix shows the effects abroad.

the two calibrations.[27]

The worsening of trade-offs after a large markup shock could appear mechanical given that a large part of the inflation surge after markup shocks is exogenous and hence cannot be affected by the financial channel. In fact, financial channels affect output and the *endogenous* component of inflation similarly in this case too.

To better illustrate this point, we follow Del Negro, Giannoni, and Schorfheide (2015), who break inflation down into an exogenous component driven by current and future markup shocks, and a "fundamental inflation" component $\tilde{\pi}_t$:

$$\pi_t = \tilde{\pi}_t + \mu_t \tag{48}$$

Fundamental inflation is the discounted sum of expected marginal costs:

$$\tilde{\pi}_{i,t} = lc_{i,t} + kc_{i,t}, \tag{49}$$

where

$$lc_{i,t} = \frac{1}{\kappa(\mu - 1)}(1 - \alpha)(w_{i,t} - p_{ii,t}) + \beta E_t[lc_{i,t+1}], \tag{50}$$

$$kc_{i,t} = \frac{1}{\kappa(\mu - 1)}\alpha(z_{i,t} - p_{ii,t}) + \beta E_t[kc_{i,t+1}]. \tag{51}$$

The term $lc_{i,t}$ captures the component of fundamental inflation driven by labor costs, while the term $kc_{i,t}$ captures the component driven by capital rental costs.

Returning to Figure 8, financial frictions cause a large GDP decline—at the trough, GDP declines about 50 percent more with frictions than without. By contrast, the decline in inflation is smaller with financial frictions. In response to a markup shock that reduces activity, the drop in fundamental inflation is similar regardless of whether leverage constraints are present or not: $\tilde{\pi}_t$ falls 4.2 percentage points with leverage constraints and 3.7 without, an extra decline of 15 percent. This behavior occurs both because the cost-of-capital component of inflation is unaffected by financial constraints—financial frictions persistently reduce capital accumulation mitigating any decline in the rental rate—and because the cost of labor falls less than proportionally relative to GDP—because of the smaller stimulus to labor supply through wealth effects. These economic

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[27] To implement the unconstrained response we assume that the agency friction is not present. An alternative is to think that banks receive a large positive equity injection in the same quarter in which the markup shock hits. We choose this approach in order to measure the effect of financial frictions keeping the size of the shock fixed. The alternative approach of letting financial constraints switch on endogenously as the size of the shock varies was used in Figure 7.

forces through which financial amplification affects policy trade-offs are invariant to the nature of the shock.

In sum, the impulse responses to asynchronous and synchronous tightening episodes and to inflationary shocks illustrate two key findings from our model: first, the domestic effects of a monetary tightening by the domestic central bank depend on the simultaneous response of foreign central banks and how they affect the balance sheet of global financial intermediaries. Second, a tightening of global financial intermediaries' leverage constraints worsens monetary policy trade-offs globally. These findings are important in evaluating the gains from international monetary cooperation, which we turn to in the next section.

6 Policy coordination in a global inflation surge

We now turn to study how financial spillovers affect gains from monetary policy coordination. We do so in two steps. We first show that when global inflationary shocks are small and credit spreads do not rise, our model suggests that the optimal monetary policy from an individual country's perspective remains nearly optimal from a global perspective.[28] Next, we show that, when the inflationary shocks are large enough and credit spreads rise, strategic considerations become relevant in global policy actions, with optimal policy choices in one country depending on the policy stance in the other country. In addition, both countries can gain by coordinating their policy actions.

6.1 The global policy game

After observing a positive, one-time global shock to retailers' desired markups, ϵ^μ, policymakers in each country set the policy rule parameter governing the response to inflation, $\varphi_j \in (1, 10]$. After a markup shock of size ϵ^μ, and given policy choices φ_H and φ_F at home and abroad, central banks losses depend on the associated inflation and output deviations from steady-state as follows:

$$\mathcal{L}_i(\varphi_H, \varphi_F; \epsilon^\mu) = \sum_{t=0}^{T} \beta^t (\lambda_\pi \pi_{i,t}^2 + y_{i,t}^2) = \lambda_\pi \mathcal{L}_i^\pi + \mathcal{L}_i^y, \tag{52}$$

where π_{it} and y_{it} are inflation and output in deviation from steady state, and λ_π is the central banks' weight on inflation, which is assumed to be common across countries. For ease of notation, we omit the dependence of π_{jt} and y_{jt} from policy actions and the size of the shock.

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[28] This prediction is consistent with a large body of literature. See, for example, Corsetti and Pesenti (2005), Corsetti, Dedola, and Leduc (2010), Taylor (2013), or Bodenstein, Corsetti, and Guerrieri (2020), and references therein.

Some observations about our specification of the global policy game are in order. We restrict the strategy space to the choice of the Taylor coefficients φ_j and assume that central banks can commit to this choice. We follow this approach for several reasons. First, given the size of our model, an analytical characterization of the optimal policy problem is infeasible. Moreover, the non-linearity induced by the occasionally binding constraint impedes the use of standard techniques to computationally derive a Ramsey solution to the policy problem. Aside from the technical challenges that the size and non-linear nature of the equilibrium system pose to the characterization of a Ramsey optimum, an important argument in favor of modelling strategies in terms of the degree of aggressiveness in response to inflation is that these types of policy rules are easily implemented.[29]

We parameterize the game by the size of the unexpected global markup shock, ϵ^μ, and conduct "comparative static" exercises on the properties of the global policy game as the size of the unexpected shock parameter ϵ^μ changes. An alternative approach would be to assume that global markup shocks follow a stochastic process and simulate the economy under different assumptions about the standard deviation of the innovations to global markup shocks. The advantage of our approach is that it allows us to illustrate in the clearest possible way how central banks' incentives and strategic interaction vary as shocks become large enough to trigger the leverage constraint.[30]

Finally, we adopt the ad-hoc loss function in equation (52) for two reasons. First, the presence of occasionally-binding leverage constraints makes it challenging to compute a high-order approximation of our system of equilibrium equations that could be used to determine a utility-based welfare criterion. Second, we want to focus on how the presence of financial spillovers affects policy trade-offs and strategic interaction in global monetary policy actions, in a context in which monetary policymakers' objectives are based on the traditional stabilization motives which guide central banks' actions in practice. Accordingly, in what follows we assume a high value for the weight on inflation, $\lambda_\pi = 48$, to capture a substantial focus on inflationary pressures—consistent with central banks' communications in the wake of the post-Covid inflation spike.[31]

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[29] See Schmitt-Grohé and Uribe (2007) for a similar approach motivated by implementability arguments.

[30] In a stochastic environment, central banks' trade-offs would depend on the likelihood of observing markup shocks large enough to trigger the leverage constraint. So for any fixed standard deviation of the markup shock, the incentives guiding optimal policy would incorporate both the trade-offs involved in reacting to small shocks and to shocks that trigger the constraint, and these trade-offs would be weighted by the relative probability of these shocks.

[31] Applied analyses of federal reserve monetary policy often assume a loss function depending on quadratic deviations of annualized inflation and unemployment from their respective targets.

6.2 Financial spillovers and monetary policy interdependence

Let $\varphi_H^{br}(\varphi_F; \epsilon^\mu)$ be the best response of country H to country F choice φ_F given shock ϵ^μ:

$$\varphi_H^{br}(\varphi_F; \epsilon^\mu) = \arg\min_{\varphi_H} \mathcal{L}_H(\varphi_H, \varphi_F; \epsilon^\mu),$$

and let the foreign best response function $\varphi_F^{br}(\varphi_H; \epsilon^\mu)$ be defined analogously.[32]

For any given size of the inflationary shock ε^μ, a Nash equilibrium is given by a pair of policies $(\varphi_H^*(\varepsilon^\mu), \varphi_F^*(\varepsilon^\mu))$ that are best responses to each other:

$$\varphi_H^*(\varepsilon^\mu) = \varphi_H^{br}(\varphi_F^*; \epsilon^\mu) \ ; \ \ \varphi_F^*(\varepsilon^\mu) = \varphi_F^{br}(\varphi_H^*; \epsilon^\mu). \tag{53}$$

The Nash equilibrium of the global policy game depends on whether the shock is large enough to trigger financial spillovers. Figure 9 illustrates this result by plotting the Nash policy and credit spreads for the home economy (top row) and the foreign economy (bottom row) as functions of the size of the global mark-up shock. When the shock is sufficiently small, both countries respond aggressively to inflation in the Nash equilibrium, a policy described by an inflation coefficient of 10. The equilibrium is invariant to the size of the shock until the point where constraints are binding, the portion to the left of the green circle. As discussed in the previous section, an increase in markups that is sufficient to trigger the leverage constraint results in worse trade-offs between output and inflation stabilization, and policies that aggressively respond to inflation, i.e. high values of φ_j, are more costly both in terms of domestic output and in terms of cross country spillovers. As a result, to the right of the green circle, Nash equilibria are characterized by less aggressive policies.

The less-aggressive equilibrium response to inflation when shocks are large enough to trigger the leverage constraint depends on worse domestic trade-offs and larger cross-country spillovers from policy actions, as we illustrate in Figure 10. The figure plots best response functions of the home and foreign central banks. These functions describe the optimal policy of one country for a given policy in the other country. The top row considers the case of a small global markup shock, the green circle in the previous figure. When shocks are small and financial spillovers muted, there is *strategic independence* of policy actions: best response functions are flat, and each country finds it optimal to aggressively respond to the inflationary shock irrespective of the policy choice in the other country. As a result, the Nash equilibrium is given by the most aggressive policy allowed.

The bottom row considers the case of a large global markup shock, the red diamond in the previous figure. When shocks are large and financial spillovers active, strategic interactions between

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[32] We verify numerically that $\varphi_i^{br}(\cdot)$ are functions rather than correspondences.

central banks become important. Policy actions are strategic substitutes. For the home country the best response function is decreasing in the aggressiveness of the foreign country (while the loss function is increasing). A more-aggressive central bank response to inflation in the foreign country, by pushing global banks further into the leverage constraint, significantly worsens the trade-offs in the home country and causes the home central bank to reduce its own response. The effect of varying the home country response is even stronger, as depicted in the lower right panel, as home policy rates have larger effects on financial conditions given the larger exposure of GFIs to home assets. Accordingly, The Nash equilibrium, shown by the red diamond, is now given by an inflation response of about 7 in the home country and 4.5 in the foreign bloc.

Having illustrated how financial spillovers affect optimal policy and strategic interaction in global policy actions, we turn to investigating potential gains from international cooperation.

6.3 Gains from cooperation

To study the gains from monetary policy cooperation, we begin by defining the global loss function:

$$\bar{\mathcal{L}}\left(\varphi_H, \varphi_F; \epsilon^\mu\right) = \sigma_h \mathcal{L}_H\left(\varphi_H, \varphi_F; \epsilon^\mu\right) + (1 - \sigma_h)\mathcal{L}_F\left(\varphi_H, \varphi_F; \epsilon^\mu\right),$$

which corresponds to the weighted average of the country loss functions. The weight of the home economy in the global loss function is given by $\sigma_h = \frac{\mathcal{N}_H}{\mathcal{N}_H + \mathcal{N}_F} = \frac{1}{4}$.

The optimal cooperative solution is the pair of home and foreign policies $(\varphi_h^{coop}(\varepsilon^\mu), \varphi_f^{coop}(\varepsilon^\mu))$ that minimizes the global loss $\bar{\mathcal{L}}\left(\varphi_H, \varphi_F; \epsilon^\mu\right)$:

$$(\varphi_H^{coop}\left(\epsilon^\mu\right), \varphi_F^{coop}\left(\epsilon^\mu\right)) = \arg \min_{\varphi_H, \varphi_F} \bar{\mathcal{L}}\left(\varphi_H, \varphi_F; \epsilon^\mu\right). \tag{54}$$

The optimal cooperative solution does not guarantee that both countries are better off relative to the Nash equilibrium. Policies that minimize the global loss function could imply losses for one of the countries that are larger than under Nash. Accordingly, we also define the set of policies that improve upon the Nash equilibrium policies for both countries simultaneously:

$$\mathcal{P}\left(\epsilon^\mu\right) = \left\{(\varphi_H, \varphi_F) \in [1, 10]^2 \quad | \quad \mathcal{L}_i\left(\varphi_H, \varphi_F; \epsilon^\mu\right) \geq \mathcal{L}_i\left(\varphi_H^*(\epsilon^\mu), \varphi_F^*(\epsilon^\mu); \epsilon^\mu\right) \text{ for } i = H, F\right\}.$$

Policies in the set $\mathcal{P}\left(\epsilon^\mu\right)$ are *Pareto improvements* on the Nash equilibrium: both countries are better off. Therefore, international agreements that select policies in this set are more realistically enforceable. We define the "optimal Pareto improvement" policies as the strategies within the set

of Pareto improvements $\mathcal{P}$ that minimize the global loss:

$$\left(\varphi_H^{pi}\left(\epsilon^\mu\right), \varphi_F^{pi}\left(\epsilon^\mu\right)\right) = \arg \min_{(\varphi_H,\varphi_F)\in\mathcal{P}(\epsilon^\mu)} \bar{\mathcal{L}}\left(\varphi_H, \varphi_F; \epsilon^\mu\right). \tag{55}$$

Figure 11 illustrates the gains from international policy coordination. We highlight three results. First, there is a large set of policies—the light blue area—associated with a global loss that is smaller than under the Nash equilibrium. These policies feature a less-aggressive home monetary response to inflation than under Nash, while the foreign response can be more or less aggressive.

Second, the global cooperative optimum—denoted by the black square—features a response to inflation of the home economy that is significantly smaller than in the Nash equilibrium, and a foreign response to inflation that is larger. Key to understand this optimal policy configuration is the observation that the home economy has a large influence on global financial conditions, but a small weight in the global loss function. A looser monetary policy at home eases global financial conditions—-improving monetary tradeoffs globally—and allows the foreign bloc to fight inflation aggressively and obtain both lower inflation and higher output than under Nash. However, the less aggressive policy response in the home country causes home inflation to be higher than under Nash. As a result, the home country is worse off in the optimal cooperative solution, which is the reason why the optimal cooperative policy configuration is not part of the Pareto improving set $\mathcal{P}(\epsilon^\mu)$, the green area. The reason this configuration is optimal from a global perspective is that the weight of the foreign economy in the loss function is three times as large as the weight of the home economy.

