International Strategic Spillovers of Monetary Policy

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Abstract

This paper studies the endogenous reaction of domestic monetary policy to changes in foreign policies. In particular, I examine the existence and magnitude of cross-border *strategic spillovers* between countries that are tightly linked through global financial and trade networks. Using a spatial/network model that treats every country's monetary policy as potentially endogenous, I provide empirical evidence that strategic spillovers are not only sizable but are also amplified depending on the network structure of the global economy. That a change in policy in one country compels an adjustment in policy in another country suggests that the underlying macroeconomic spillovers are significant. I also present evidence that capital account policies provide substantial insulation against foreign monetary shocks.

JEL codes: F38, F41, F63

Keywords: International spillovers, monetary policy, capital controls, networks

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1 Introduction

International developments during the last decade have reignited debate on the multilateral consequences of self-oriented macroeconomic policy and raised old questions about what policy mix is appropriate to successfully weather turbulent global market conditions. Indeed, the extraordinary monetary easing pursued in the aftermath of the global financial crisis prompted policymakers in several emerging market economies (EMEs) to adopt capital controls and accuse advanced economies of waging "currency wars," blaming them for excessive exchange rate appreciation, destabilizing capital inflows, and a loss of monetary autonomy. Similarly, as the Federal Reserve has recently began to normalize monetary policy, several EMEs, in particular Argentina and Turkey, have come under stress and faced increasing market pressure to defend their currencies against large capital outflows by tightening domestic monetary policy.

As these episodes underscore, there exists considerable empirical evidence that monetary policy in one country may create substantial multilateral spillovers. It is well understood that contractionary monetary policy in large advanced economies is associated with lower output growth, a retrenchment in capital flows, and real exchange depreciation in small countries and EMEs (Georgiadis, 2016; Banerjee et al., 2016; Chen et al., 2016; Fratzscher et al., 2018; Canova, 2005; Bruno and Shin, 2015). There is also evidence that monetary policy shocks in the U.S. may impose significant spillovers on other advanced economies (e.g. Kim, 2001; Neely, 2011) and that unconventional policy or so-called "quantitative easing" has had particularly large effects on global financial markets.[1]

Interest in the magnitude of spillovers has coincided with a renewed theoretical debate on the efficiency of the non-cooperative global equilibrium and the desirability of multilateral policy coordination.[2] And yet, while the empirical literature has studied macroeconomic spillovers extensively, little attention has been paid to how countries endogenously react to changes in each other's policies and how global financial and trade networks structure these interactions. This is perhaps surprising considering that the theoretical debate is often cast explicitly in game theoretic terms, emphasizing strategic interdependencies and characterizing monetary policy as a Nash equilibrium in a simultaneous move game. Indeed, to the extent that monetary authorities react to domestic conditions, the existence of significant macroeconomic spillovers should imply an endogenous reaction by domestic policy.[3]

[1]For instance, Apostolou and Beirne (2017) provide evidence that changes in the size of the Federal Reserve's and ECB's balance sheets increased the volatility of certain types of financial assets in EMEs, with especially large effects on bond markets.

[2]The international policy coordination literature reached its peak during the mid 1980s, following seminal works by Niehans (1968) and Hamada (1979). Interest in monetary policy cooperation subsequently subsided following studies showing that although cooperation could produce Pareto improvements in principle, empirically plausible gains from cooperation are likely small (see eg. Oudiz and Sachs, 1984). The idea that the international uncooperative Nash equilibrium is inefficient has regained prominence in recent years following, for instance, the debate on so-called currency wars (see eg. Stiglitz, 2015; Korinek, 2016; Blanchard, 2016). A recent survey of the modern debate on international cooperation is provided by Taylor (2013).

[3]There is substantial anecdotal evidence that central banks take each other's policies into account when setting their own

Strategic interactions have major implications for the international transmission of monetary policy. Depending on whether monetary policies are strategic complements or substitutes, shocks to policy in one country will either be amplified or dampened in equilibrium. In addition, the magnitude of general equilibrium effects will also depend on the structure of bilateral linkages and a country's position in global financial and trade networks. In particular, interdependencies between large financial centers imply the possibility of significant higher-order spillovers, where a shock in one center country is transmitted and amplified through the endogenous response of another systemically important country.

This paper empirically studies the international transmission of monetary policy in a network setting during the 2000-2016 period. I present evidence of the existence of substantial *strategic spillovers* between countries that are highly linked through global financial and trade networks. Using a spatial/network model that allows every country's policy to be potentially endogenous and makes it possible to identify contemporaneous reactions, I find that monetary policies are strategic complements and exhibit amplification in equilibrium. The results imply substantially larger spillovers from advanced economy shocks than those predicted by a naive model failing to account for endogenous interactions and network structure. I also find evidence that these strategic spillovers are weaker in countries with regulated capital accounts, indicating that capital controls afford some degree of monetary autonomy. The main results are robust to a wide range of robustness exercises, including several strategies to account for common factors, different estimation approaches, and alternative network structures.

Static estimates of contemporaneous effects suggest that on average countries tighten monetary policy by roughly 0.7 percent in response to a one percent increase in neighboring countries' policy rates. The combination of strategic interdependencies and higher-order network effects appear to substantially amplify monetary shocks originating in highly central advanced economies, with multipliers substantially greater than unity in the benchmark specification. Perhaps surprisingly, relatively less central economies like the United Kingdom and the Eurozone produce average general equilibrium spillovers on par with those of the United States, despite the latter's greater immediate prominence in global financial networks. This is because a significant share of the total spillover generated by a shock in these countries is transmitted through the endogenous reactions of U.S. monetary policy.

This paper is related to the extensive literature on the international transmission of monetary policy and the existence of the classic Mundellian policy Trilemma. Several studies have provided evidence that capital controls and exchange rate flexibility can grant small open economies with some degree of monetary autonomy (see, e.g., Shambaugh, 2004; Obstfeld et al., 2005; Aizenman et al., 2013; Klein and Shambaugh, 2015; Davis and Zlate, 2017). In contrast, Rey (2015) has famously argued for the existence of a "global financial cycle" driven by monetary policies in "core" economies. In her view, this implies a policy "dilemma":

policy. See Taylor (2013) for a detailed discussion.

countries can either have capital mobility or an independent monetary policy, but not both simultaneously. Others have questioned the notion that capital controls are effective and argued that these do not provide any insulation against foreign monetary shocks (e.g. Miniane and Rogers, 2007).

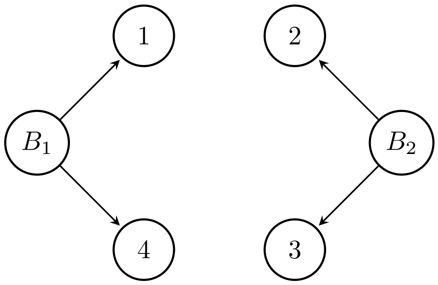
My results support the proposition that capital controls increase domestic monetary autonomy in so far as countries with highly regulated capital accounts react systematically less to neighboring countries' shocks. Heterogeneous estimates imply that strategic spillovers in countries with extensive capital controls are not statistically different from zero. Dynamic estimates obtained through local projection methods imply a modest medium-term reaction in countries with capital controls, albeit one that is smaller than in fully liberalized economies. In contrast, I do not find evidence that the exchange rate regime affects the magnitude of spillovers, although with the caveat that I consider a more recent and smaller sample than in the Trilemma studies.

Existing monetary policy spillover studies can be broadly classified into two categories: (1) "base-country" studies and (2) "bilateral" VAR studies. Base-country studies examine the passthrough of short-term interest rates in a "base" country – typically the United States – on foreign short-term rates using panel data (e.g. Frankel et al., 2004; Shambaugh, 2004; Klein and Shambaugh, 2015). These types of studies assume that monetary policy in the base country is exogenous and estimate the interest rate passthrough under alternative monetary regimes. Bilateral VAR and Global VAR studies, in contrast, employ time-series techniques to examine the dynamic impact of a monetary policy shock in the U.S. or another advanced economy on international macroeconomic conditions. As is standard, shocks are identified either through recursive exclusion restrictions (e.g. Kim, 2001; Canova, 2005; Miniane and Rogers, 2007), or in some cases using Romer and Romer (2005) narrative identification (e.g. Bluedorn and Bowdler, 2011).

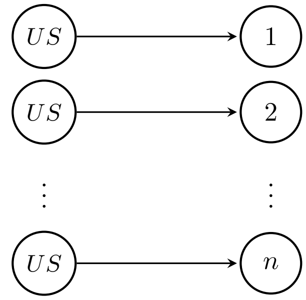
Studying the international transmission of monetary policy in a network setting has a number of advantages relative to existing studies. Exploiting the network structure of international financial and trade flows makes it possible to treat every country's policy as potentially endogenous and identify strategic interaction effects similar to what has been referred to elsewhere as a *peer effect* (e.g. Manski, 1993) or a *social interaction effect* (e.g. Bramoullé et al., 2009). This is in contrast to base-country or VAR studies that impose some type of weak or strong exogeneity condition on neighboring countries' monetary policy and therefore implicitly rule-out higher-order spillover effects arising from strategic interdependence. Intuitively, I estimate contemporaneous spillovers that are akin to best response functions in a simultaneous move game. Identification is obtained under the mild assumption that domestic monetary policy reacts to local macroeconomic conditions.

In addition, both types of studies implicitly impose strong assumptions regarding the network structure of cross-country economic linkages. For example, in base-type studies countries in the "periphery" are unidirectionally linked – through, e.g., an exchange rate peg – to their respective base-country (see Panel (a)

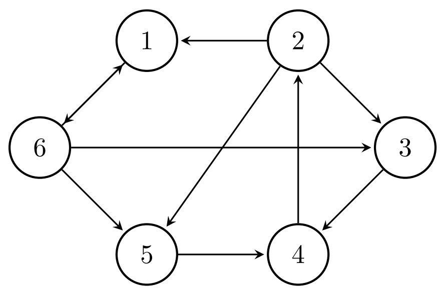
Figure 1: Taxonomy of Monetary Policy Spillover Specifications



(a) **Base-country studies:** Periphery countries (1) through (4) are connected to base countries B_1 and B_2 (e.g. through a currency peg). Base countries are assumed to be exogenous. Examples include Frankel et al. (2004), Shambaugh (2004).



(b) **Bilateral studies:** Examine the impact of a (possibly identified) monetary policy shock in one large country, typically the U.S., on a set of macroeconomic and financial outcome variables in n foreign countries. The spillovers are estimated for each country pair separately. Examples include Bluedorn and Bowdler (2011), Canova (2005), and Miniane and Rogers (2007).



(c) **Spatial / Network Model:** General structure of connections between countries, including bi-directional causality (e.g. between countries (1) and (6)). Monetary policy is allowed to be endogenous in every country.

in Figure 1). While this structure is perhaps appropriate for studying the impact of international interest rates on small open economies, it is problematic when considering interactions between medium and large economies whose policies have non-negligible effects on world markets.

Indeed, my results suggest that these endogenous reactions mediated through global financial networks act as powerful amplification channels that are absent from existing approaches that impose exogeneity and ignore network structures. To illustrate this point, I compare the average spillovers implied by my benchmark specification to those obtained from a naive model treating a single large economy as the exogenous base-country. As this exercise implies, the average spillover estimates in the base-country model are severely biased: the average spillovers obtained after accounting for network structure and strategic reactions is nearly twice as large.

The remainder of the paper is structured as follows. Section 2 frames the empirical exercise through a stylized model and describes the econometric methodology in detail. Section 3 discusses the sample and data used in the empirical analysis and presents benchmark estimates of contemporaneous spillover effects. Next, section 4 presents estimates of spillover dynamics using local projections. Section 5 presents a series of robustness exercises, including specifications using forecasting errors, placebo tests for misspecification of the weighting matrix, and a data-driven approach to selecting the first-stage instruments. Finally, section 6 concludes.

2 Conceptual Framework and Methodology

2.1 Strategic monetary policy

In order to fix ideas and develop intuition, consider a stylized simultaneous move game between N central banks who non-cooperatively choose their own domestic policy rate in order to minimize a loss function defined over K domestic macroeconomic target variables. Suppose country i's loss function is quadratic and given by

$$\mathcal{L}_i = \frac{1}{2}\sum_{k=1}^{K} \alpha_{ik} \left(Y_{ik} - \bar{Y}_{ik}\right)^2 \tag{1}$$

where Y_{ik} denotes country i's kth macroeconomic target variable, while $\bar{Y}_{ik}$ denotes its respective target level. The parameters α_{ik} capture the weight placed by country i's central bank on achieving its kth target. For simplicity, assume that the equilibrium level of each macroeconomic variable can be represented by the reduced form function $Y_{ik} = Y_{ik}(\boldsymbol{r}, \boldsymbol{X})$, which relates the kth variable to the vector of monetary policy instruments in all N countries, $\boldsymbol{r} = \{r_1, r_2, \ldots, r_N\}$, and to a set of exogenous observables $\boldsymbol{X}$. International spillovers in this simple model are captured by allowing non-negligible effects of, say, country j's monetary policy on country i's macroeconomic outcomes ($\partial Y_{ik}/\partial r_j \neq 0$).

The first-order conditions for each country's optimal choice of the monetary policy instrument are given by:

$$F_i(\boldsymbol{r}, \boldsymbol{X}) = \sum_{k=1}^{K} \alpha_{ik} \left(Y_{ik} - \bar{Y}_{ik}\right) \frac{\partial Y_{ik}}{\partial r_i} = 0 \quad \text{for} \quad i = \{1, 2, \ldots, N\} \tag{2}$$

where each equation in (2) implicitly defines a particular country's best response to every other country's monetary policy choice. Assuming each equation has a unique solution, country i's best response function can be expressed as $r_i^* = f_i(\{r_j\}_{j\neq i}, \boldsymbol{X})$. A Nash/Cournot equilibrium in this game is defined as a vector of policy instruments such that every country best responds; that is, when $r_i^* = f_i(\{r_j^*\}_{j\neq i}, \boldsymbol{X})$ for all $i = \{1, 2, \ldots, N\}$.

We are interested in how policy choices in a foreign country influence the strategic policy choice of the domestic policymaker. A *strategic spillover* between country j and country i is said to exist if $\partial r_i/\partial r_j \neq 0$, that is, when a change in monetary policy in a foreign country impacts domestic macroeconomic conditions sufficiently to warrant an adjustment in domestic policy.[4] Intuitively, the magnitude and sign of the strategic spillovers will depend on the strength of the economic linkages between country pairs, including, for example, the extent of bilateral trade and financial integration, the relative size and importance of each economy in global financial and goods markets, as well as other country-specific structural and cyclical factors.

The sign of the strategic spillover is inherently ambiguous due to several factors. On the one hand, expansionary monetary policy in one country may have positive aggregate demand spillovers on its neighbors (as reported, for example, Kim, 2001). If the latter are already near full capacity or near their inflation target, the neighboring central banks may wish to counteract the increase in aggregate demand through a contractionary policy adjustment. On the other hand, a monetary expansion in one country may divert capital flows to its neighbors, potentially producing unwanted exchange rate appreciation. If policymakers in recipient countries place a significant weight on the level of the exchange rate – for example, due to concerns about export sector competitiveness – they may wish to counteract the surge in capital flows by easing monetary policy, provided inflationary concerns are not binding. The sign of the strategic spillover, in these cases, will therefore depend on which of the two channels dominates.

Similarly, a capital inflows surge may also lead to the the build-up of financial fragilities, creating an additional incentive to adjust domestic policy in order to discourage speculative flows. Indeed, recent studies have argued monetary policy is transmitted internationally through a "risk-taking channel" (see Bruno and Shin, 2015), where loose monetary policy in the U.S. and other financial centers lowers funding costs for domestic banks, promoting riskier financial conditions. Moreover, several theoretical models have emphasized a "financial amplification" channel, whereby loose global monetary conditions can encourage decentralized agents to borrow excessively from international markets relative to the socially optimal level that internalizes externalities due to financial fragility (see eg. Jeanne and Korinek, 2010).

This analysis is further complicated, of course, by country-specific institutional and monetary arrangements, such as the use of capital controls, the exchange rate regime, and the availability of other policy tools such as macroprudential regulations. If an economy with tight capital controls is able to successfully insulate itself against surges in capital flows, its strategic reaction to neighbors' monetary policy may be negligible.[5] Conversely, uncovered interest parity predicts that countries with completely open capital accounts and with a pegged exchange rate will fully import the monetary policy of the base currency's country. Access to

[4]Implicitly differentiating in the neighborhood of the Nash equilibrium $\boldsymbol{r}^*$, the strategic spillover between j and i can be expressed as:

$$\left.\frac{\partial r_i}{\partial r_j}\right|_{\boldsymbol{r}=\boldsymbol{r}^*} = -\frac{\sum_{k=1}^{K} \alpha_{ik} \left[\frac{\partial Y_{ik}}{\partial r_i}\frac{\partial Y_{ik}}{\partial r_j} + \left(Y_{ik} - \bar{Y}_{ik}\right)\frac{\partial^2 Y_{ik}}{\partial r_i \partial r_j}\right]}{F_{r_i}} \tag{3}$$

where $F_{r_i} > 0$ is the partial derivative of (2) with respect to country i's own policy rate and the sign follows from the second-order condition for a minimum.