Third, the set of policies associated with higher welfare for *both* countries relative to the Nash equilibrium features a less aggressive response to inflation both in the home and foreign economy. The globally optimal constrained policy (the "optimal Pareto improvement") is characterized by an inflation coefficient of 5 at home and of 3 in the foreign economy, 2 and 1.5 lower than under Nash, respectively. Under this policy, easier financial conditions result from the cooperation of the two countries, as both forgo some inflation stabilization relative to the Nash equilibrium. The home economy continues to bear a prominent role in easing financial conditions, but can stabilize domestic inflation enough to be better off relative to Nash.

Figure 12 plots outcomes for the home and foreign economies under the cooperative solutions and the Nash equilibrium, conditional on the same large global markup shock considered in optimal policy analysis. Under the optimal constrained cooperative solution—in which both countries are better off than in the Nash equilibrium— both countries are less aggressive in fighting inflation, moderating the rise in credit spreads both at home and abroad relative to Nash. The ability of both countries to simultaneously achieve better outcomes by coordinating is ultimately driven by two factors: First, reducing the extent of tightening of leverage constraints improves trade-offs for

both countries, as discussed in section 5.2. Second, individual central banks do not internalize the fact that the effects of their actions on global banks affect trade-offs in the foreign economy. Thus, when acting in concert in choosing an easier policy, they are able to improve trade-offs globally. As a result, both countries are able to benefit from noticeably smaller output declines compared to the Nash equilibrium while experiencing just slightly larger increases in inflation.

7   Conclusions

Global tightening events are associated with larger economic downturns, worse financial conditions, and a relatively muted decline in inflation, with a total impact on activity that is larger than the sum of the effects of individual interest rates hikes. Motivated by these events, we have developed a model where the amplification of synchronous tightening events works through its effects on the balance sheets of global financial intermediaries that face occasionally binding leverage constraints. The financial amplification of global tightening episodes is larger on output than inflation, thus worsening monetary policy trade-offs. Two key elements of the model are leverage constraints that bind only occasionally, and policy trade-offs that are worsened by such constraints. When global adverse shocks are small and the financial channel is not active, we find that there are no quantitative gains from coordination of monetary policy. However, when adverse shocks are large and the net worth of intermediaries is low, the financial channel becomes active, and we find larger gains from international monetary policy coordination.

Our analysis of policy coordination has restricted attention to "conventional" monetary policy, that is, policy conducted by setting the short-term nominal interest rate. Our model, however, can be easily extended to study "unconventional" monetary policies—such as direct interventions by central banks in financial markets—aimed at supporting credit flows when private intermediaries face binding leverage constraints (Gertler and Karadi, 2011). There is an interesting set of open questions related to the setting of these unconventional policies in the face of an inflation surge, on how these policies should interact with conventional rate-setting decisions, and on the scope for coordination of both types of policies across countries.[33] As a concrete example, the U.S. banking failures in March of 2023 followed the decline in banks' asset values due to higher interest rates, and prompted regulators to intervene swiftly to contain wider banking panics. What were the effects of these financial interventions on output and inflation in the U.S. and abroad? Did financial intervention affect the policy trade-offs involved in the fight against inflation? A version of our model that is extended to allow for unconventional policy intervention could be used to

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[33] Dedola et al. (2013) have made progress on the latter question by studying the gains from cooperation across countries in setting unconventional policies.

address these questions. A second set of open questions that our model might help shed light on concerns the role of U.S.-based global financial intermediaries in driving the "global financial cycle" (Miranda-Agrippino and Rey, 2022) and the "global dollar cycle" (Obstfeld and Zhou, 2023), and the implications of this role for optimal monetary policy in the U.S. and for the desirability of policy coordination.[34] We view these questions as highly interesting topics for future research.

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[34] Akinci et al. (2022) have shown that a model with U.S.-based financial intermediaries that operate globally is consistent with many of the facts on global asset prices, exchange rates, and capital flows emphasized in the aforementioned literature. Corsetti and Trezzi (2023) have made a case for monetary policy coordination based on the "dollar cycle."

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Table 1: Spillovers and Nonlinear Effects of Monetary Shocks

	(1) $\Delta GDP(t+8)$	(2) $\Delta GDP(t+8)$	(3) $\Delta GDP(t+8)$
Dummy Own Tightening	-0.96***	-0.50**	-0.56***
	(-5.09)	(-2.31)	(-2.59)
Dummy Foreign Tightening	-0.85***	-0.42**	-0.46***
	(-4.41)	(-2.57)	(-2.91)
Dummy Own × Foreign Tightening		-0.88***	
		(-3.22)	
Dummy Own × Foreign Tightening: Hi Growth			-0.27
			(-1.23)
Dummy Own × Foreign Tightening: Lo Growth			-1.63***
			(-4.09)
Observations	3,026	3,026	2,994
Fixed Effects	yes	yes	yes

Notes: This table shows the results of a regression of log quarterly GDP eight quarters ahead against a time-t dummy for contractionary monetary shocks at home or abroad.

t statistics in parentheses. ***, ** and * denote 1, 5 and 10 percent significance levels, respectively. Standard errors based on 500 wild bootstrap replications.

Table 2: Calibrated Parameter Values

Parameter	Symbol	Value	Target/Source
Country Size	$\mathcal{N}_H, \mathcal{N}_F$	1,3	Relative GDP share of United States
Discount Factor	β	0.9975	World Interest Rate =1%
CRRA coefficient	ρ	1	Standard
Inverse Frisch Elasticity	φ	1	Standard
Habit parameter	ι	0.8	Justiniano, Primiceri, and Tambalotti (2010)
Disutility of Labor	ψ	0.85	$L_h = L_f = 1$
Home Bias	ω_H, ω_F	0.85, 0.95	U.S. import share =15 % and $X_{hf} = 1$
Foreign deposits	D_F	9	Balanced trade in steady state
Trade Elasticity	θ	1	Standard
Capital Depreciation Rate	δ	0.025	Standard
Capital Share	α	0.33	Standard
Markup	μ	1.1	10% steady-state markup
Rotemberg costs	κ	300	Phillips Curve slope=0.03
Investment adjustment cost	γ_k	2	Justiniano, Primiceri, and Tambalotti (2010)
Taylor rule coefficient on inflation	φ_π	1.5	Standard
Taylor rule inertia	ρ_r	0.8	Standard
Share of capital held by households	γ_H, γ_F	0.67, 0.90	GFIs hold 33% of US capital, GFIs foreign asset share=0.25
GFIs survival rate	σ_b	0.95	Gertler and Kiyotaki (2015)
GFIs Subsidiary Leverage Constraint	λ	0.66	Leverage of GFIs subsidiaries =3
Households capital holding costs	χ	100	Global spreads rise 60bps with syncronous tightening
Agency problem parameters	θ_H, θ_F	0.1, 0.5	Ratio of foreign to home spread=1.5; Steady-state leverage=4.75
GFIs endowment	ξ	0.013	Equity 5% above constraint

Note: this table reports the calibration of our baseline model, see section 3 for additional details.

Figure 1: Global Tightening Episodes

Global Interest Rates

Share of Countries with Rising Interest Rates
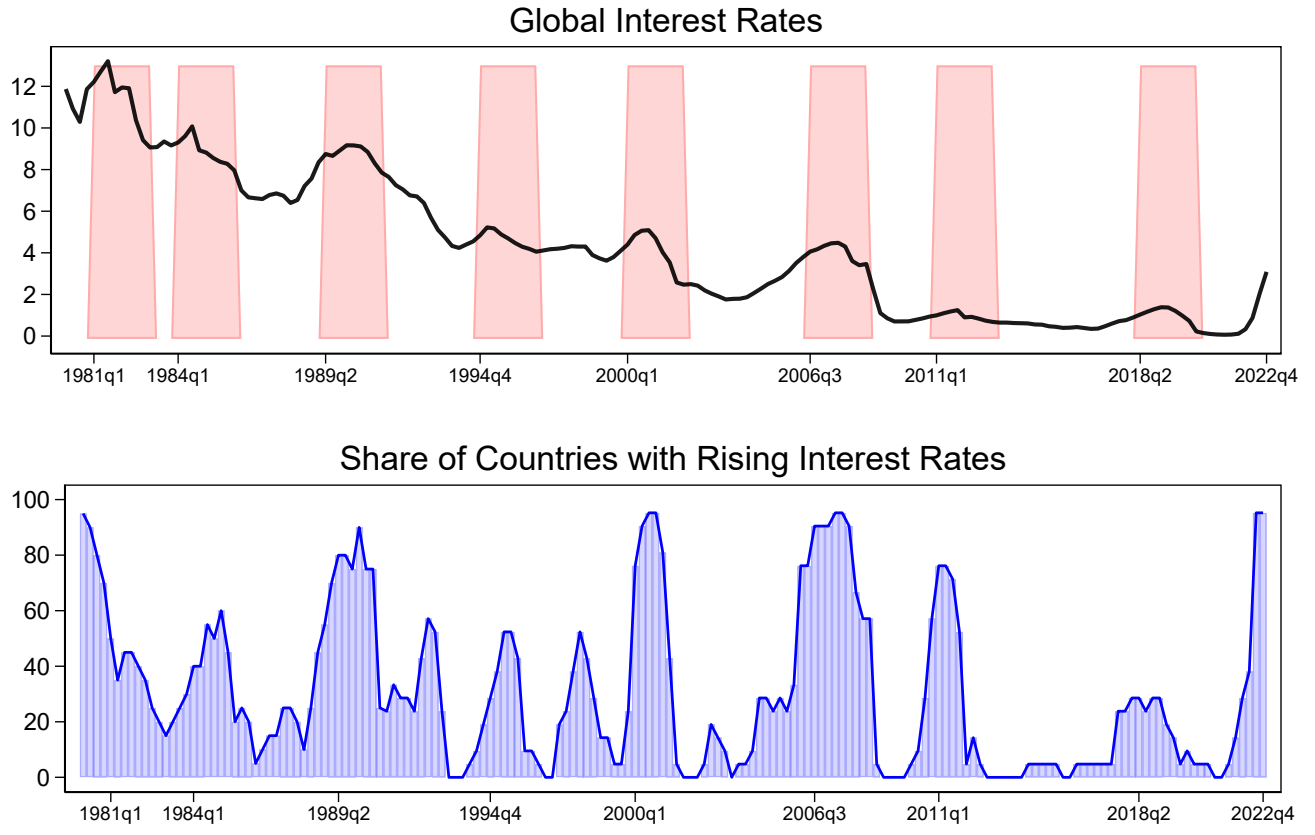
Note: Global Interest Rates with global tightening events denotes by the shaded areas. The bottom panel plots the share of countries in the sample with higher rates (by 25 basis points) than in the year before. Observations end in 2022q4.

Figure 2: Synchronous and Asynchronous Monetary Tightening Episodes
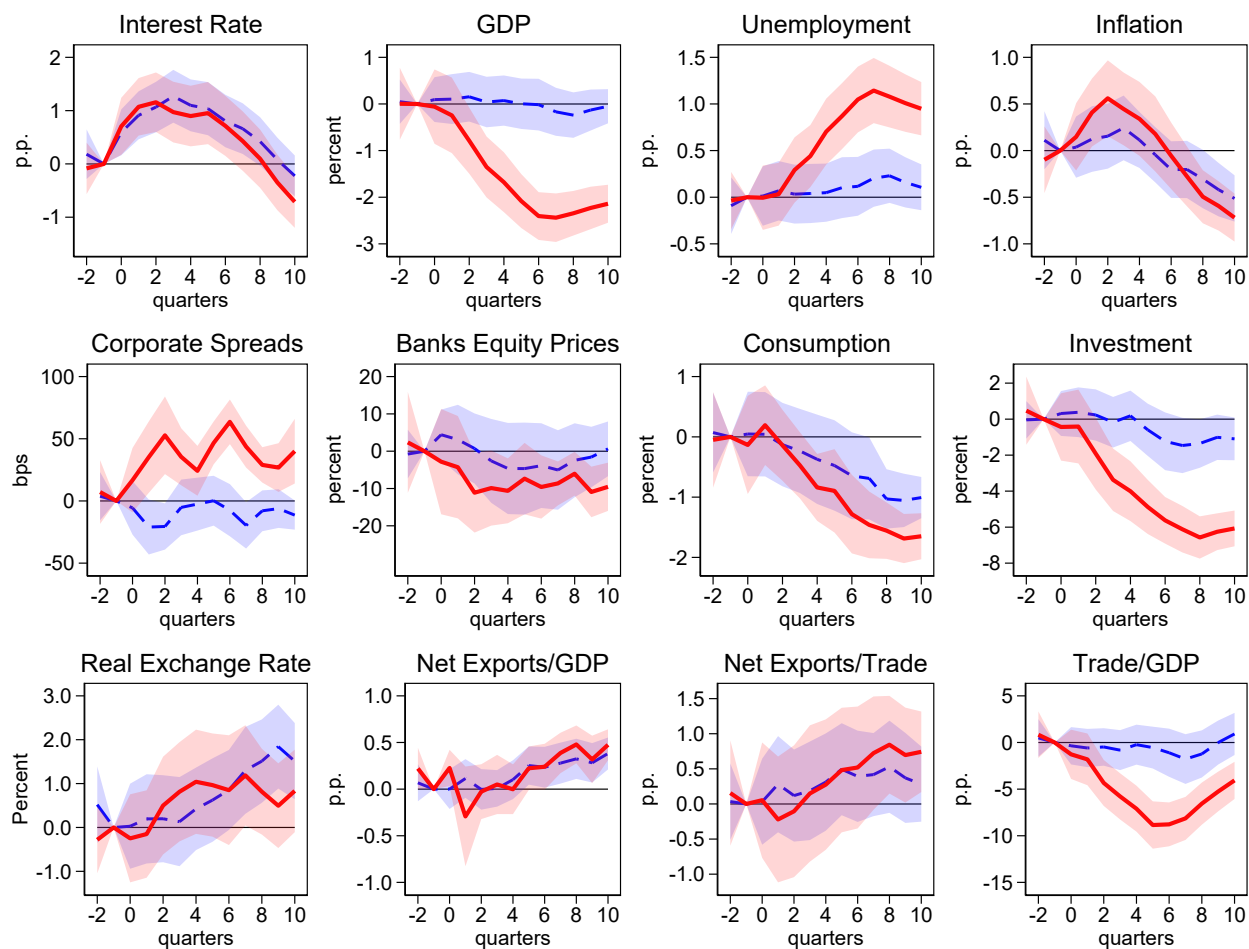
Note: Macroeconomic variables around interest rate tightening episodes. Each period is one quarter. Period 0 identifies events where a contractionary monetary shock takes place. Synchronous episodes occur during a global tightening window (solid lines). Asynchronous episodes occur outside a global tightening window (dashed lines). The responses are constructed using event-study regressions. The shaded regions show 70% confidence intervals.