[5]Blanchard (2016) makes this point in the context of a two-country version of the Mundell-Fleming model where countries set monetary policy non-cooperatively.

effective macroprudential regulations may further alter the relative tradeoffs in so far as domestic policy is free to target non-financial stability concerns.[6]

2.2 Empirical Model

The stylized strategic monetary policy model outlined above suggests an empirical model for estimating the average strategic spillover effects from foreign monetary policy. Linearizing the best response functions in the neighborhood of the equilibrium, we can express every country's monetary policy as the following $N \times N$ linear system of equations:

$$r_{it} = \delta \sum_{j=1}^{N} w_{ij} r_{jt} + \boldsymbol{\beta} \boldsymbol{X}_{it} + u_{it} \qquad \text{for} \quad i = \{1, 2, \ldots, N\} \tag{4}$$

where observations are indexed by country i and time t, w_{ij} captures the strength of the linkage from country j to i, and the coefficient δ measures the average strategic spillovers from foreign monetary policy. As above, I assume that the vector of observables are strictly exogenous so that $E\{\boldsymbol{X}_{it} u_{it}\} = 0$ holds. The term $\bar{r}_i = \sum_{j=1}^{N} w_{ij} r_j$ is known in the literature on spatial econometrics as the *spatial lag* of the dependent variable r_i, and is equivalent to a weighted average of all other countries' dependent variables when the vector of weights are normalized to sum to one. It is worth noting that the spillover coefficient has also been referred to in the microeconometrics literature as a *peer effect* (e.g. Manski, 1993) or a *social interaction effect* (e.g. Bramoullé et al., 2009). This model can be expressed more compactly in matrix notation as:

$$\boldsymbol{r}_t = \delta \boldsymbol{W} \boldsymbol{r}_t + \boldsymbol{\beta} \boldsymbol{X}_t + \boldsymbol{u}_t \tag{5}$$

where $\boldsymbol{W}$ is an $N \times N$ weighting matrix capturing the direction and strength of linkages between countries. The weighting matrix $\boldsymbol{W}$ is assumed to be known by the researcher and must be specified a priori in order to construct the spatial lag variable for r_i. In addition, one can incorporate time-varying linkages between countries by allowing the weighting matrix to be indexed by time, $\boldsymbol{W}_t$. The empirical analysis presented below will use a variety of alternative weighting matrices, including weights constructed from bilateral financial flows and bilateral international trade.

The existence of strategic interdependence implies that the policy rates on the right hand side are endogenous and therefore OLS estimates of the strategic spillover coefficient δ in (5) will be inconsistent (i.e. $E\{\boldsymbol{W}\boldsymbol{r}\boldsymbol{u}\} \neq 0$). Intuitively, this is because for every foreign policy rate there exists a corresponding equation relating it to other countries' policy rates. Consistent estimates of δ can be obtained through instrumental variable methods. In particular, it is possible to construct identifying instruments using higher-order spatial lags of $\boldsymbol{X}$. To appreciate this point, we can solve the structural model for its reduced form:

$$\boldsymbol{r}_t = (\boldsymbol{I} - \delta \boldsymbol{W})^{-1} \boldsymbol{\beta} \boldsymbol{X}_t + (\boldsymbol{I} - \delta \boldsymbol{W})^{-1} \boldsymbol{u}_t \tag{6}$$

[6] A "portfolio" approach to managing international spillovers and capital flows using a broad set of policy tools is set forth in Ghosh et al. (2018).

Assuming $\boldsymbol{W}$ is row-normalized, the matrix inverse will exist and can be expressed as the series expansion $(\boldsymbol{I} - \delta \boldsymbol{W})^{-1} = \sum_{\ell=0}^{\infty} \delta^l \boldsymbol{W}^{\ell}$. The conditional expectation of the spatial lag can therefore be expressed as:

$$E\{\boldsymbol{W}\boldsymbol{r}_t | \boldsymbol{X}_t\} = \boldsymbol{W}\boldsymbol{\beta}\boldsymbol{X}_t + \delta \boldsymbol{W}^2 \boldsymbol{\beta}\boldsymbol{X}_t + \delta^2 \boldsymbol{W}^3 \boldsymbol{\beta}\boldsymbol{X}_t + \cdots + \delta^{\ell} \boldsymbol{W}^{\ell+1} \boldsymbol{\beta}\boldsymbol{X}_t + \ldots \tag{7}$$

where we have relied on the assumption that $E\{\boldsymbol{u}_t | \boldsymbol{X}_t\} = 0$. As expression (7) makes clear, the terms $\boldsymbol{W}\boldsymbol{X}_t$, $\boldsymbol{W}^2\boldsymbol{X}_t$, $\boldsymbol{W}^3\boldsymbol{X}_t$, etc., can be used to construct instruments for $\boldsymbol{W}\boldsymbol{r}_t$. General conditions for identification are outlined in Bramoullé et al. (2009), who show that identification is obtained as long as the observables are relevant (i.e. $\boldsymbol{\beta} \neq 0$) and there exists sufficient cross-country variation in the bilateral linkages (i.e. $\boldsymbol{W}$ is not a complete network). In traditional instrumental variable parlance, these conditions simply state that identification requires that it is possible to construct relevant instruments that satisfy the exclusion restriction.

Intuitively, the idea is to instrument the monetary policy of foreign countries using the macroeconomic conditions of their neighbors and neighbors' neighbors, and so forth. For example, suppose that South Korea and Japan are highly interlinked, while Brazil is only linked to Japan. In order to ascertain the impact of Japanese monetary policy on Brazilian policy, we can instrument using exogenous or predetermined macroeconomic characteristics in Korea, which indirectly impacts Brazil through its spillovers on Japan but has no *direct* effect of its own.

As the preceding discussion makes clear, a crucial consideration is the choice of macroeconomic characteristics $\boldsymbol{X}$ to which the domestic central bank reacts. Obvious candidates include proxies for the output gap, real GDP growth, the level of unemployment, and the inflation rate. Additionally, some countries may likely also set domestic monetary policy in response to changes in the real exchange rate or domestic financial conditions. While it is important to include characteristics that directly influence domestic monetary policy, identification may be compromised if these are correlated with the disturbance term. Moreover, since the effect of a change in foreign monetary policy may operate precisely through its spillovers on current domestic outcomes, including these in $\boldsymbol{X}$ would mute a significant portion of the very effects we are attempting to capture. For these reasons, I only include pre-determined or lagged macroeconomic outcomes in $\boldsymbol{X}$, which can be treated as plausibly exogenous. Since the sample includes several medium and large countries, the same logic holds, albeit to a lesser extent, for international variables typically used to account for common global factors, such as the VIX.[7]

One potentially important complication is the role of anticipation effects and forward looking central bank and market behavior. If expectational effects are significant and are correlated across countries, estimates of δ may suffer from omitted variable bias. While this problem can be partially addressed by controlling for common global factors that may shift expectations across all countries simultaneously, it would not address

[7] Indeed, several recent studies have found that monetary policy in the U.S. affects the VIX. See for example, Rey (2015) and Bruno and Shin (2015).

bias arising from country-specific factors. Therefore, to minimize these concerns, the benchmark specifications considered below include the forecast errors of inflation and real GDP growth. This specification has the intuitive interpretation that changes in monetary policy are driven by the unexpected components of output growth and inflation.

3 Empirical Analysis

3.1 Data and sample description

The data consists of a sample of 33 advanced and emerging market economies (EMEs) observed at a quarterly frequency between 1999 and 2017.[8] It is worth highlighting that the member countries of the Eurozone are treated as a single country, reflecting the fact that they share a common monetary policy set by the European Central Bank. Although the full sample of countries includes most advanced economies and prominent EMEs, the number of countries included in a given specification will vary depending on the weighting matrix under consideration due to data limitations. For example, specifications using weights based on bilateral bank financial positions include a smaller sample of 14 countries.

In order to adequately capture intentional changes in a country's monetary policy stance, I rely on the newly available dataset of monetary policy interest rates compiled by the BIS. This dataset has several advantages. First, it was constructed in consultation with the Central Banks of each BIS member country, which provided input into selecting the most relevant policy rate. Second, for most countries the series report policy targets and therefore do a better job of capturing a country's intended monetary policy stance than market rates. Third, in situations where a Central Bank relied on a multiple target rates or implemented monetary policy according to a different instrument, the BIS determined the most relevant market rate with input from the member country.

One important shortcoming of relying on the BIS target rates series, however, is that the policy rate is ill-suited to measuring the policy stance at the zero-lower-bound or when a country in question conducts unconventional monetary policy. To overcome this limitation, I supplement the BIS target rates measures with estimates of so-called "shadow rates" in advanced economies constrained by the zero-lower-bound during the aftermath of the global financial crisis. The advantage of using shadow rates is that these can fall below zero during periods of unconventional policy and therefore more accurately reflect the implied stance of monetary policy. In particular, I use the series provided by Krippner (2012), which include shadow rate estimates for the United States, Eurozone, Japan, and the United Kingdom. I use the shadow rates to construct composite monetary policy series equal to the BIS target rate series during normal periods and

[8]Please refer to Appendix G for the full set of included countries.

Table 1: Summary statistics and variable definitions

Variable Description	*Mean*	*Sd*	*Min*	*Min*
Policy rate (first-difference)	-0.002	0.012	-0.220	0.130
Real GDP Growth (Y-o-Y)	0.031	0.032	-0.155	0.187
Inflation rate	0.038	0.056	-0.025	0.774
Real exchange rate appreciation	0.001	0.083	-0.599	0.291
Stock Market Index	2.213	0.863	0.141	4.937
VIX Global volatility index	0.846	7.924	-10.278	38.010
Price of oil (log US$)	3.955	0.619	2.407	4.811
Price of agricultural raw materials (log US$)	4.708	0.162	4.437	5.104
Year-ahead growth forecast	0.028	0.025	-0.106	0.115
Year-ahead inflation forecast	0.040	0.069	-0.092	1.037
Inverse Chinn-Ito liberalization index	0.325	0.328	0.000	1.000
Schindler index of capital controls	0.382	0.333	0.000	1.000
Schindler index of inflows controls	0.356	0.315	0.000	1.000
Change in reserves (% of GPD)	0.694	3.523	-29.777	40.811
Observations		2233		

equal to the shadow rate whenever monetary policy is constrained by the zero-lower-bound.[9]

In order avoid potentially spurious results due to non-stationarity, in what follows I consider models estimated using the first-difference of the composite policy rate (as in, e.g. Shambaugh (2004) and Klein and Shambaugh (2015)). Although evidence on whether policy rates exhibit unit roots is mixed, these nevertheless exhibit sufficient persistence to warrant caution.[10] Country-specific unit root tests fail to reject the unit root null for more than half the countries in the sample. Panel-based tests, which in theory provide more power to reject the null, offer somewhat mixed results, depending on whether common or heterogeneous autoregressive coefficients are specified.[11]

I consider a variety of domestic and international macroeconomic observables to include in the empirical best response functions estimated below. These include: real GDP growth, inflation, real exchange rate appreciation, an equity price index, the VIX index of global financial volatility, indices of commodity prices, as well as forecasts of GDP growth and inflation. The growth and inflation forecasts were obtained from a variety of sources, including surveys of professional forecasters published by various Central Banks, forecasts published in the IMF's World Economic Outlook (WEO), as well as those published by Consensus Economics.[12] Summary statistics and variable definitions are presented in Table 1. I also use data on *de jure* restrictions on capital flows and changes in international reserves to capture spillover heterogeneity arising from differences in capital account and exchange rate policies.

[9] Details are provided in Appendix G.

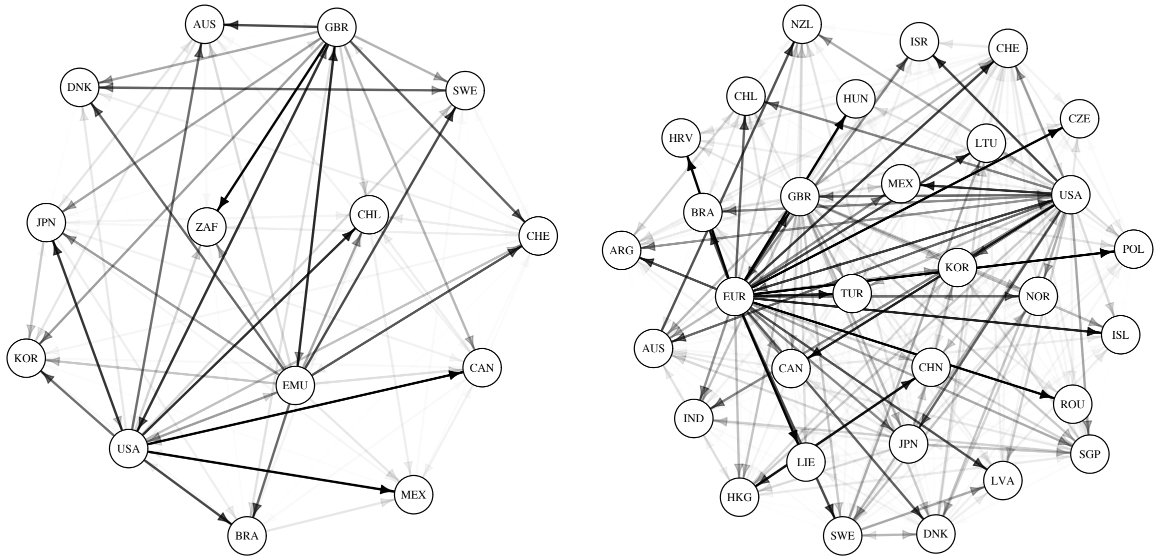
[10] See the detailed discussion on the time series properties of short-term interest rates contained in Shambaugh (2004).

[11] Full test results are presented in Appendix F.

[12] Details for each country are summarized in Appendix G.

Figure 2: Alternative Weighting Matrices ($\boldsymbol{W}$)

(a) Gross bilateral bank positions (b) Gross bilateral investment positions



Note: This figure depicts the network structure of gross bilateral bank positions (panel a) and gross bilateral investment positions (panel b), where all entries of each $\boldsymbol{W}$ matrix have been row normalized. Stronger (weaker) bilateral linkages are illustrated with darker (brighter) arrows. The bilateral bank positions matrix is time-varying and is depicted for the fourth quarter of 2016. The bilateral investment positions matrix is a constant average for the full sample window. Data for bilateral bank positions comes from the Bank for International Settlements (BIS) while data for bilateral investment was obtained from Hobza and Zeugner (2014).

Naturally, a key consideration is the network structure of interlinkages between economies, which must be specified *a priori* in order to construct the weighting matrices used to calculate spatial lags of the policy rate. In what follows I use weighting matrices built with data on gross bilateral bank financial positions and bilateral foreign asset positions, obtained from the BIS and Hobza and Zeugner (2014), respectively. These are depicted in Figure 2. As a robustness check, I consider additional alternative weighting matrices, including one constructed from gross bilateral trade flows.[13] All matrices are row-normalized such that the sum of any row is equal to one. For example, denoting by f_{ijt} the gross capital flows from country j to i at time t, the bilateral capital flows weight is calculated as:

$$w_{ijt} = \frac{f_{ijt}}{\sum_{j=1}^{N} f_{ijt}} \tag{8}$$

where the denominator is the row-sum at time t. Finally, all weighting matrices are lagged in order to minimize potential endogeneity concerns.

[13]See Appendix D for more details.

Table 2: Strategic spillover estimates under alternative first-stage specifications

Weighting Matrix ($\boldsymbol{W}$): Bilateral bank positions						
				dropping outliers		
	(1)	(2)	(3)	(4)	(5)	(6)
First-Stage Results						
$\boldsymbol{W} \cdot FEG$	0.122***			0.119***		
	(0.040)			(0.029)		
$\boldsymbol{W}^2 \cdot FEG$		0.215***			0.230***	
		(0.065)			(0.054)	
$\boldsymbol{W}^3 \cdot FEG$			0.276***			0.281***
			(0.078)			(0.063)
Second-Stage Results						
$\boldsymbol{Wr}$	0.708***	0.823**	0.782***	0.814***	0.778***	0.836***
	(0.214)	(0.338)	(0.242)	(0.240)	(0.300)	(0.265)
Observations	1008	1008	1008	928	932	937
Kleibergen-Paap F-stat	9.135	10.833	12.384	16.492	17.801	19.356
Anderson-Rubin test (χ^2)	3.945	4.835	5.018	5.393	4.295	4.762
p-value	0.047	0.028	0.025	0.020	0.038	0.029

Note: This table reports estimates of the strategic spillover coefficient $\hat{\delta}$ under alternative specifications for the first-stage. FEG refers to the forecast errors of real GDP growth, while $\boldsymbol{W}FEG$, $\boldsymbol{W}^2FEG$, and $\boldsymbol{W}^3FEG$ refer to its first-order, second-order, and third-order spatial lags, respectively. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.2 Static strategic spillovers

Estimates of the strategic spillover coefficient $\hat{\delta}$ and first-stage results using the bilateral bank positions weighting matrix are reported in Table 2. All models are estimated using two-step GMM and instrumenting neighbors' monetary policy with spatial lags of the forecast errors of real GDP growth. The benchmark model includes forecast errors of GDP growth and inflation and controls for the occurrence of the global financial crisis. Standard errors are estimated non-parametrically using the method proposed by Driscoll and Kraay (1998) and are robust to heteroskedasticity and arbitrary forms of temporal and spatial autocorrelation.[14]

The benchmark estimates suggest that monetary policies are strategic complements, as indicated by a positive and statistically significant spillover coefficient $\hat{\delta}$. On average, countries tighten monetary policy between 0.7 and 0.84 of a percentage point in response to a one percent tightening of foreign monetary policy.