Figure 3: International Financial Frictions in the Model
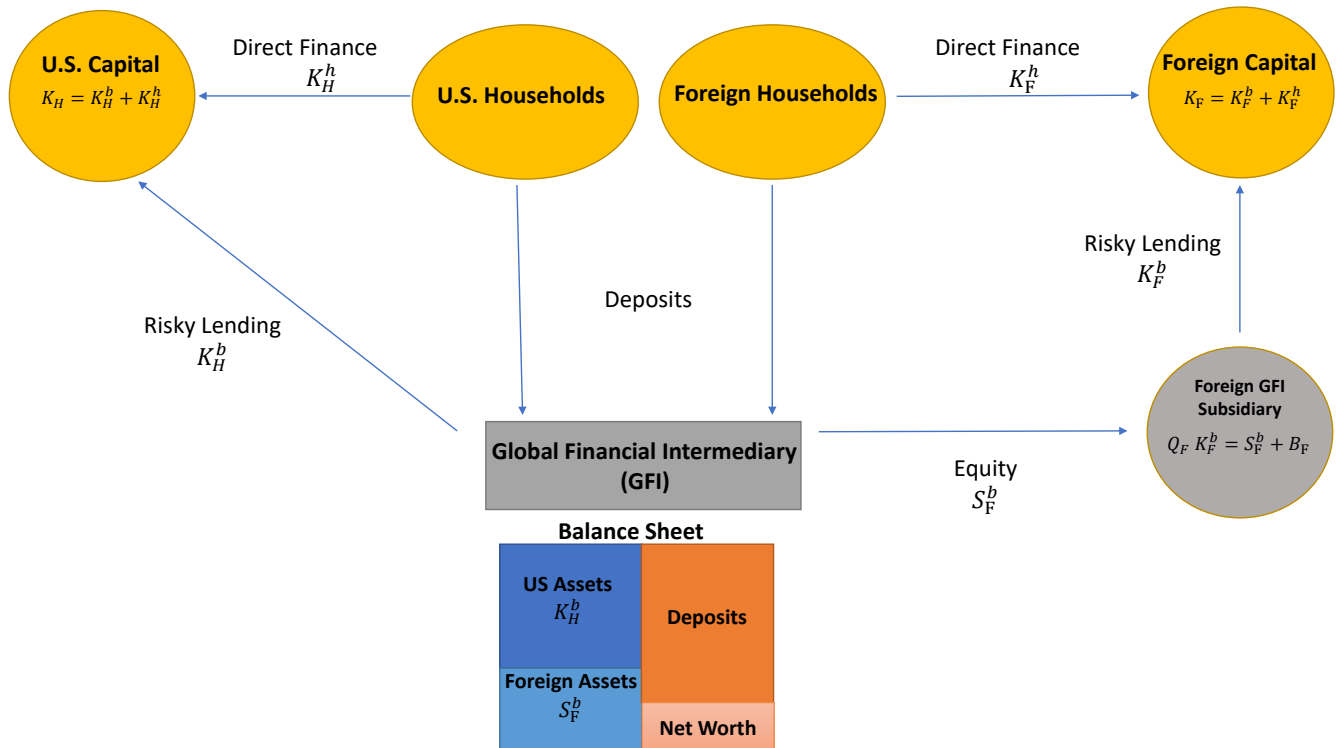
Note: Visual representation of global financial flows in the model. See Section 3 for additional details.

Figure 4: Nonlinear Financial Amplification of Monetary Policy Shocks of Different Sizes
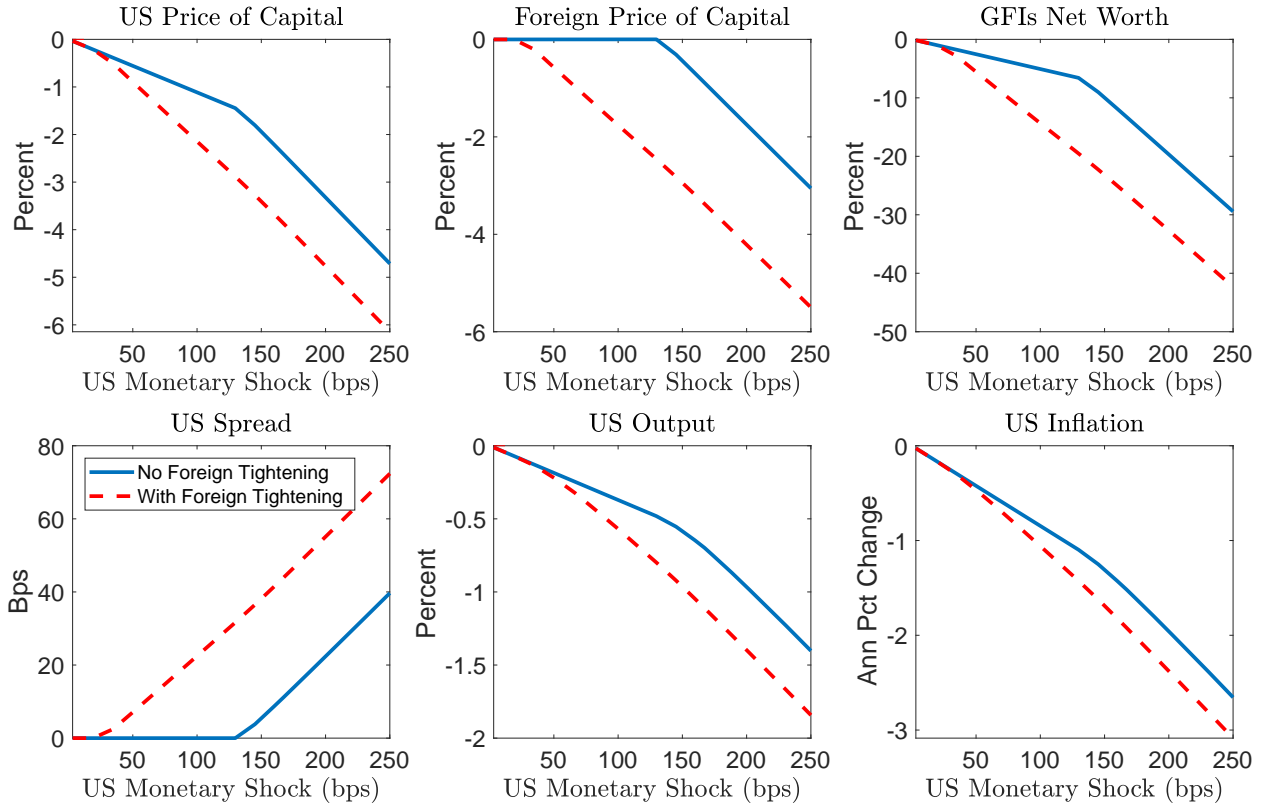
Note: The figure reports the impact impulse responses of selected model variables varying the size of a U.S. monetary policy tightening between 0 and 250 basis points. U.S. output denotes one-year ahead output growth, since output bottoms out after around one year due to the rigidities present in the model. The solid lines depict the effects under the assumption that the foreign policy rate follows the path implied by the policy rule. The dashed lines depict the effects of a U.S. tightening under the assumption that the path of the foreign policy rate is 150 basis points higher, on impact, than implied by the policy rule. This alternative path is calculated as the difference between the model simulation with both countries tightening and the one with only the foreign country tightening by 150 basis points.

Figure 5: Model Impulse Responses to a Monetary Tightening in the U.S. or Abroad
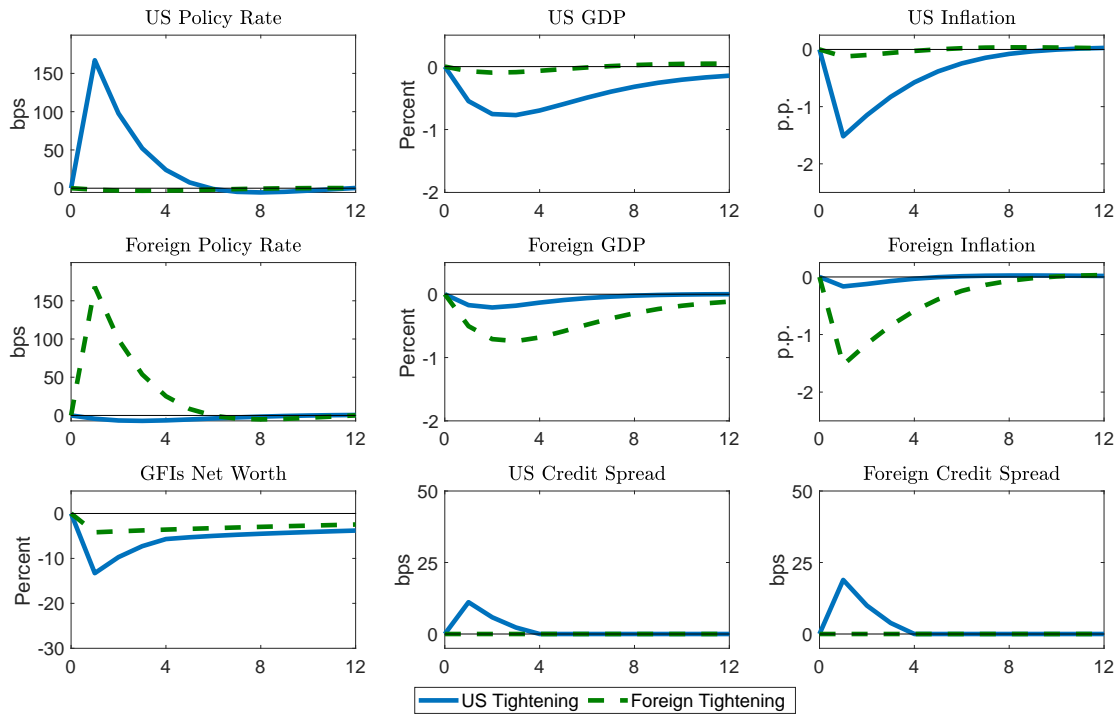
Note: The panels in the figure report the impulse responses of selected model variables following an exogenous monetary policy tightening happening in the U.S. (solid lines) or in the foreign economy (dashed lines). All variables are in deviation from steady state. Policy rates and inflation rates are annualized values. Spreads are computed over a 5-year horizon. Each period is one quarter.

Figure 6: Impulse Responses to a Joint Monetary Tightening

| U.S. Tightening | Foreign Tightening | Nonlinear Effect |
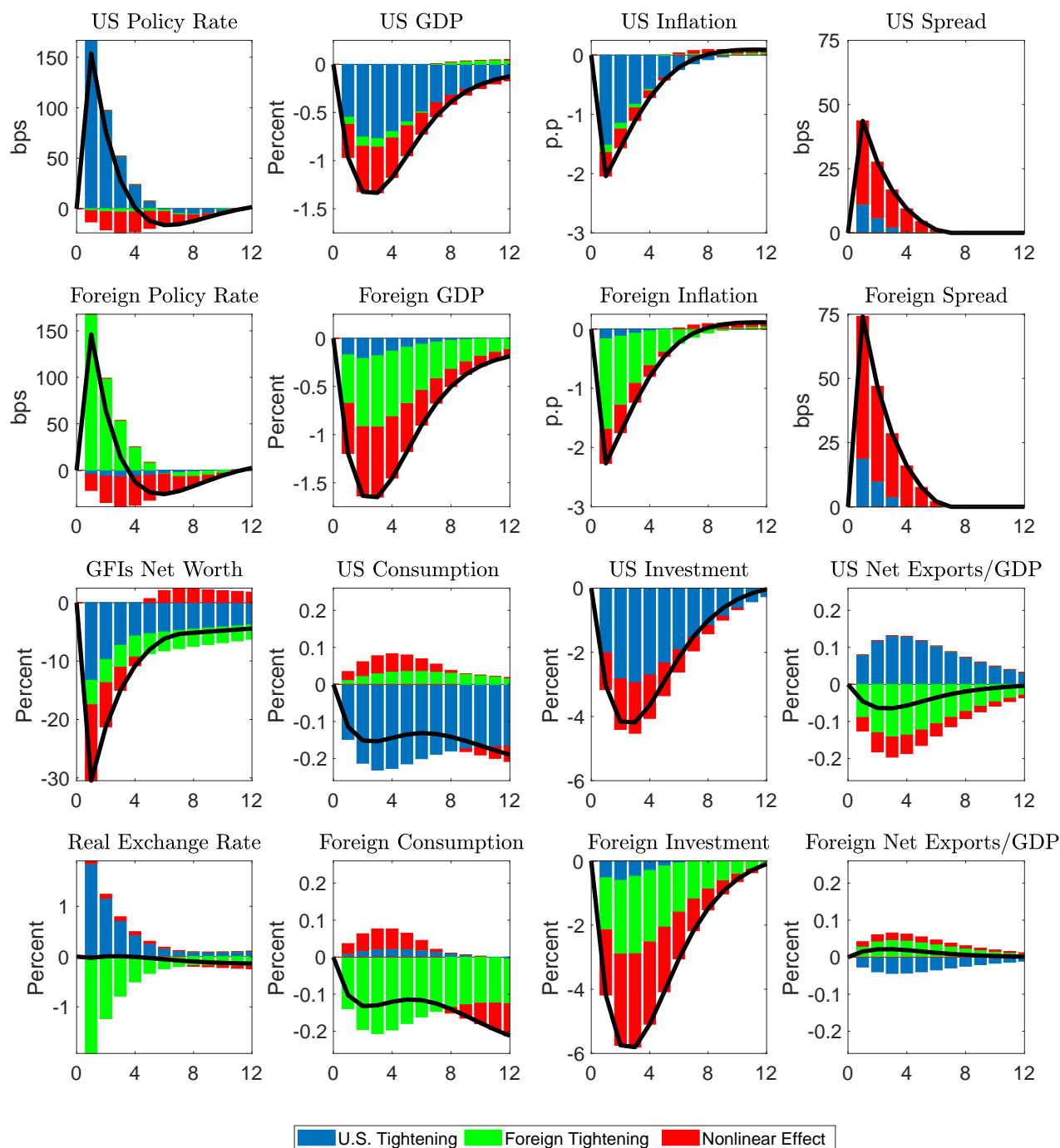
Note: The black lines in the figure report the impulse responses of selected model variables following a 160 basis points exogenous monetary policy tightening that happens jointly in the U.S. and and the foreign economy. To illustrate the amplification, we report the effects of a monetary shock, of approximately 150 basis points, happening in isolation either in the U.S. (blue bars) or in the foreign economy (green bars). Thus, the red bars measure the size of the nonlinear amplification of a joint tightening relative to the sum of the two tightening shocks happening in isolation. Each period is one quarter. The variables are reported in deviation from their steady state. Policy rates and inflation rates are annualized values. Spreads are computed over a 5-year horizon. Each period is one quarter.