[14]The spatial econometrics literature typically assumes the disturbance term is characterized by a first-order (or potentially higher order) spatial autoregressive process. The most popular estimation strategy is the Feasible Generalized Spatial Two-Stage Least Squares (FGS2SLS) estimator proposed by Kelejian and Prucha (1998), which has well-understood asymptotic properties and has been extended to accommodate a variety of richer models (See Prucha, 2014, for a recent survey of advances in this field). While in principle the FGS2SLS estimator can improve upon the efficiency of a traditional 2SLS estimator, this is only the case if the error-process is assumed to be correctly specified.

These estimates suggest that strategic spillovers are not only quite large but that the equilibrium reactions will amplify an initial shock.

Although, in principle, a wide set of spatially lagged covariates could be valid instruments, the inclusion of multiple instruments that are only weakly correlated with the endogenous regressor can give rise to a weak identification problem and bias our estimates of the strategic spillover coefficient. Since spatial lags of the unexpected component of real GDP growth appear to yield the strongest first-stage results, I opted for a more parsimonious exactly identified model.[15] Table 2 reports results from alternative first-stage specifications using the first, second, and third-order spatial lag of growth forecast errors. Intuitively, this amounts to instrumenting foreign monetary policies using the unexpected GDP growth of one's neighbors, neighbors' neighbors, and so forth.

First-stage results indicate that the instruments are relevant and that neighbors' monetary policy does indeed react to neighbors' macroeconomic conditions, as indicated by the Kleibergeen-Paap F-statistic, which exceeds the rule of thumb level of 10 in all but one specification. The third-order spatial lag of unexpected GDP growth appears to yield the strongest first-stage results. As such, I use this instrument in most subsequent specifications below. Using higher-order spatial lags as instruments has the additional advantage that these are more likely to satisfy the exclusion restriction, as these have increasingly indirect impacts on domestic conditions.

In order to test the sensitivity of the benchmark results, Table 3 reports several alternative specifications accounting for common factors, additional covariates, and different network structures. The models range from a stripped down specification without accounting for any form of common factors (column 1), to richer specifications controlling for global financial conditions (column 2), common and country-specific GFC effects (columns 3 and 4), time fixed-effects (column 5), and an expanded set of covariates (column 6). Panel (a) reports results using the bilateral bank financial positions weighting matrix, while the results in panel (b) use the bilateral investment positions matrix. As can be seen in the table, the results are broadly comparable across all six specifications. Perhaps unsurprisingly, failing to account for common factors (column 1) appears to bias the estimated spillover upwards.

3.3 Partial equilibrium and general equilibrium spillovers

While the strategic spillover coefficient $\hat{\delta}$ summarizes the average impact of a uniform change in foreign policy rates (i.e. $dr_{it}/d\bar{r}_{it} = \hat{\delta}$), we are also interested in characterizing the magnitude of spillovers arising from shocks in particular countries. The latter exercise involves two elements: (1) the direct partial equilibrium effects from, say, a shock in country ℓ on its neighbors, as well as (2) the resultant indirect general equilibrium

[15] It is worth noting, however, that overidentified models with multiple instruments yield qualitatively similar estimates. See Appendix A.

Table 3: Robustness of strategic spillover estimates to common factors and alternative specifications

(a) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral bank positions						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.882***	0.767***	0.782***	0.781***	0.666***	0.733***
	(0.236)	(0.195)	(0.242)	(0.244)	(0.143)	(0.201)
Observations	1008	966	1008	1008	1008	948
Kleibergen-Paap F-stat	6.801	7.783	12.384	12.493	10.669	15.369
Anderson-Rubin test (χ^2)	2.473	3.783	5.018	4.769	3.363	4.914
p-value	0.116	0.052	0.025	0.029	0.067	0.027
(b) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral investment position						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.896***	0.834***	0.694***	0.690***	0.725***	0.685***
	(0.173)	(0.159)	(0.231)	(0.241)	(0.141)	(0.218)
Observations	1715	1647	1715	1715	1715	1537
Kleibergen-Paap F-stat	6.286	8.236	11.996	11.688	13.242	16.193
Anderson-Rubin test (χ^2)	3.786	5.056	4.433	3.947	3.488	3.983
p-value	0.052	0.025	0.035	0.047	0.062	0.046
Common factors?	No	Yes	No	No	No	No
Common GFC effects?	No	No	Yes	No	No	No
Country-specific GFC effects?	No	No	No	Yes	No	No
Time FE?	No	No	No	No	Yes	Yes
Additional covariates?	No	No	No	No	No	Yes
Drop outliers?	No	No	No	No	No	Yes

Note: This table reports Two-Step GMM estimates of the SAR model in (4). The dependent variable is the first difference of the monetary policy interest rate. The vector of exogenous observables $\boldsymbol{X}_t$ includes lags of quarterly real GDP growth, the change in inflation, as well as country-specific forecasts of growth and inflation. Common factors refers to the inclusion of the VIX index and indices for the global price of oil and commodities. Additional covariates refers to the inclusion of lagged unemployment and changes in the real exchange rate. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

effects. Defining $\boldsymbol{W}_\ell$ as the vector given by the ℓ-th column of $\boldsymbol{W}$, the partial equilibrium strategic spillovers arising from a shock in country ℓ is given by:

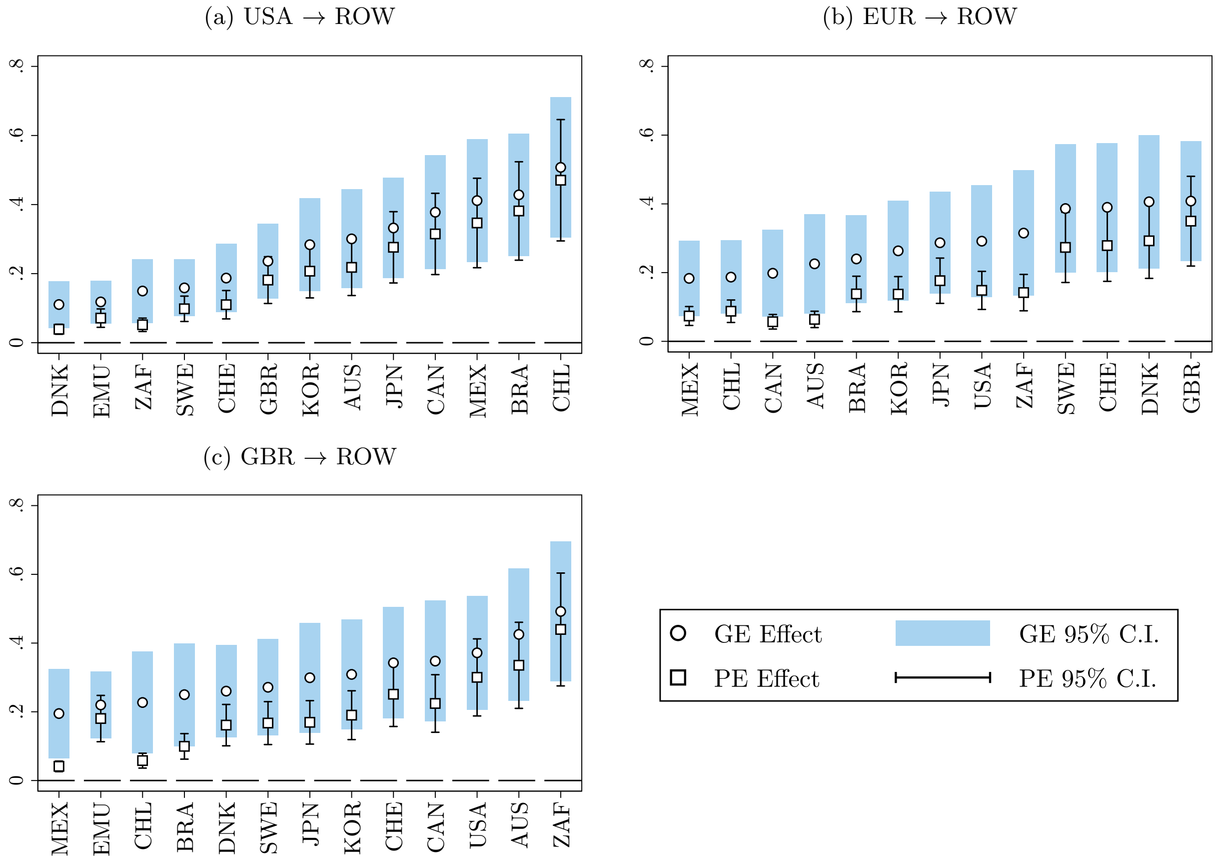
$$\boldsymbol{dr}_{PE} = \hat{\delta}\boldsymbol{W}_\ell du_\ell \tag{9}$$

where each element of $\boldsymbol{dr}_{PE}$ measures the direct reaction in a given country to a shock in country ℓ. Clearly, if a country is not linked to country ℓ the direct spillover effect will be zero. Similarly, we can use the model's reduced form (6) to express the general equilibrium spillover as:

$$\boldsymbol{dr}_{GE} = \boldsymbol{B}_\ell du_\ell \tag{10}$$

where $\boldsymbol{B}_\ell$ is the ℓ-th column of $\boldsymbol{B} = (\boldsymbol{I} - \hat{\delta}\boldsymbol{W})^{-1}$. Each element of $\boldsymbol{dr}_{GE}$ contains both the direct effects of a shock in country ℓ and the additional spillovers due to the endogenous responses of every other country in the network.

Figure 3: Partial ($\boldsymbol{dr}_{PE}$) and General ($\boldsymbol{dr}_{GE}$) equilibrium strategic spillover effects



Note: This figure reports the estimated general equilibrium (GE) and partial equilibrium (PE) spillovers from shocks originating in, respectively, the United States (panel a), Eurozone (panel b), and United Kingdom (panel c). The estimated model corresponds to specification (5) in Table 3 using the gross bilateral bank positions weighting matrix.

Figure 3 reports the estimated partial and general equilibrium spillover effects for the case using bilateral bank positions for the weighting matrix. Panel (a) shows the effects of a one percent shock to monetary policy in the U.S. on the rest of the world. Panels (b) and (c), in turn, show the effects on the rest of the world of shocks originating, respectively, in the Eurozone and United Kingdom. Unsurprisingly, the U.S. has relatively large spillovers on the rest of the world, with the largest GE effects taking place in Mexico, Canada, and Chile, all three of which have tight direct linkages to the United States. Similarly, monetary policy shocks in the Eurozone and United Kingdom also have rather large spillovers.

Although it is hardly surprising to find large spillover effects arising from the financial centers of the world on smaller economies and emerging markets, it is worth emphasizing that these results also point to important interdependencies *between* these large economies. For example, panel (c) of Figure 3 shows that shocks in the United Kingdom impose significant spillovers on the United States, with a GE elasticity of nearly 40 percent. In some cases, these interdependencies between large economies can amplify otherwise smaller shocks to third countries with comparatively small direct linkages to the source of the original shock. For instance, although the direct linkages from the United Kingdom to Mexico are small, as evidenced by a modest direct partial equilibrium spillover, Mexico is nevertheless highly exposed to shocks in the UK through its tight linkages to the United States, amounting to an indirect general equilibrium elasticity of approximately 20 percent.

3.4 Comparison of spillover specifications

This section illustrates the combined importance of endogenous strategic interactions and network structure by contrasting the estimated spillovers to those obtained from a model treating a single large country as the relevant exogenous "base." This could be thought of as a special case of a network model where the weight on every other country are zero and the base country is exogenous. Concretely, the base-country model is given by:

$$r_{it} = \gamma r_t^B + \boldsymbol{\beta} \boldsymbol{X}_{it} + u_{it} \tag{11}$$

where r_t^B is the first-differenced policy rate in the base country and γ measures the spillover effect on country i. It is worth noting that this model imposes a homogenous spillover effect on all countries, in contrast to the network model where the actual spillover effect will depend on the bilateral weight w_{ij}.

In order to compare the spillovers implied by the base-country and network models, I consider four alternative large reserve currency countries as the relevant base: the United States, United Kingdom, Eurozone, and Japan. This is shown in the first row of Table 4. On average, countries react to a one percent contractionary shock in the United States by tightening domestic policy by 0.18 percent. The elasticities are of a similar magnitude when other countries are chosen as the relevant base: 0.22, 0., and 0.14 for the United Kingdom, Eurozone, and Japan, respectively.

Next, Table 4 reports the *average* general equilibrium spillovers arising from a shock in a given country as estimated using the network model.[16] Presenting the average spillover, as opposed to the spillover coefficient $\hat{\delta}$, facilitates comparison with the base-country model. Row (2) reports the average spillovers using a network model that naively treats neighbors' monetary policy as exogenous. As can be seen in the table, failing to account for the endogeneity of the neighbors' policy biases the estimated average spillovers downward. Next, row (3) reports the average spillovers using two-step GMM.

Comparing rows (1) and (3), we can conclude that the base-country specification tends to underestimate the average spillover from large systemically important countries. This is especially true for the United

[16] Letting $\boldsymbol{B} = (\boldsymbol{I} - \hat{\delta}\boldsymbol{W})^{-1}$, the average spillover of a shock in country ℓ on every other country is given by:

$$E\left(\frac{dr_i}{dr_\ell}\right) = \frac{\sum_{i \neq \ell}^N \boldsymbol{B}_{i\ell}}{N-1} \tag{12}$$

Table 4: Comparison of average spillovers across alternative specifications

	United States		**United Kingdom**		**Eurozone**		**Japan**	
	dr_i/dr_B	SE	dr_i/dr_B	SE	dr_i/dr_B	SE	dr_i/dr_B	SE
(1) *Base-country*	0.175^{***}	(0.056)	0.223^{**}	(0.098)	0.155^{***}	(0.050)	0.142^{**}	(0.060)
Network model								
(2) *OLS*	0.117^{**}	(0.057)	0.099^{*}	(0.055)	0.107^{*}	(0.057)	0.019^{*}	(0.012)
(3) *2S-GMM*	0.325^{***}	(0.096)	0.335^{***}	(0.121)	0.337^{***}	(0.113)	0.072^{**}	(0.028)
Higher-order effects								
(4) *Avg. multiplier*	1.384^{***}	(0.106)	1.977^{***}	(0.284)	1.767^{***}	(0.204)	2.442^{***}	(0.413)
(5) *Share of total*	0.277^{***}	(0.055)	0.494^{***}	(0.073)	0.434^{***}	(0.065)	0.591^{***}	(0.069)

Note: This table reports the average spillover from country B for three alternative model specifications. The base-country specification (1) reports estimates of $\hat{\gamma}$ in (12), while (2) and (3) report estimates of $E(dr_i/dr_\ell)$ derived from the spatial/network model using both OLS and two-step GMM. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

States and the Eurozone: the average spillover in the base-country specification is nearly half the size of that obtained from the network model. As already noted, these dramatic differences are due to the absence of higher-order strategic feedback effects in the base-country model. This is illustrated in rows (4) and (5) of Table 4, which report, respectively, the implied average multiplier from a shock in each base country and the share of the average spillover explained by higher-order effects. As can be seen in the table, strategic interactions imply multipliers that are substantially greater than unity. As a result, a significant share of the total equilibrium monetary policy reaction is due to these high-order effects.

3.5 Capital account and exchange rate policies

Having established the existence of significant strategic spillovers, this section now examines heterogeneity arising from cross-country differences in capital account and exchange rate policies. Specifically, I estimate models that allow the strategic spillover coefficient to depend non-linearly on indicators of capital controls and exchange rate policy. That is, the extended model is given by:

$$r_{it} = (\delta_0 + \boldsymbol{\theta} \boldsymbol{K}_{it}) \cdot \bar{r}_{it} + \boldsymbol{\beta} \boldsymbol{X}_{it} + u_{it} \tag{13}$$

where $\bar{r}_{it}$, as before, is the spatial lag and $\boldsymbol{K}_{it}$ is a vector of indicators capturing a country's capital account and exchange rate policies. The coefficients $\boldsymbol{\theta}$ therefore measure the differences in country i's endogenous response to its neighbors' policy due to the presence of capital controls and exchange rate policy. Intuitively, a positive and significant coefficient on the interaction term for, say, an indicator of capital account restrictions would indicate that capital controls amplify spillovers and therefore decrease monetary autonomy. Conversely, a negative and significant interaction term would indicate that the policy regime in question

Table 5: Strategic spillovers under capital account and exchange rate policies

Weighting Matrix ($\boldsymbol{W}$): Gross bilateral bank positions						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.817***	0.867***	0.876***	0.835***	0.878***	0.890***
	(0.170)	(0.174)	(0.150)	(0.164)	(0.172)	(0.150)
$\boldsymbol{Wr} \cdot K_{CI}$	-0.589**			-0.622**		
	(0.285)			(0.277)		
$\boldsymbol{Wr} \cdot K_{SCH}$		-0.721**			-0.733***	
		(0.298)			(0.269)	
$\boldsymbol{Wr} \cdot K_{IN}$			-0.952***			-0.973***
			(0.321)			(0.331)
$\boldsymbol{Wr} \cdot RES$				-0.032	-0.025	-0.027
				(0.032)	(0.021)	(0.020)
Closed capital account spillover						
$\hat{\delta}_0 + \hat{\theta}_1$	0.229	0.145	-0.076	0.213	0.145	-0.084
	(0.240)	(0.228)	(0.293)	(0.238)	(0.200)	(0.291)
Observations	952	884	884	952	884	884

Note: This table reports control function estimates of model (13). K_{CI}, K_{SCH}, and K_{IN} refer, respectively, to the inverse Chinn-Ito index of capital mobility, the Schindler index of capital controls, and the Schindler index of controls on capital inflows. RES denotes changes in international reserves as a percent of GDP. The endogenous spatial lag of monetary policy is instrumented using the third-order spatial lag of GDP growth forecast errors. Bootstrap standard errors with 500 repetitions in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

insulates countries against spillovers and increases monetary autonomy.