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Figure 7: Policy Trade-offs in Response to Monetary and Markup Shocks
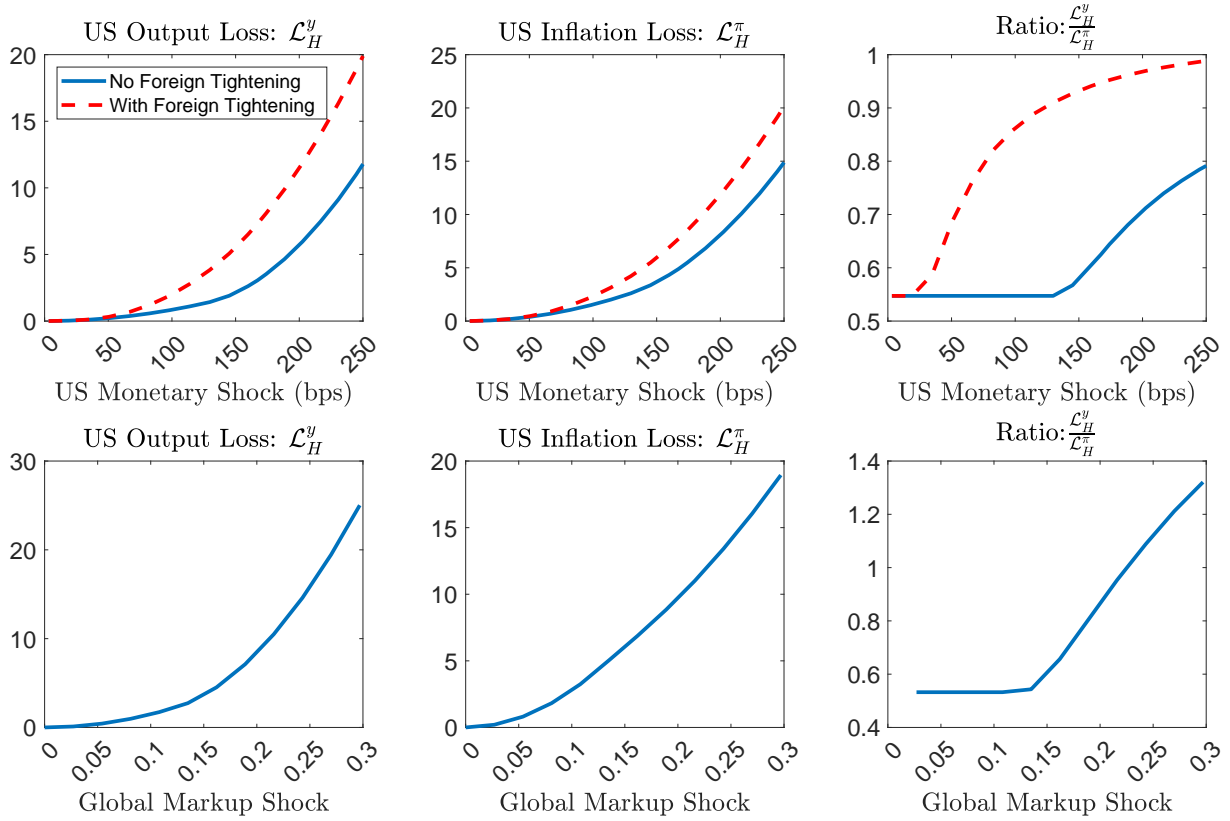
Note: The panels plot output and inflation losses as defined in equation (47), as a function of the size of the shocks in the x-axis. The "ratio" panel is the ratio of the output loss over the inflation loss. The top row shows losses in response to U.S. policy shocks. The bottom row shows losses in response to global markup shocks.

Figure 8: Model Impulse Responses to a Global Markup Shock, U.S. Variables
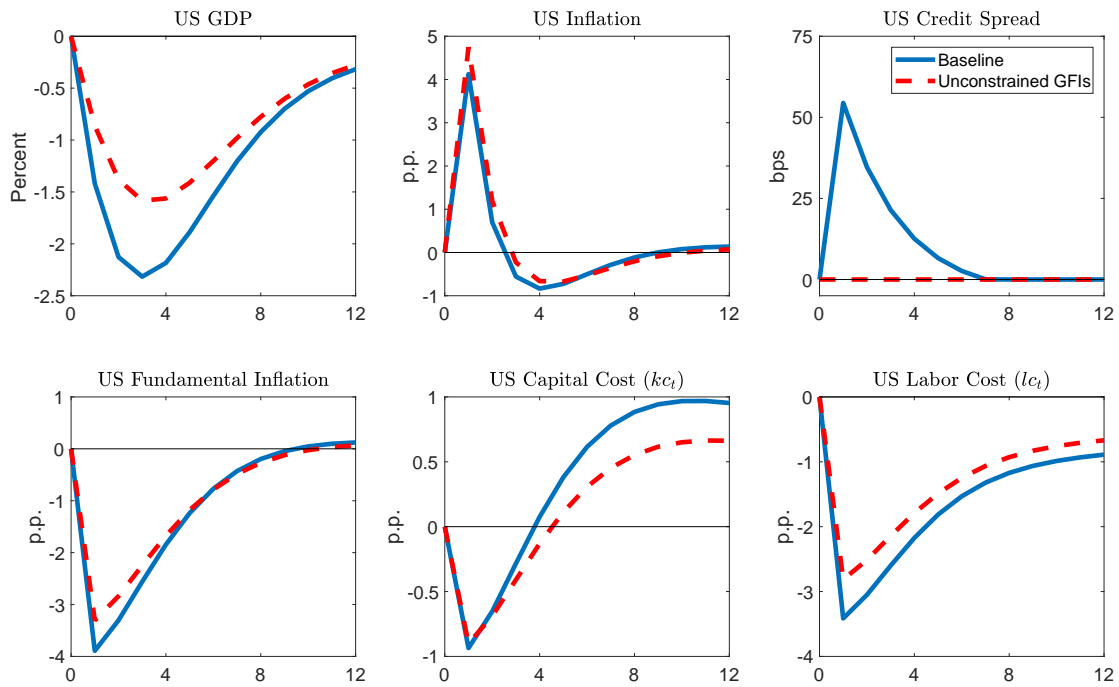
Note: The panels show the impulse responses to a global markup shock sized to raise global inflation by about 4 percent. The solid lines depict responses for the baseline model. The dashed lines depict responses under the assumption that agency frictions are not present. All variables are in deviation from steady state. Each period is one quarter.

Figure 9: Nash equilibria and the size of the inflationary shock
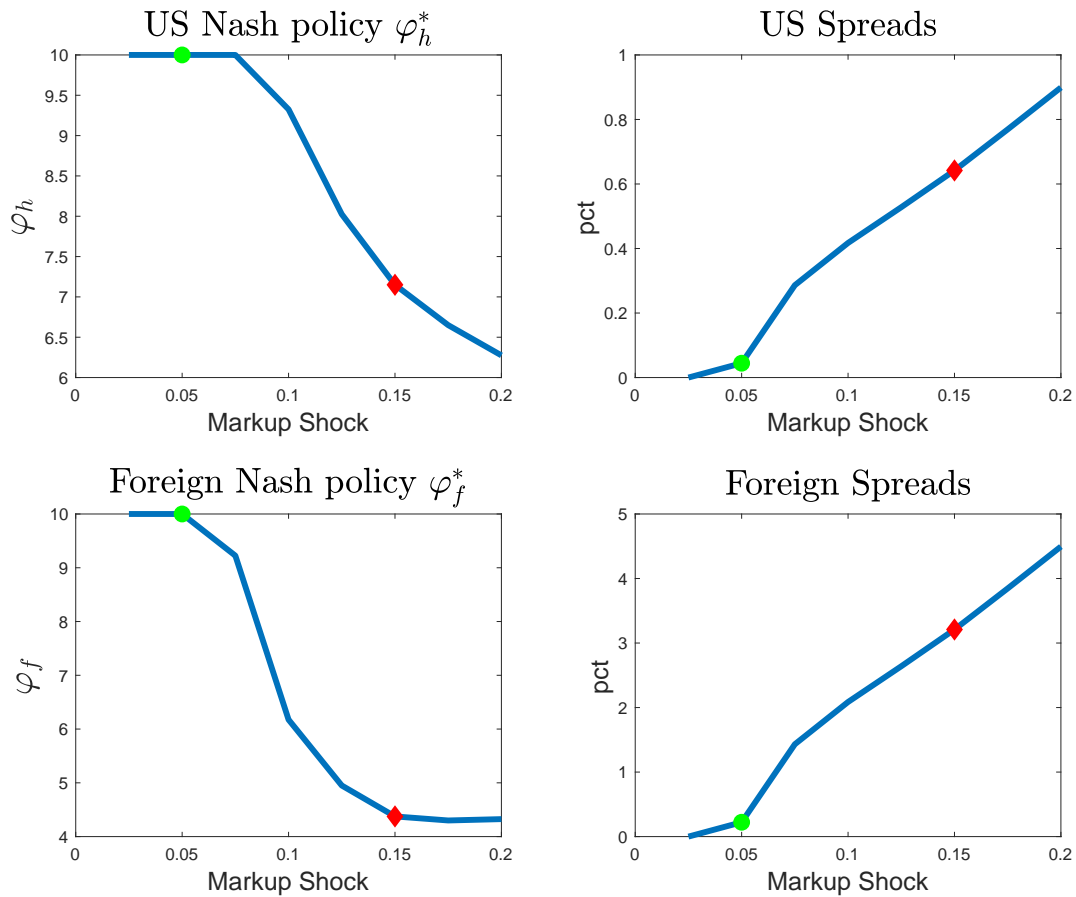
Note: The figure plots the response coefficient to inflation in the Taylor rule under the Nash policy and credit spreads for the U.S./home economy (top row) and the foreign economy (bottom row), as function of the size of the global markup shock. The green circle highlights the case of small shock analyzed further in the top row Figure of 10. The red diamond highlights the case of small shock analyzed further in the bottom row of Figure 10 and in Figures 11 and 12.

Figure 10: Strategic Dependence and Financial Spillovers for Small and Large Markup Shocks
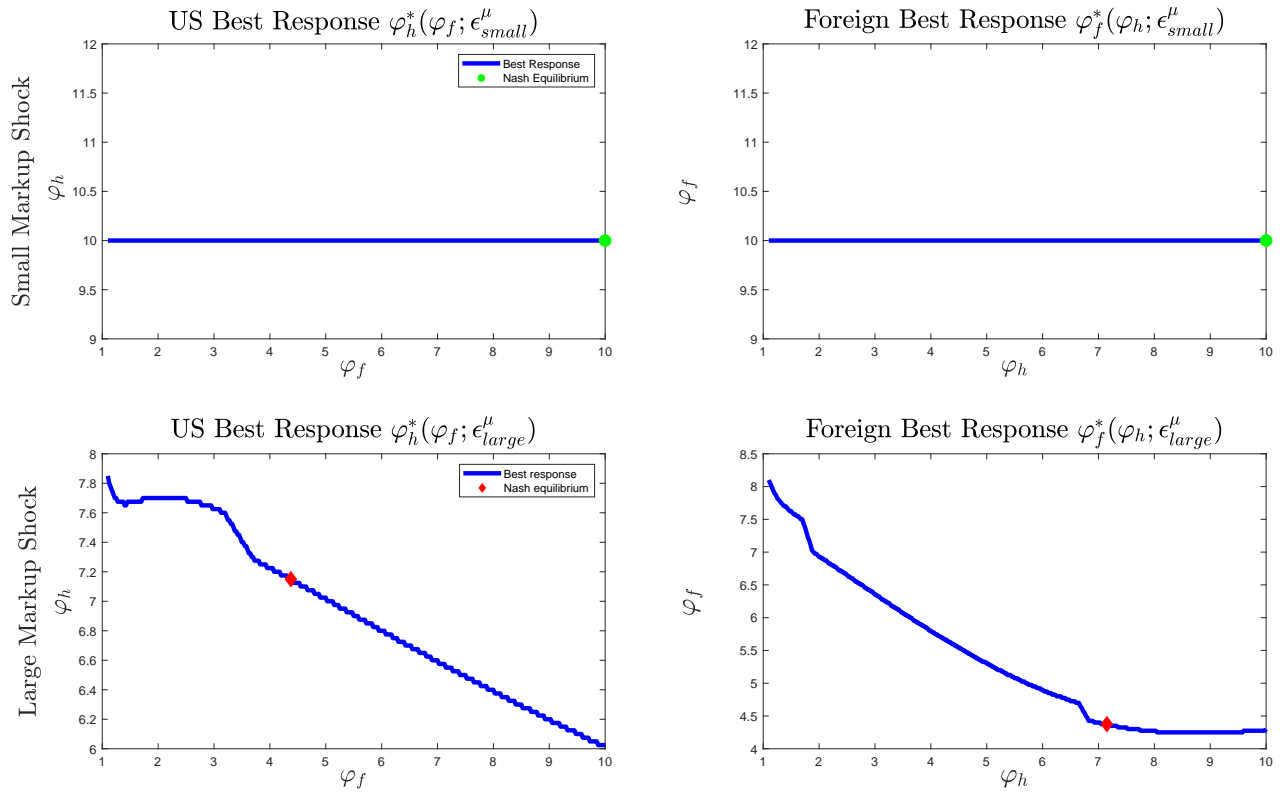
Note: The figure plots best response functions of the home and foreign central banks. The top row illustrates strategic independence of policy actions, arising when markup shocks are small. The bottom row illustrates strategic interactions of policy actions, arising when markup shocks are large.

Figure 11: Coordination and Pareto-Improving Policies with Global Inflation Surge
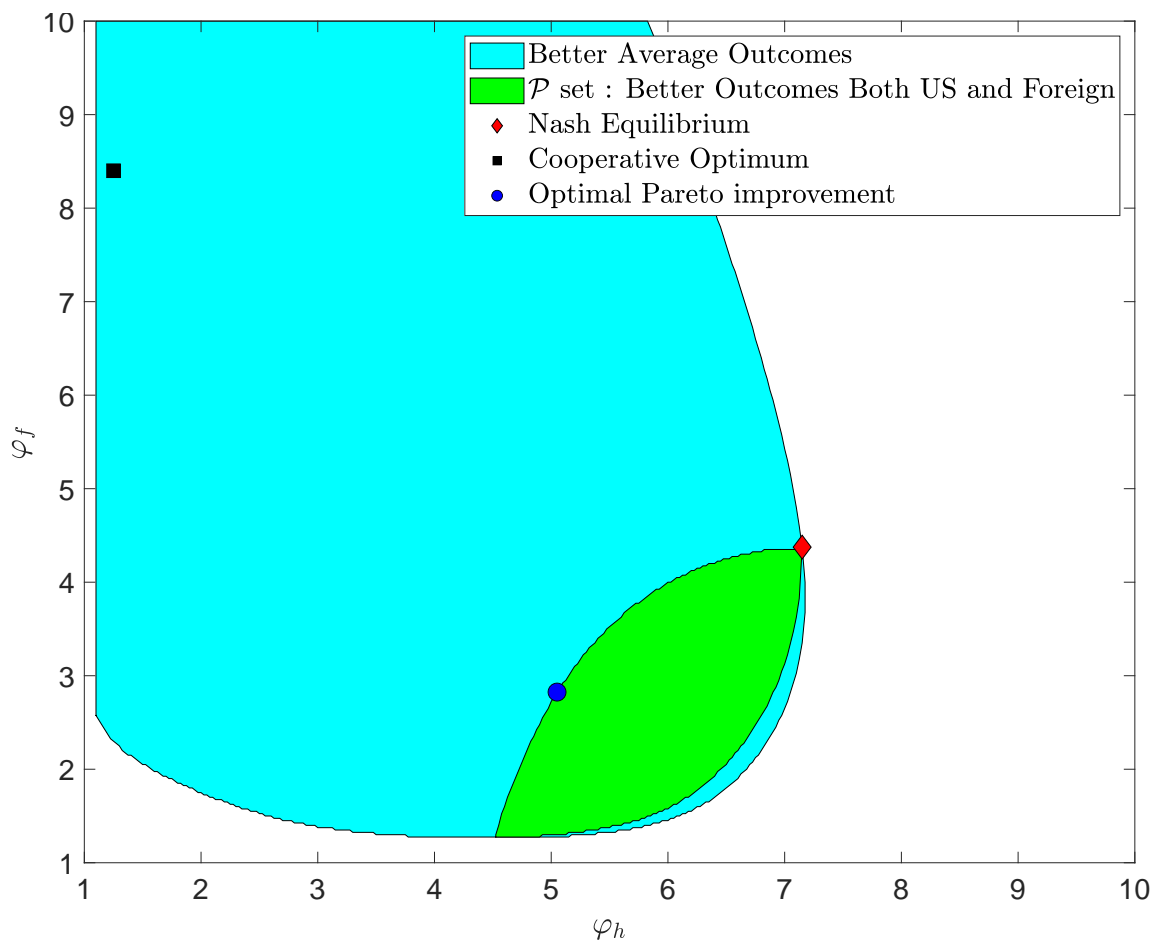
Note: The x and y-axis denote the response coefficients to inflation in the Taylor rule for the home and foreign economy, respectively. The shaded cyan area reports the combination of response coefficients that result in a smaller global loss for the home and foreign economies relative to the Nash equilibrium, when losses are evaluated according to the loss function in equation 6.3 and the markup shock is sized at 0.15, as in the case of the red diamond of Figure 9. The shaded green area reports the combination of response coefficients that improve upon the Nash equilibrium for both countries simultaneously, thus resulting in a Pareto improvement. Outside of the cyan and green area, all other combinations of response coefficients deliver worse average outcomes than under Nash.

Figure 12: Model Impulse Responses to Large Markup Shock under Alternative Policies
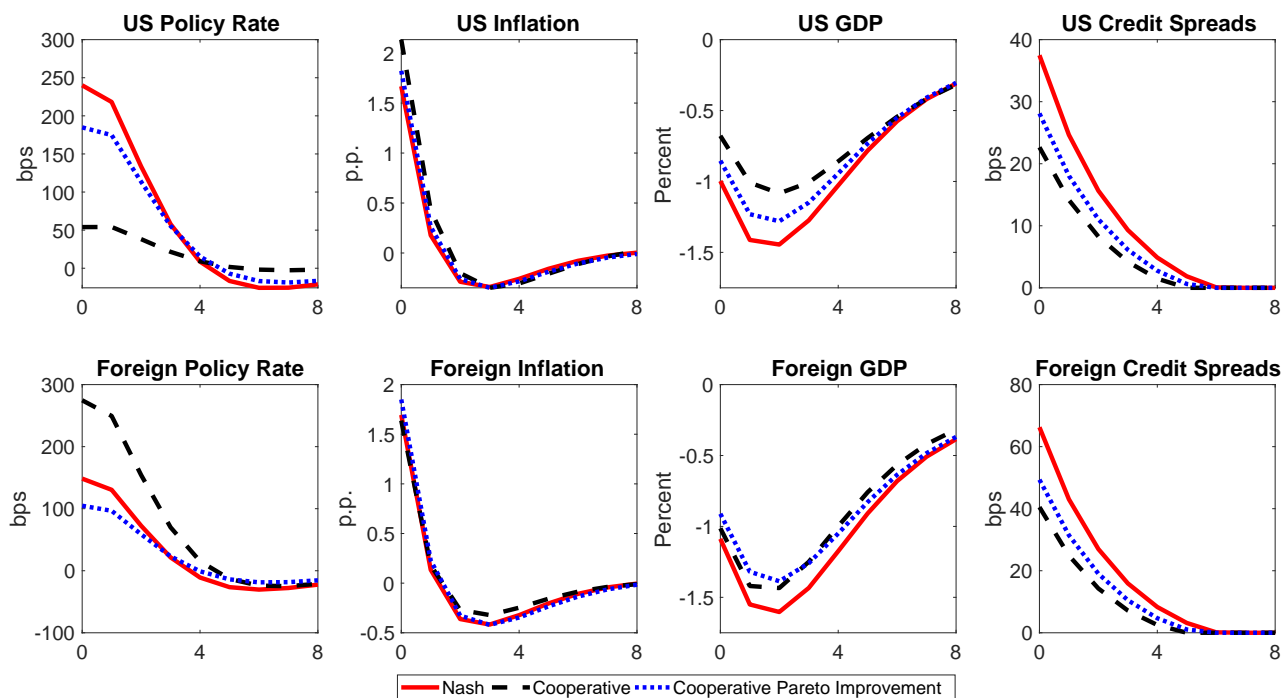
Note: The panels plot the impulse responses of several variables following a large markup shock under the Nash equilibrium (solid lines), the cooperative optimum (dashed lines), and the cooperative Pareto improvement (dotted lines). Policy rates and inflation rates are annualized values. Spreads are computed over a 5-year horizon. Each period is one quarter.

Online Appendix for

The International Spillovers of Synchronous Monetary Tightening[*]

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Andrea Prestipino, and Albert Queralto

Appendix

A   Data Sources

The sample runs from 1980Q1 through 2019Q4. Due to missing data coverage for some countries, the panel is unbalanced, with the initial period varying by country. The sample includes 21 advanced economies, and, for the specification with emerging economies, 9 additional emerging economies. The list of countries and data coverage for each country/variable is summarized in Table A.1. To create world aggregates for any variable, we weigh country-specific variables using nominal GDP (expressed in USD) from the World Bank's World Development Indicators.

Below, we discuss data construction for advanced economies.

- GDP is taken from each country's national statistical office, through Haver, and is quadratically detrended separately for each country.

- The unemployment rate is taken in each country from the national statistical offices through Haver, the OECD statistical database, or FRED, and is linearly detrended by country. For Finland, the original series (lrhuttttfim156s@FRED) was available starting in 1988Q1. The series was extended back to 1980Q1 using the predicted values of an auxiliary regression of the unemployment rate on current and four lags of the unemployment level (finurtotqdsmei@FRED), which is available since 1960. For Norway, we use the same procedure. The original series starts in 1989Q1. The unemployment level (lmunrlttnom647s@FRED) goes back to 1960. For Italy, the Netherlands, and Spain, quarterly data on the unemployment rate start in 1983Q1, 1983Q1, and 1986Q2, respectively. They were extended back to 1980 using interpolated values from annual unemployment data going back to 1960. The procedure is as follows. First, we convert the annual unemployment levels to quarterly by assigning the annual value to each quarter. Second, at the quarterly frequency, we take 5-period centered moving averages. Third, wherever the original quarterly unemployment data are missing, we fill it in with the moving average plus the first value of the original unemployment minus the value of the smoothed unemployment in that same period.

- For interest rates, we use the following sources, in order of first preference to last preference: the central bank interest rate from the IMF International Financial Statistics (IFS), the treasury bill rate from the IFS, the short-term interest rate from the OECD Main Economic Indicators, and the overnight interest rate from the OECD Main Economic Indicators.

  Australia: 1969Q3-2019Q4 from IFS/central bank, then extended back until 1968Q1 by OECD/short-term.

  Austria: 1960Q1-1998Q4 from IFS/central bank, then extended forward through 2019Q4 by OECD/short-term.

Belgium: 1960Q1-1998Q4 from IFS/central bank, then extended forward through 2017Q4 by IFS/treasury bill, then through 2019Q4 by OECD/short-term.

Canada: 1992Q4-2019Q4 from IFS/central bank, then extended back until 1960Q1 by IFS/treasury bill.

Denmark: 1960Q1-2019Q4 from IFS/central bank.

Finland: 1960Q1-1998Q4, and 2004Q1-2005Q4 from IFS/central bank, then the gap from 1999Q1-2003Q4 and forward through 2019Q4 by OECD/short-term.

France: 1970Q1-2017Q2 from IFS/treasury bill, then extended forward through 2019Q4 by OECD/short-term, then extended backward until 1960Q1 by OECD/overnight.

Germany: 1960Q1-1998Q4 from IFS/central bank, then extended forward through 2007Q3 by IFS/treasury bill, then extended forward through 2019Q4 by OECD/short-term.

Ireland: 1960Q1-1998Q4 from IFS/central bank, then extended forward by one quarter (1999Q1) by IFS/treasury bill, then extended forward through 2019Q4 by OECD/short-term.

Italy: 1964Q1-1998Q4 from IFS/central bank, then extended forward through 2019Q4 by IFS/treasury bill.

Japan: 1960Q1-2015Q2 from IFS/central bank, then extended forward through 2017Q2 by IFS/treasury bill, then extended forward through 2019Q4 by OECD/short-term.

Netherlands: 1964Q1-1993Q4 from IFS/central bank, then extended forward through 2019Q4 by OECD/short-term.

New Zealand: 1999Q1-2019Q4 from IFS/central bank, then extended back until 1978Q1 by IFS/treasury bill, then back again until 1974Q1 by OECD/short-term.

Norway: 1964Q1-2017Q2 from IFS/central bank, then extended forward through 2019Q4 by OECD/short-term.

Poland: 1998Q1-2013Q2 from IFS/central bank, then extended backward until 1992Q1 by IFS/treasury bill, back again until 1991Q2 by OECD/short-term, and back again until 1990Q1 by OECD/overnight. Extended forward through 2019Q4 by OECD/short-term, with IFS/treasury bill data in 2016Q1 and 2017Q1.

Portugal: 1960Q1-1998Q4 from IFS/central bank, then 1991Q1 from IFS/treasury bill, then forward through 2019Q4 by OECD/short-term.

Spain: 1964Q1-1998Q4 from IFS/central bank, then extended forward through 2019Q4 by IFS/treasury bill.

Sweden: 2002Q3-2017Q2 from IFS/central bank, then extended back until 1960Q1 by IFS/treasury bill, and then extended forward through 2019Q4 by OECD/short-term.

Switzerland: 2000Q1-2019Q2 from IFS/central bank, then extended forward through 2019Q4 by OECD/short-term. Extended backward until 1980Q1 by IFS/treasury bill, then back to 1974Q1 by OECD/short-term, then back to 1972Q1 by OECD/overnight.

United Kingdom: 1960Q1-2016Q3 from IFS/central bank, then extended forward through 2019Q4 by OECD/short-term.

United States: 1982Q3-2019Q4 from IFS/central bank, then extended backward until 1960Q1 by IFS/treasury bill.

- Inflation is measured by the year-to-year change in quarterly core CPI (or core PCE) constructed as follows. We use core CPI from each country's national statistical offices, provided by Haver. For some countries, we extend the data back with inflation data from the Global Database of Inflation from the World Bank. Specifically, we fill in 1972Q2-1987Q3 for Australia, 1971Q1-1990Q4 for Austria, 1977Q3-1991Q4 for Belgium, 1971Q1- 1990Q4 for Finland, 1971Q1-1990Q4 for Italy, 1971Q1-1971Q4 for Japan, 1971Q1-1990Q4 for the Netherlands, 1971Q1-1989Q3 for New Zealand, 1977Q1-1986Q3 for Spain, 1971Q1-1990Q4 for Sweden, and 1971Q1-1988Q4 for the UK. For some other countries, we extend the data back using the coefficients of a regression of core inflation on contemporaneous values and four lags of headline inflation and oil price inflation, two variables which were available over a longer sample. Specifically, we fill in 1962Q2-1990Q4 for France, 1962Q2-1994Q2 for Switzerland, 1962Q2-1995Q4 for Norway, and 1968Q1-1990Q4 for Denmark.

- Measures of credit spreads are not available for all countries. For each country, we calculate spreads as follows.

  Canada: 5-year BBB-rated industrial yield minus 5-year government bond yield, from Bloomberg.

  France: From 1991Q1 onward, we use corporate spreads from Gilchrist and Mojon (2018). We supplement this with the difference between French corporate bond yields and 10-year German government bond yields, reaching back until 1983Q4. The supplementary data comes from Global Financial Data (GFD).

  Germany: Corporate bond yields minus 10-year government bond yields, from GFD.

  Italy: Italian corporate bond yields minus 10-year German government bond yields, from GFD.