To capture international differences in capital account policies, I rely on two *de jure* indices widely used in the literature: the Chinn-Ito index (Chinn and Ito, 2006) and the narrative Schindler indexes (Fernandez et al., 2016). The latter indexes have the advantage of providing disaggregated subindexes for restrictions on capital inflows and outflows. To capture differences in exchange rate policy, I use reserve accumulation as a percentage of GDP.[17] Capital controls and reserve accumulation are included as lags in every specification in order to minimize potential concerns of simultaneity bias.

Estimation results for the extended models are reported in Table 5. All models are estimated using the control function (CF) approach, which involves controlling for the residuals from the first-stage when estimating the effect of the endogenous explanatory variable. CF estimation parsimoniously handles non-linear effects of the endogenous explanatory variable and can be more efficient than instrumental variable

[17] In principle, one could also include interaction terms for an index of the exchange rate regime, such as the *de facto* classification provided by Ilzetski, Reinhart, and Rogoff (IRR) (Ilzetzki et al., 2017). One problem with using the IRR classification is that very few countries in my sample are classified as "floating" regimes and there is limited variation across time. Additionally, it is not obvious how to handle the case of the Eurozone, which is a currency union from the perspective of its member countries but is arguably a flexible exchange regime vis-a-vis the rest of the world. Finally, it is often the case that countries classified as having a flexible exchange rate regime nevertheless intervene actively in foreign exchange markets.

methods in this setting.[18] All standard errors in Table 5 are calculated by bootstrapping.

The first three specifications in columns (1)-(3) consider the impact of capital account restrictions separately while models (4)-(6), in turn, additionally control for changes in international reserves. The coefficient for the term $\boldsymbol{Wr}$ measures the base strategic spillover effect in the absence of capital controls or reserve accumulation while the coefficients on each interaction term capture the difference relative to the baseline. The main takeaway from this exercise is that capital account restrictions appear to provide strong immediate insulation against foreign monetary policy shocks. This is evidenced by the negative and significant interaction terms for each of the capital control indices considered in Table 5. Indeed, the marginal effect $(\hat{\delta}_0 + \hat{\theta}_1)$ of foreign monetary policy is not statistically different from zero in countries with tight capital controls. In contrast, exchange rate policy, as captured by the changes in reserves, does not appear to have a significant effect on the magnitude of spillovers.

4 Dynamics

Whereas the previous sections of this paper has provided evidence on the existence of *static* or *contemporaneous* strategic interactions between central banks, this section investigates the dynamic properties of spillovers. To accomplish this, I use the semi-parametric approach of local projections proposed by Jordà (2005) to estimate impulse response functions. Local projections have the advantage that they are easily implemented in a panel data context and can be combined with instrumental variables techniques in order to identify the dynamic treatment effect of a shock (see Jordà et al., 2017). The basic idea behind a local projection is to estimate the impact of a shock at time t on leads of the dependent variable at various points over the forecast horizon $h = 1, 2, \ldots, H$. The impulse response h periods after the initial shock can be estimated by simply replacing the dependent variable with an h-period ahead lead.

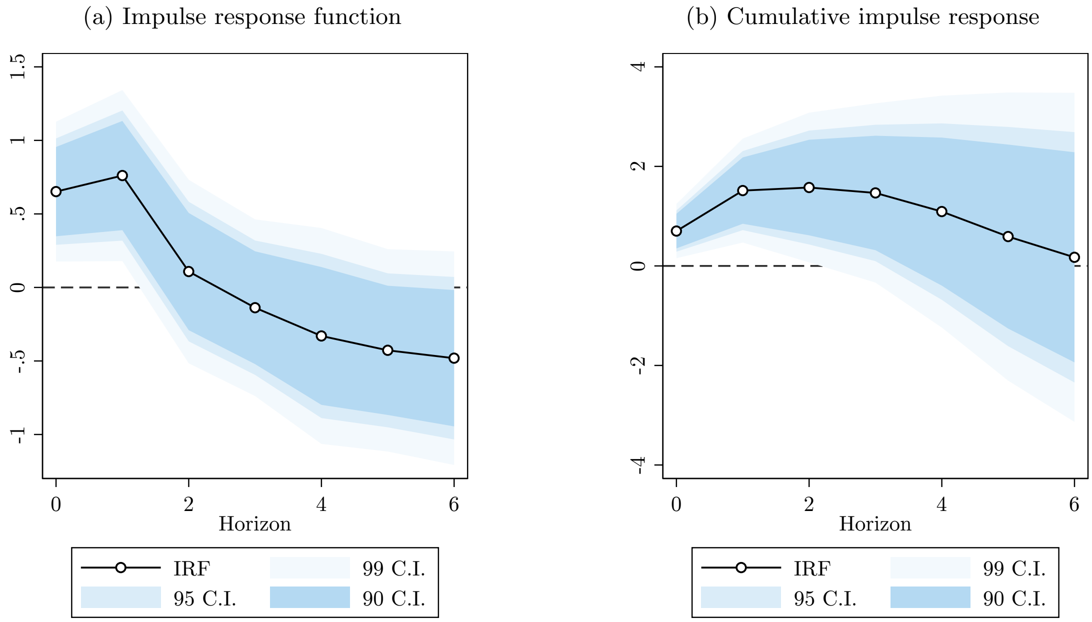
In our specific setting, we can estimate the impulse response function for a change in foreign monetary policy using:

$$\boldsymbol{r}_{t+h} = \delta_h \boldsymbol{W}\boldsymbol{r}_t + \boldsymbol{\beta}_h \boldsymbol{X}_t + \boldsymbol{u}_t \qquad \text{for} \quad h = \{1, 2, \ldots, H\} \tag{14}$$

where $\boldsymbol{r}_{t+h}$ denotes the vector of policy rate changes at horizon h. The impulse response at horizon h is given by δ_h, where it is worth noting that the coefficient is indexed by h since the response is estimated individually at each horizon. Local projections can also be used to estimate a *cumulative* impulse response function by replacing the left-hand-side variable with $\Delta_h \boldsymbol{R}_t = \boldsymbol{R}_{t+h} - \boldsymbol{R}_{t-1}$, where R_{it} refers to the *level* of the policy rate target (as opposed to the first-difference). As in the static spatial/network model considered above, foreign monetary policy is endogenous due to the existence of strategic interdependence. Therefore,

[18] See Wooldridge (2015) for a recent review.

Figure 4: Impulse response function for a 1% shock to $\boldsymbol{Wr}$



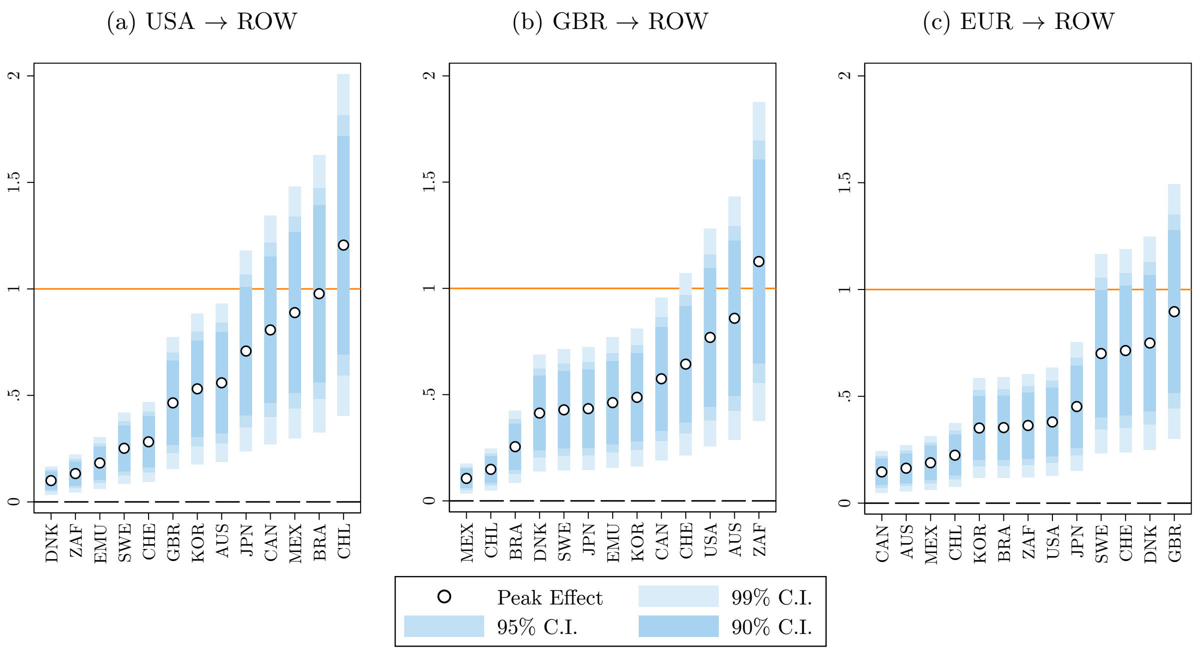
Note: This figure reports impulse response and cumulative impulse response functions (panel a and b, respectively) estimated by local projection using Two-Step GMM estimates of (14). The spatial lag $\boldsymbol{Wr}$ is instrumented using the third-order spatial lag of unexpected GDP growth. Standard errors are calculated using the method proposed by Driscoll and Kraay (1998) and are robust to heteroskedasticity, temporal autocorrelation, as well as arbitrary forms of spatial correlation.

as before, the impulse response is estimated using two-step GMM and instrumenting using spatial lags of unexpected GDP growth.