  Japan: Corporate bond yields minus 10-year government bond yields, from GFD.

  Spain: Corporate spreads from Gilchrist and Mojon (2018).

  Switzerland: Corporate bond yield minus 10-year government bond yield, from GFD.

  UK: Corporate bond yields minus 10-year government bond yields, from GFD.

  USA: Corporate bond yields minus 10-year government bond yields, from GFD.

- Net worth of global banks is available for Canada, France, Germany, Japan, Spain, Switzerland, United Kingdom and the United States. Net worth is constructed using a weighted stock price index of banks in each country that are global, using the definition of global banks in Acalin (2022). Specifically, the U.S. bank net worth is the weighted stock market index (using market capitalization share as a weight) of JPMorgan, Citi, Wells Fargo, Bank of America, Goldman Sachs, Morgan Stanley; the French index is the weighted index of BNP Paribas and Societe Generale; the UK index is the weighed index of HSBC, Barclays, NatWest, Lloyd's; the Japan index is the weighted index of Sumitomo Mitsui FG and Mitsubishi UFJ FG. The German index is the Deutsche Bank price index; the Spain index is the weighted index of Banco Santander and BBVA; the Switzerland index is the Credit Suisse price index; and the Canada index is the weighted index of Royal Bank of Canada and Toronto Dominion.

- In each country, the construction of the monetary shocks is based on a Taylor rule regression in which the real exchange rate and oil prices are used as additional controls. The real exchange rate is expressed in logs and is the effective measure described in Darvas (2012) and is available online. Oil prices are expressed in one year percent changes and measured by the WTI Spot dollar price.

- The last six panels of Figure 2 show the responses to tightening episodes of real consumption, real private investment, the real exchange rate, (real) net exports divided by trend GDP, (real) net exports divided by exports plus imports, and exports plus imports divided by trend GDP. Consumption and investment are log detrended by country using a quadratic trend. Real net exports are detrended by country using a quadratic trend. In general, we have fewer observations in total (about 10 percent less) in our panel for the components of GDP than we have for GDP.

For emerging economies, we followed a similar approach, with the following exceptions:

- We use total inflation instead of core inflation.

- We use dollar corporate spreads for Chile and Mexico and local currency spreads for Korea, both from the Intercontinental Exchange (ICE). For the Philippines, we use sovereign spreads from JPMorgan. Finally, we use corporate blended spreads from JPMorgan for Hong Kong, Indonesia, Israel, South Africa, and Taiwan.

- In some cases, unemployment was not available in the early part of the sample. We use the predicted values of a regression of unemployment on four lags of GDP to fill in the missing data by country.

Table A.1: Data Coverage

| Country	Unempl.	Inflation	Int.Rate	GDP	Spreads	BankEq.
Australia	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4		
Austria	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4		
Belgium	1983q1 2019q4	1983q1 2019q4	1983q1 2019q4	1980q1 2019q4		
Canada	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1992q1 2019q4	1980q1 2019q4
Denmark	1983q1 2019q4	1983q1 2019q4	1983q1 2019q4	1980q1 2019q4		
Finland	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4		
France	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1983q4 2019q4	1992q1 2019q4
Germany	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1992q1 2019q4
Ireland	1984q1 2019q4	1984q1 2019q4	1984q1 2019q4	1980q1 2019q4		
Italy	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	
Japan	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	2001q2 2019q4
Netherlands	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4		
New Zealand	1986q1 2019q4	1986q1 2019q4	1986q1 2019q4	1980q1 2019q4		
Norway	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4		
Poland	1999q1 2019q4	1999q1 2019q4	1999q1 2019q4	1995q1 2019q4		
Portugal	1983q1 2019q4	1983q1 2019q4	1983q1 2019q4	1980q1 2019q4		
Spain	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1999q1 2019q4	1980q4 2019q4
Sweden	1983q1 2019q4	1983q1 2019q4	1983q1 2019q4	1980q1 2019q4		
Switzerland	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1997q2 2019q4	1992q1 2019q4
United Kingdom	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4
United States	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4
Chile	1995q2 2019q4	1995q2 2019q4	1995q2 2019q4	1986q1 2019q4	1998q4 2019q4	
Hong Kong	1992q2 2019q4	1992q2 2019q4	1992q2 2019q4	1990q1 2019q4	2001q4 2019q4	
Indonesia	1990q1 2019q4	1990q1 2019q4	1990q1 2019q4	1983q1 2019q4	2001q4 2019q4	
Israel	1995q1 2019q4	1995q1 2019q4	1995q1 2019q4	1995q1 2019q4	2001q4 2019q4	
Korea	1991q1 2019q4	1991q1 2019q4	1991q1 2019q4	1980q1 2019q4	1999q1 2019q4	
Mexico	1987q1 2019q4	1987q1 2019q4	1987q1 2019q4	1980q1 2019q4	1998q4 2019q4	
Philippines	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1981q1 2019q4	1993q4 2019q4	
South Africa	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	2001q4 2019q4	
Taiwan	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	1980q1 2019q4	2005q2 2019q4	

Data Coverage for the variables shown in the event-study analysis of Figure 2. The top group denotes advanced economies, the bottom group emerging economies.

Effects of Domestic Tightening Events

Note: How the effects of tight monetary policy at home depend on foreign stance and economic conditions.

Figure A.2: Behavior around Tightening Episodes: HP-filtered Criterion for Global Tightening
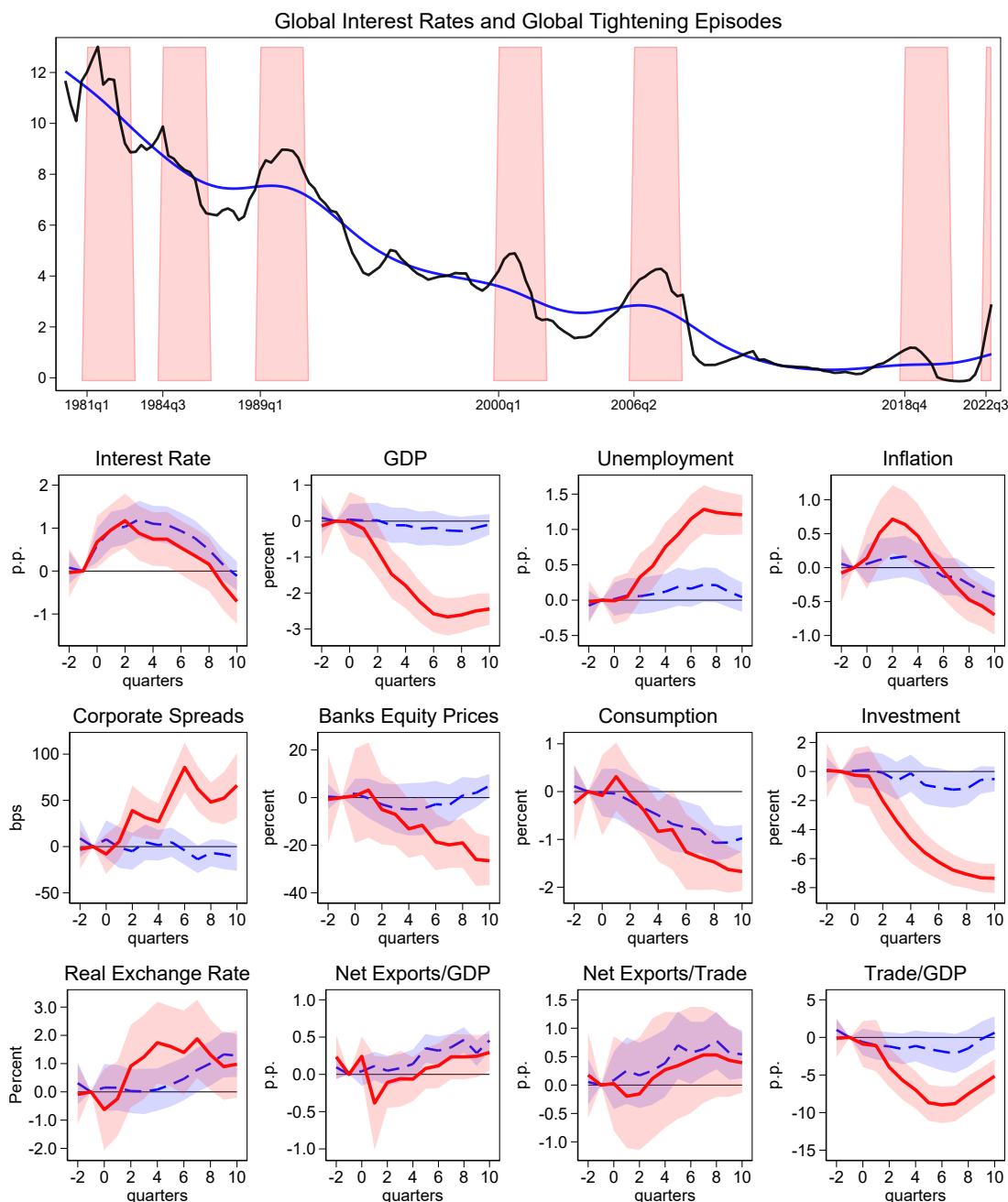
Note: The top chart plots global interest rates and global tightening episodes in the shaded areas. Global tightening episodes are assumed to start when the HP-filtered global interest rate (the difference between the global interest rate—black line—and its trend—blue line, estimated using a smoothing parameter of 1,600—) exceeds 0.5 percent, and are assumed to last no more than eight quarters. This criterion identifies seven global tightening events starting in 1981q1, 1984q3, 1989q1, 2000q1, 2006q2, 2018q4, 2022q3.

The panels at the bottom show the event-study analysis around tightening episodes constructed using HP-filtered criterion described above. Synchronous episodes are in red and asynchronous ones are blue. The lines are constructed using event-study regressions. The shaded regions show 70% confidence intervals.
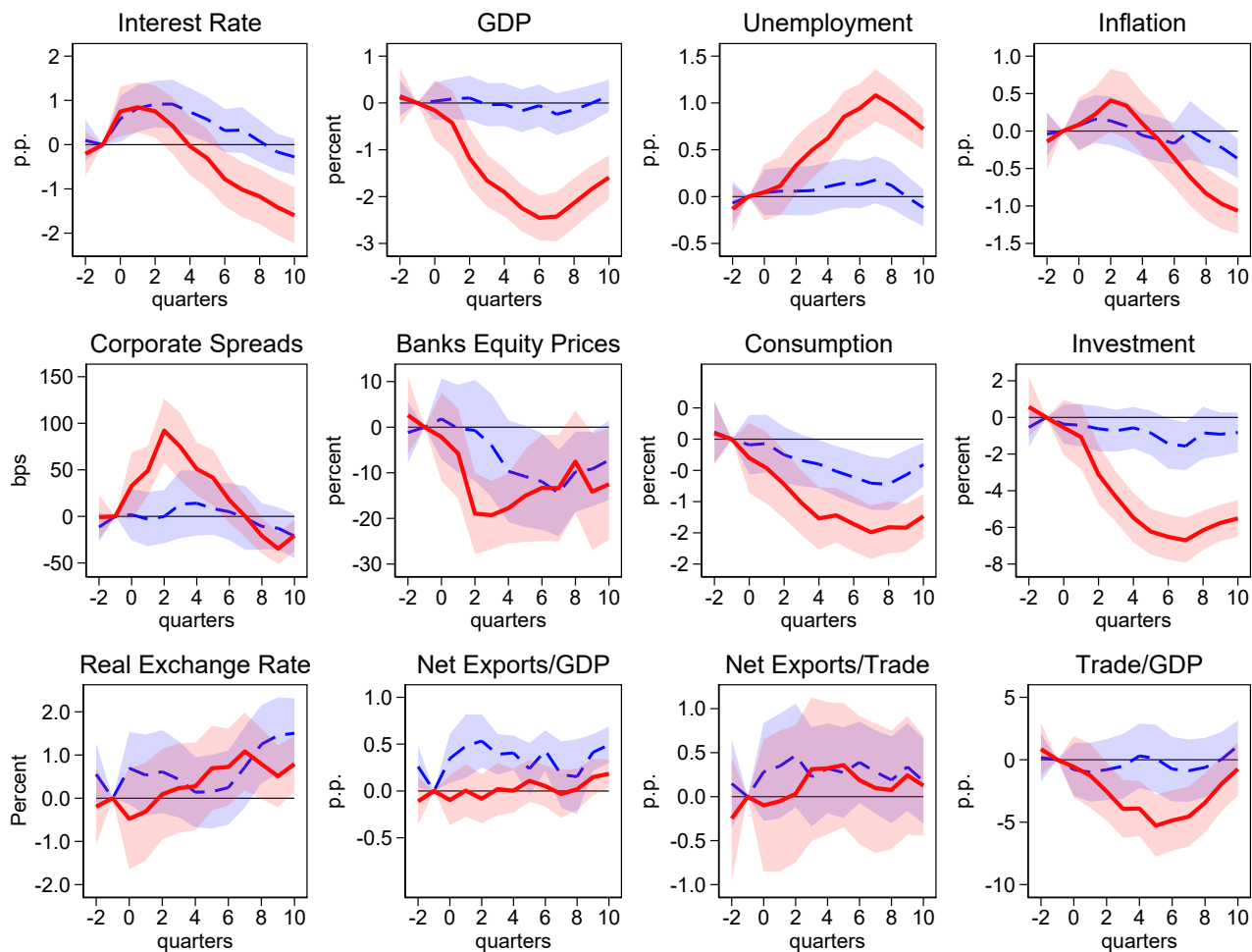
Figure A.3: Behavior around Tightening Episodes: Sample Including Advanced and Emerging Economies
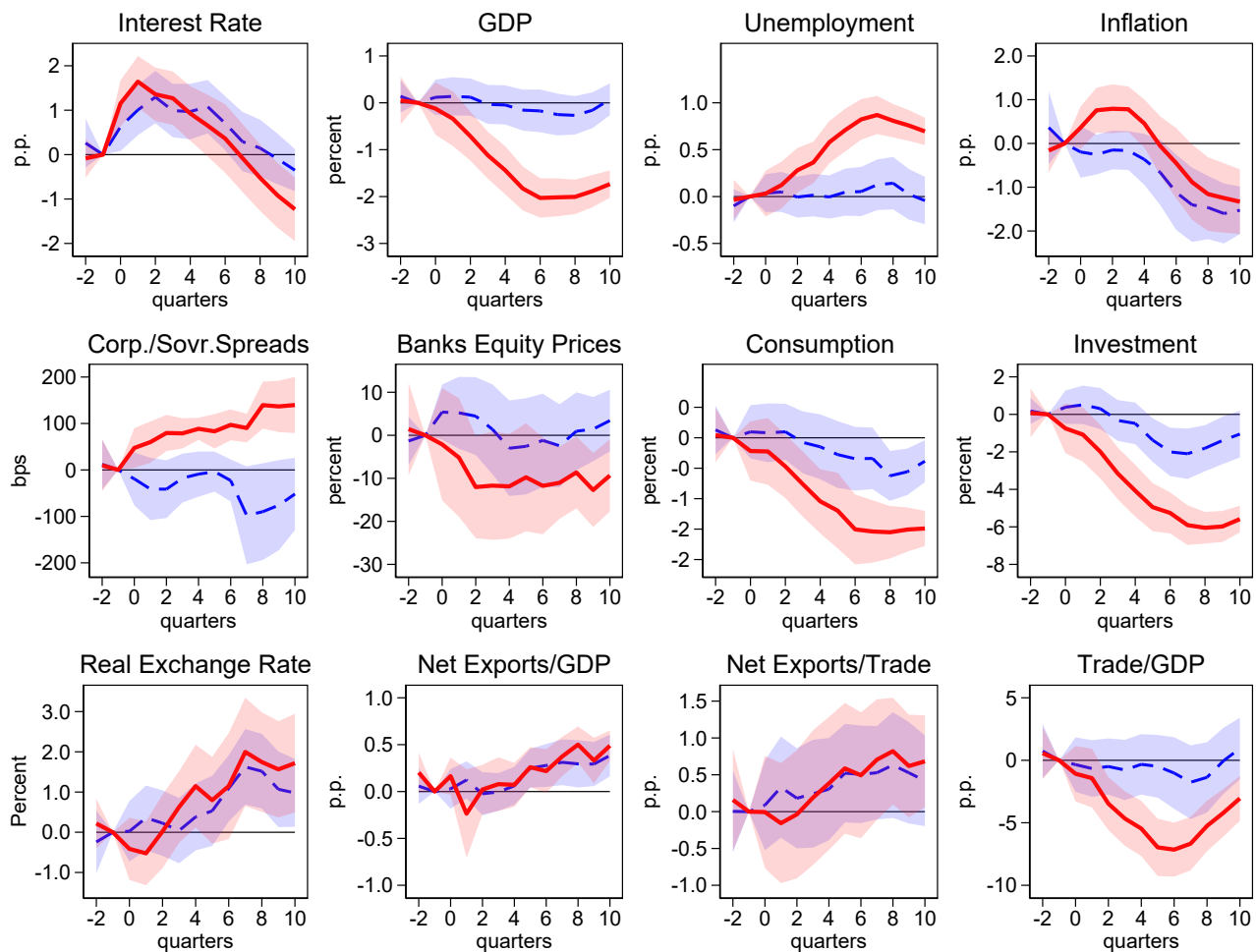
Note: Evolution over time of macroeconomic variables around interest rate tightening episodes in a sample that includes both advanced and emerging economies. Synchronous episodes are in red and asynchronous ones are blue. The lines are constructed using event-study regressions. The shaded regions show 70% confidence intervals.

Figure A.4: Distribution of Monetary Shocks across Synchronous and Asynchronous Episodes

Distribution trimmed at the 99th percentile
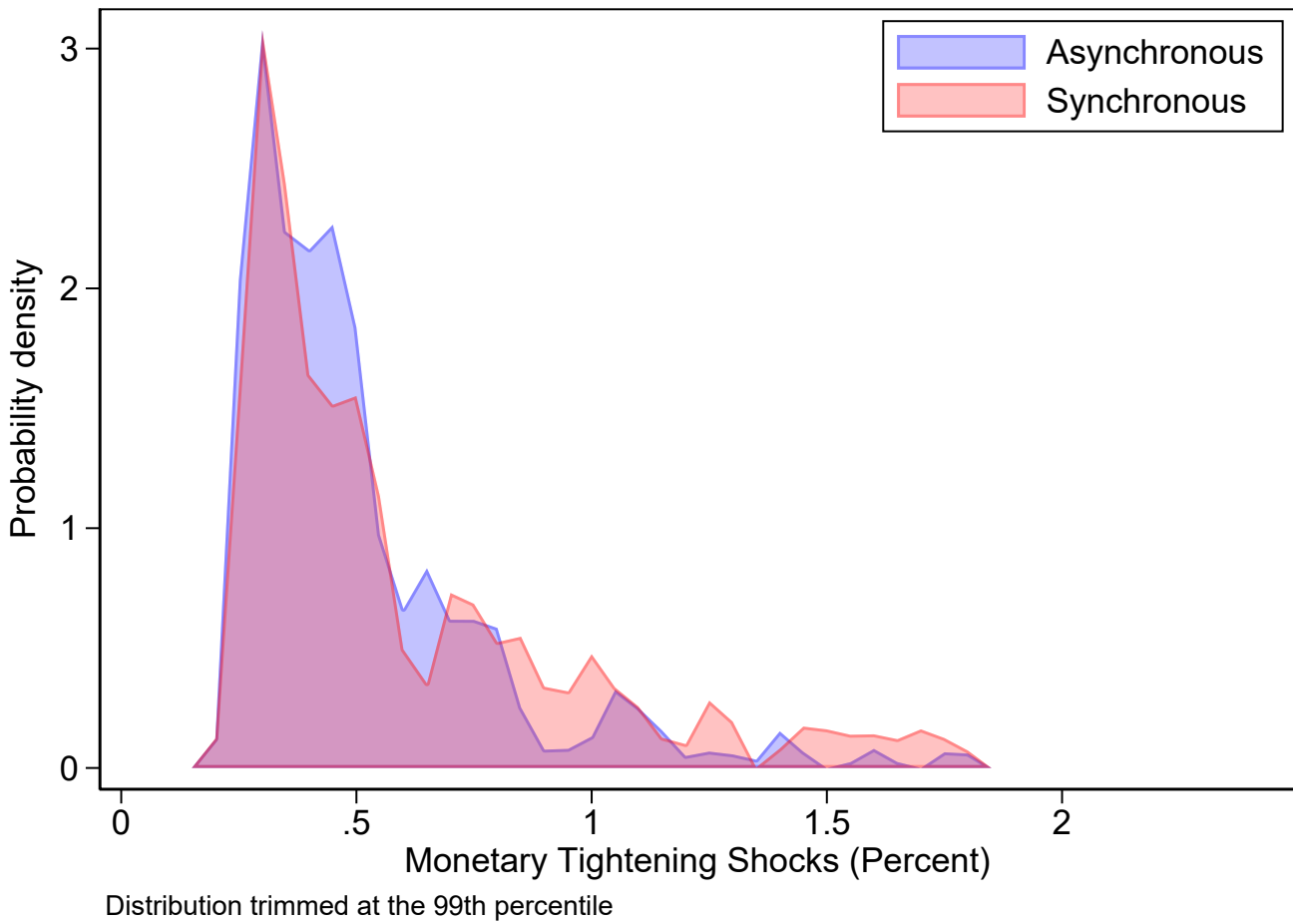
Note: Estimated Distributions of Contractionary Monetary Shocks across Synchronous and Asynchronous Episodes.

Figure A.5: Behavior around Tightening Episodes: Using Global Variables to Estimate Country-Specific Monetary Shocks

Note: Evolution over time of macroeconomic variables around interest rate tightening episodes estimated adding global controls in each country's reaction function when estimating monetary shocks. Synchronous episodes are in red and asynchronous ones are blue. The lines are constructed using event-study regressions. The shaded regions show 70% confidence intervals.
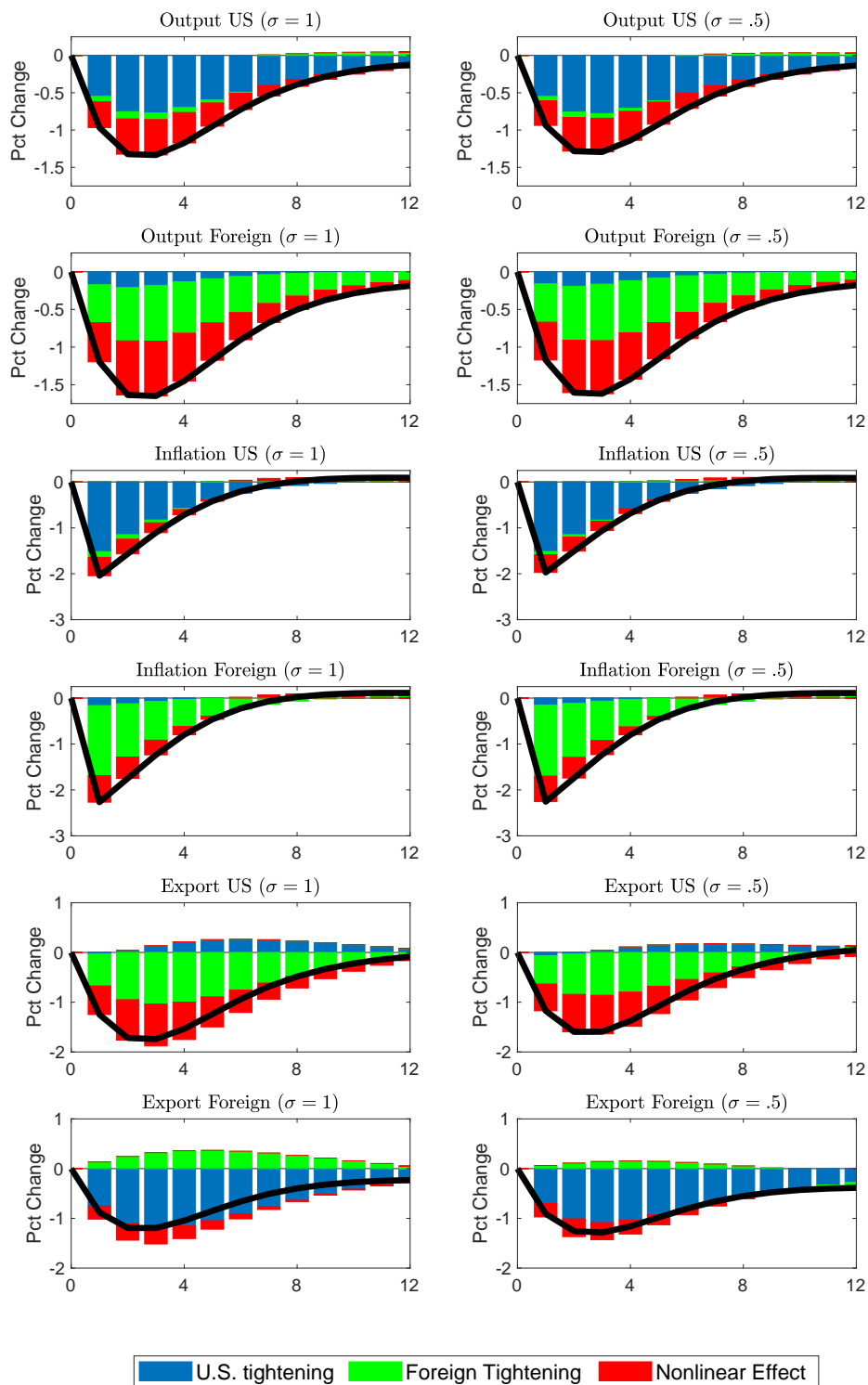
B Additional Model Results

B.1 Additional Impulse Responses from Baseline Experiments

Figure B.1: Model Simulation of a Global Markup Shock, Foreign Variables
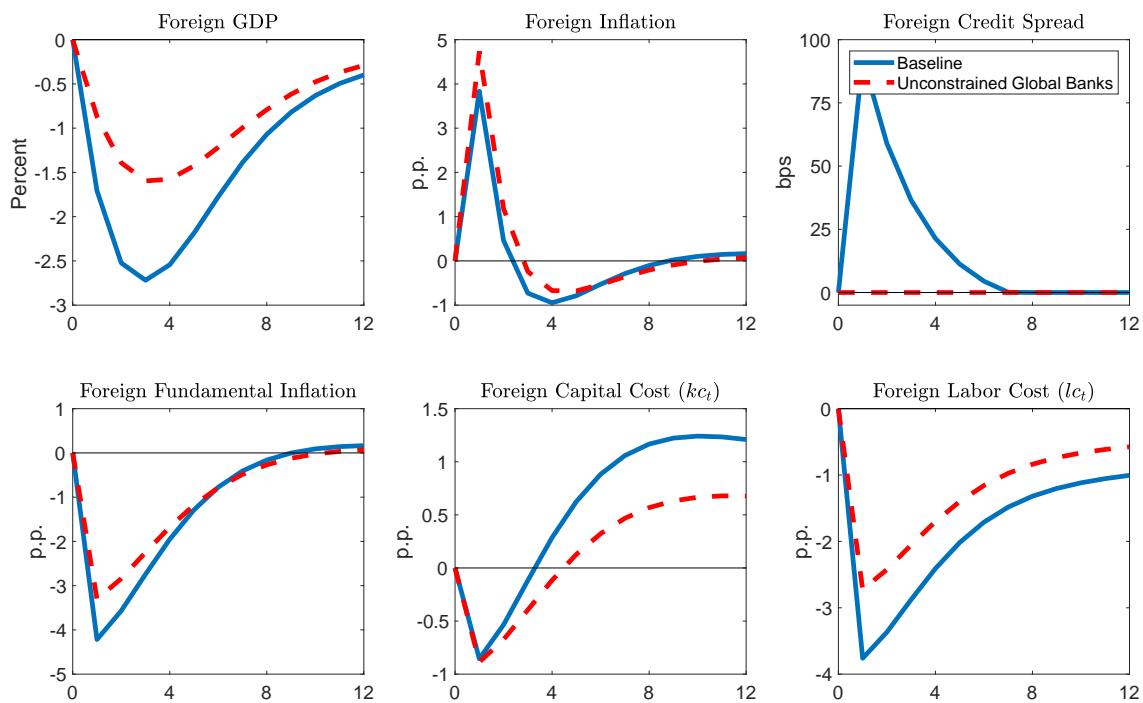

Note: All variables are in deviation from steady state.

Figure B.2: Impulse Responses to Monetary Tightening: Robustness to Calibration of Trade Elasticity

Note: The figure plots impulse responses of selected variables for the baseline model with unitary trade elasticity ($\sigma = 1$) and an alternative with a lower trade elasticity ($\sigma = -0.5$).

Figure B.3: Impulse Responses to a Monetary Tightening: Robustness to Firms Choice of Currency Invoicing
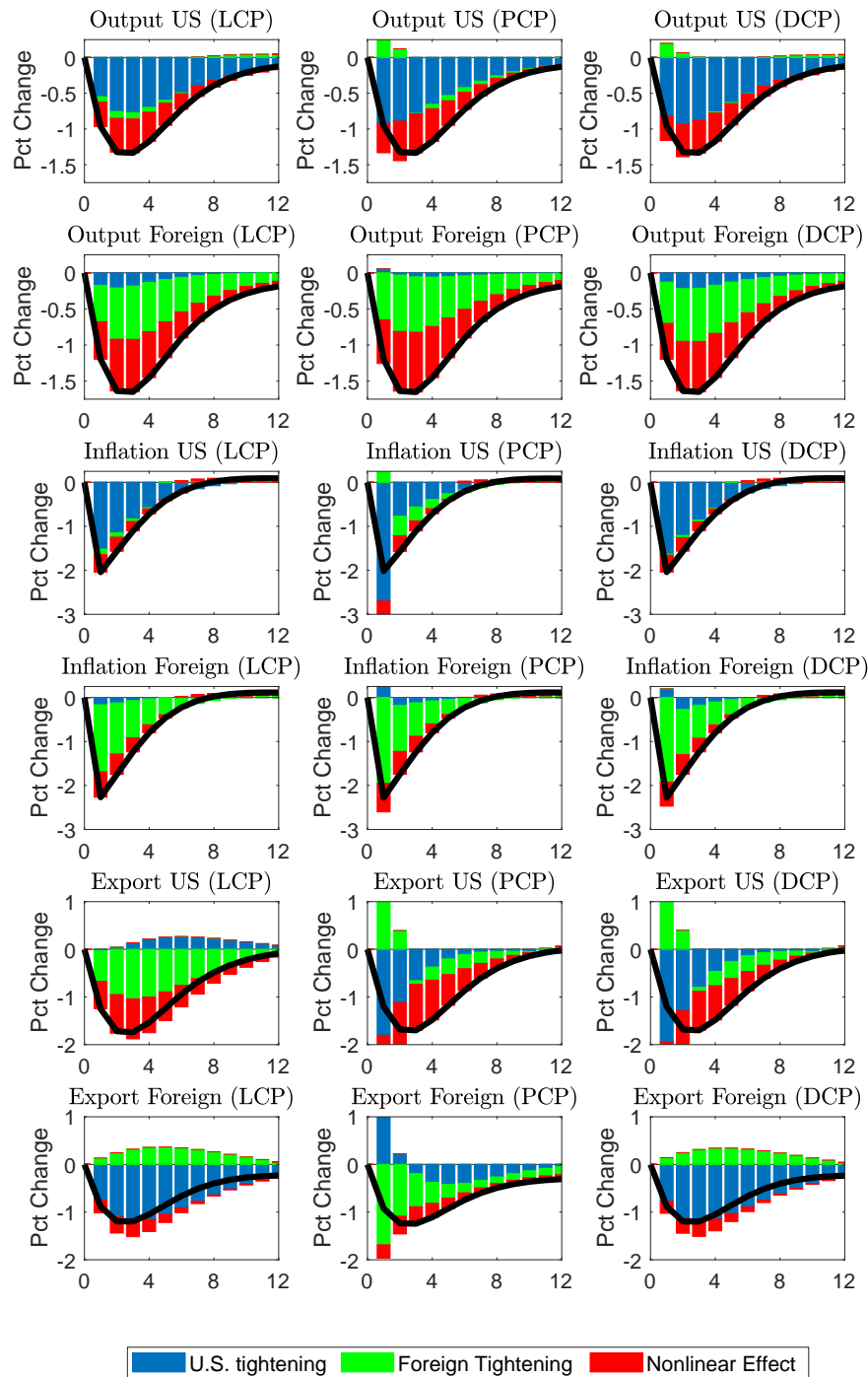
Note: The figure plots impulse responses of selected variables for three alternative assumptions regarding firms choice of currency invoicing: Local Currency Pricing (LCP), the assumption adopted in the benchmark model; Producer Currency Pricing (PCP); and Dominant Currency Pricing (DCP). The three models differ in their degree of exchange rate pass-through to prices.

B.2 Business Cycle Moments

The two-country model described in the main text is designed to study the nonlinear amplification of global tightening shocks arising from the interaction between the financial accelerator mechanism and the global exposure of financial intermediaries. However, the model can have broader applicability. In this section, we show that a version of the model augmented with a broad set of shocks performs well in generating business cycle moments in line with the data.

To test the quantitative performance of our model, we introduce a large set of shocks and calibrate the exogenous processes using evidence available in the literature. Specifically, we rely on the analysis in Bodenstein et al. (2023), who estimate a two-country New-Keynesian model using full information Bayesian techniques. We do so as the model in Bodenstein et al. (2023) includes financial frictions, as well as key nominal and real rigidities, as those used in our framework.[2]

We introduce in our model a subset of the shocks considered by Bodenstein et al. (2023)—focusing on the ten shocks that account for most of the variation in domestic and foreign output: two demand shocks in each country—a monetary policy shock and the risk-premium shock; two supply shocks in each country—a total factor productivity (TFP) shock and a markup shock; a global risk-premium shock and a UIP shock, meant to capture shifts in global preferences for dollar-denominated securities.

These shocks are commonly present in medium-scale estimated macroeconomic models. The demand and supply shocks affect each economy just as, for instance, in the (Smets and Wouters, 2007) model. Versions of the global risk premium shock and the UIP shock have also been extensively studied in the international quantitative macro literature.[3]

Below we describe how each shock enters the equations of the baseline model. The country-specific monetary shocks are already present in the model described in the main text. The country-specific risk premium shocks, ξ_{it}^{RP}, and the global risk-premium shock, ξ_{t}^{GRP}, affect households' demand for government bonds by entering equation (27) as follows:

$$\xi_{it}^{RP}\xi_{t}^{GRP} = \beta E_t \Lambda_{i,t+1} \frac{R_{it+1}^g}{\pi_{it+1}}. \tag{A.1}$$

TFP shocks, ξ_{it}^{TFP}, enter the production function of intermediate goods producers, equation (32), as follows:

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[2]The model of Bodenstein et al. (2023) features financial frictions at the country level and abstracts from frictions in international credit flows. Moreover, it does not include an occasionally binding constraint on global financial intermediaries and also differs on other details. However it is the closest model to ours that we are aware of. Other papers estimating two countries new Keynesian models are De Walque, Smets, and Wouters (2005) and Lubik and Schorfheide (2005), who use U.S. and Euro area data to estimate models which focus on different quantitative features than the ones we emphasize here.

[3]Kekre and Lenel (2021) and Bodenstein, Cuba Borda, Goernemann, Presno, Prestipino, Queralto, and Raffo (2023) study flight to safety shocks that combine elements of our global risk premium and UIP shock. Devereux and Engel (2002) and Eichenbaum, Johannsen, and Rebelo (2021) are two examples of papers that study UIP shocks. Itskhoki and Mukhin (2021) provide the micro-foundations of these shocks and discuss their empirical relevance.

$$\bar{Y}_{it} = \xi_{it}^{TFP} l_{it}^{1-\alpha} k_{it-1}^{\alpha}. \tag{A.2}$$

We replace the global markup shock, μ_t, in the Phillips curves equations in the home and foreign country, (33) and (34), with country-specific markup shocks, ξ_{it}^{MUP}, as follows:

$$(\pi_{ii,t} - 1)\,\pi_{ii,t} = s_t \left[mc_{i,t}\xi_{it}^{MUP} - p_{ii,t} \right] + \beta E_t \Lambda_{H,t+1}\,(\pi_{iit+1} - 1)\,\pi_{iit+1}\frac{Y_{iit+1}}{Y_{ii,t}} \tag{A.3}$$

$$(\pi_{ij,t} - 1)\,\pi_{ij,t} = s_t \left[mc_{i,t}\xi_{it}^{MUP} - X_{ji,t}p_{ij,t} \right] + \beta E_t \Lambda_{t,t+1}\,(\pi_{ijt+1} - 1)\,\pi_{ijt+1}\frac{Y_{ijt+1}}{Y_{ij,t}}. \tag{A.4}$$

Finally, the UIP shock, ξ_{it}^{UIP} affects the foreign country demand for dollar deposits, equation (27)

$$\xi_{it}^{UIP} = \beta E_t \Lambda_{i,t+1}\frac{X_{Hi,t+1}}{X_{Hi,t}}R_t^d, \tag{A.5}$$

and the banker's marginal value of investing in the foreign subsidiary in equation (15)

$$\mu_{F,t} = \beta E_t \Lambda_{H,t+1}\left[1 - \sigma + \sigma\psi_{t+1}^{*}\right]\left(R_{Ft+t}^{s}\xi_{it}^{UIP} - R_t^d\right). \tag{A.6}$$

Each shock j is assumed to follow an AR1 process

$$log(\xi_{it}^{j}) = \rho_i^j log(\xi_{it-1}^{j}) + \sigma^j \epsilon_t^j, \tag{A.7}$$

where ρ^j governs the persistence and σ^j governs the standard deviation of the shock.

Table B.1 reports the calibrated values for the standard deviations and persistence parameters of the exogenous processes. The values of the shocks' standard deviations coincide with the posterior mode estimates in Bodenstein et al. (2023), scaled by a common factor to generate an output volatility in line with the data. The markup shocks and the monetary policy shocks have the same persistence parameters as in the main text, which is smaller than in Bodenstein et al. (2023). Accordingly, we adjust the standard deviations of the innovations to obtain unconditional standard deviations of the markup and monetary policy processes in line with Bodenstein et al. (2023).

Table B.2 reports business cycle moments from the model and compares them with their counterpart in the data.[4] We calculate moments simulating the model for 10000 periods. In our simulations the economy enters in a constrained region with a probability of about 3.5 percent. For comparison, using historical data from Schularick and Taylor (2012), Boissay, Collard, and Smets (2016) estimate the frequency of "financial recessions" to be around 2.5 percent.

As shown in Table B.2, the model implied standard deviation and correlation with U.S. output are close to the values in the data for domestic and foreign variables. One exception is the higher

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[4]We calculate the empirical moments using the data described in Section 2 after applying the HP filter. Foreign GDP is constructed as a GDP-weighed aggregate of the output series in our sample of advanced foreign economies.

variance of inflation relative to the data. This is due to a relatively steep Phillips curve in our paper combined with the assumption of flexible wages. Given that our model is designed to study periods of large inflation and wage volatility, a steeper Phillips curve is appropriate for the main application of the paper. The volatility of net worth of GFIs, the variable at the core of the nonlinear financial amplification in the model, is somewhat lower than in the data while net worth correlation with U.S. GDP is higher than in the data. While we abstract from pure financial shocks, introducing a financial shocks, such as an exogenous shock to GFIs net worth, could help to simultaneously increase the variance of net worth and reduce its correlation with output. A financial shock would induce autonomous variation in net worth, hence increasing its variance, and it would reduce the correlation with output because output is not sensitive to net worth fluctuations if the financial constraint does not bind (and the constraint only binds infrequently).

Overall, these results suggest that our framework could be of broader use for quantitative business cycle analysis.

Table B.1: Shocks Parameter Values

Parameter	Symbol	Value
U.S. Shocks		
Std. dev. risk premium shock	σ_h^{RP}	0.0004
Std. dev. TFP shock	σ_h^{TFP}	0.0015
Std. dev. markup shock	σ_h^{MUP}	0.5
Std. dev. monetary shock	σ_h^{MP}	0.0005
Persistence risk premium shock	ρ_h^{RP}	0.97
Persistence TFP shock	ρ_h^{TFP}	0.97
Persistence markup shock	ρ_h^{MUP}	0.6
Persistence monetary shock	ρ_h^{MP}	0
Foreign Shocks		
Std. dev. risk premium shock	σ_f^{RP}	0.0002
Std. dev. TFP shock	σ_f^{TFP}	0.0036
Std. dev. markup shock	σ_f^{MUP}	0.54
Std. dev. monetary shock	σ_f^{MP}	0.0007
Persistence risk premium shock	ρ_h^{RP}	0.57
Persistence TFP shock	ρ_h^{TFP}	0.7
Persistence markup shock	ρ_h^{MUP}	0.5
Persistence monetary shock	ρ_h^{MP}	0
Global Shocks		
Std. dev. global risk premium shock	σ^{GRP}	0.0004
Persistence global risk premium shock	ρ^{GRP}	0.94
Std. dev. UIP shock	σ_f^{UIP}	0.0006
Persistence UIP shock	ρ_f^{UIP}	0.97

Note: The table reports the values for the standard deviations and persistence parameters of the ten shocks used in the model simulations. The values of the shocks' standard deviations coincide with the posterior mode estimates in Bodenstein et al. (2023), scaled by a common factor to generate an output volatility in line with the data. In addition, the markup shocks and for the monetary policy shocks have the same persistence parameters as in the main text, which is smaller than in Bodenstein et al. (2023). Accordingly, we adjust the standard deviations of the innovations to obtain unconditional standard deviations of the markup process in line with Bodenstein et al. (2023).

Table B.2: Business Cycle Moments

Moment	Data	Model
Standard Deviation		
U.S. GDP	1.26	1.31
U.S. Net Export/GDP	0.33	0.28
U.S. Real Exchange Rate	3.68	2.95
U.S. Inflation	0.57	1.43
U.S. Investment	3.44	3.36
U.S. Consumption	0.99	1.19
U.S. GFI Net Worth	14.66	10.47
Foreign GDP	1.05	1.03
Correlation with U.S. GDP		
U.S. GDP	1	1
U.S. Net Export/GDP	-0.51	-0.48
U.S. Real Exchange Rate	-0.19	-0.22
U.S. Inflation	0.36	0.32
U.S. Investment	0.92	0.84
U.S. Consumption	0.87	0.58
U.S. GFI Net Worth	0.33	0.64
Foreign GDP	0.63	0.32

Note: The table compares business cycle moments for selected variables calculated using data and simulating the model. We calculate the empirical moments using the data described in Section 2 after applying the HP filter. Foreign GDP is constructed as a GDP-weighed aggregate of the output series in our sample of advanced foreign economies. We calculate moments in the model by simulating the economy for 10000 periods.

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