Figure 4 depicts the estimated impulse response and cumulative impulse functions, along with 99, 95, and 90 percent confidence bands. The specifications correspond to model (2) in Table 3 using the gross bilateral bank positions weighting matrix and augmented with lags of the dependent variable and its spatial lag. The contemporaneous spillover effect at $h = 0$ is approximately 0.65 and roughly corresponds to the static specification reported above. As the wide confidence bands at later horizons indicate, the reaction of monetary policy to foreign shocks highly heterogeneous. Nevertheless, we can characterize its broad path. The cumulative reaction appears to peak after two quarters, reaching a cumulative elasticity of 1.6, substantially exceeding the immediate contemporaneous effect. In addition, the cumulative effect fades back to zero after about six quarters, suggesting that these strategic reactions are quite rapid.

In order to properly interpret the magnitude of the effects, Figure 5 presents the peak partial equilibrium effects after three quarters for shocks originating in the United States, the Eurozone, and the United Kingdom (panels a, b, and c, respectively). The vector of peak effects from a shock in the ℓ-th country can be calculated

Figure 5: Peak partial equilibrium spillover effects



Note: This figure reports the peak partial equilibrium spillovers after three quarters due to shocks originating in, respectively, the United States (panel a), Eurozone (panel b), and United Kingdom (panel c). The estimated model corresponds to specification (2) in Table 3 using the gross bilateral bank positions weighting matrix.

as:

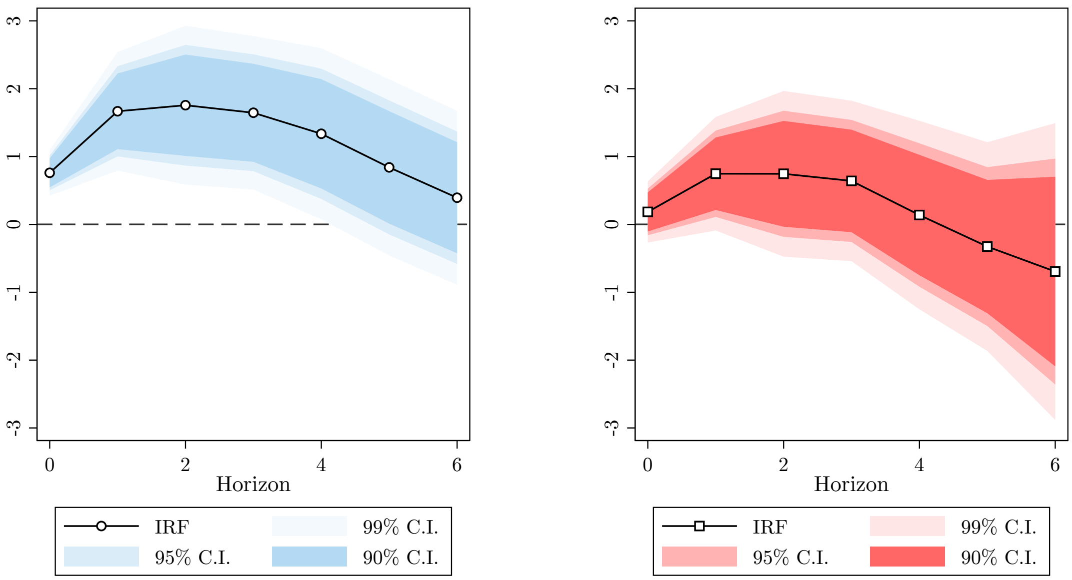
$$\boldsymbol{dr}_{peak} = \hat{\delta}_{peak}\boldsymbol{W}_{\ell}du_{\ell} \tag{15}$$

where the coefficient $\hat{\delta}_{peak}$ is the peak cumulative impulse response at $h = 2$ and $\boldsymbol{W}_{\ell}$ denotes the ℓ-th column of the weighting matrix. It is useful to compare the estimated peak effects to the case of full pass-through, where a monetary policy shock in a large country is matched by a one-to-one change in domestic monetary policy (i.e. $\hat{\delta}_{peak}\boldsymbol{W}_{\ell} = 1$). This case is depicted by the orange horizontal line. As can be seen in panel (a) for the case of a shock originating in the U.S., we cannot reject the full pass-through null at standard confidence levels for Chile, Brazil, Canada, Mexico, and Japan. These results suggest that these economies have little monetary autonomy vis-a-vis the United States and import its monetary policy due to their tight financial ties.

Figure 5 also underscores the highly integrated nature of linkages between these advanced economies. What is perhaps most remarkable is the strong implied peak spillovers from the Eurozone on the United States. While the point estimate for the peak effect of a shock in the Eurozone on the U.S. is well below unity, as panel (b) reports, we nevertheless cannot reject the full pass-through null at standard confidence levels.

Figure 6: Impact of capital account policies

(a) Liberalized capital account ($K_{SCH} = 0$) (b) Regulated capital account ($K_{SCH} = 1$)



Note: This figure reports heterogeneous cumulative impulse response functions for countries with open and closed capital accounts (panels a and b, respectively) estimated by local projection using control function methods. The spatial lag $\boldsymbol{Wr}$ is instrumented using the third-order spatial lag of unexpected GDP growth. Confidence bands were obtained by bootstrapping, $R = 500$.

4.1 Capital account and exchange rate policies: dynamics

As above, I also consider heterogeneity in the strategic spillover effect arising from differences in capital account and exchange rate policies by including interaction effects in the local projection. Specifically, I estimate impulse response functions corresponding to the static model in column (5) of Table 5, where the response is a function of both the Schindler index of capital account restrictions (K_{SCH}) and changes in reserves (RES). The heterogeneous impulse responses are estimated using control function methods and bootstrapping to obtain standard errors. Figure 6 reports cumulative impulse responses for the case of full financial liberalization (panel a) and a completely regulated capital account (panel b).

As can be seen comparing both panels of Figure 6, countries with tight capital controls appear to react systematically less to foreign monetary shocks than full liberalized countries. Indeed, when countries have capital controls we are not able to reject the no reaction null hypothesis at most horizons. Although once again there is considerable uncertainty around the responses at later horizons, the effect of capital controls is statistically significant. Formal tests of the difference between the impulse responses of financially open and closed economies are reported in Table 6. The table reports estimates of the baseline response at horizons $h = \{0, 1, \ldots H\}$, as well as the interaction term, which measures the difference relative to the base. As can

Table 6: Dynamic effect of capital controls

Horizon	$\boldsymbol{Wr}$		$\boldsymbol{Wr} \cdot K_{SCH}$		K_{SCH}	
	$\hat{\delta}_{0,h}$	SE	$\hat{\theta}_{1,h}$	SE	η_h	SE
$h = 0$	0.760***	(0.124)	-0.576**	(0.228)	-0.001	(0.001)
$h = 1$	1.667***	(0.332)	-0.920***	(0.319)	-0.001	(0.001)
$h = 2$	1.757***	(0.463)	-1.011**	(0.431)	-0.001	(0.002)
$h = 3$	1.645***	(0.427)	-1.004***	(0.370)	-0.001	(0.002)
$h = 4$	1.335***	(0.475)	-1.197***	(0.427)	-0.001	(0.003)
$h = 5$	0.840*	(0.495)	-1.167**	(0.481)	-0.001	(0.003)
$h = 6$	0.393	(0.509)	-1.088	(0.707)	-0.001	(0.003)
$h = 7$	0.107	(0.617)	-1.018	(0.803)	-0.002	(0.003)
$h = 8$	0.067	(0.655)	-0.799	(0.845)	-0.002	(0.003)

Note: This table reports heterogeneous cumulative impulse response functions for countries with open and closed capital accounts (panels a and b, respectively) estimated by local projection using control function methods. The spatial lag $\boldsymbol{Wr}$ is instrumented using the third-order spatial lag of unexpected GDP growth. Bootstrap standard errors with $R = 500$ repetitions shown in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

be seen in the table, the interaction term is negative and statistically significant at standard confidence levels, indicating that the existence of a difference between countries with open and regulated capital accounts.

5 Robustness Exercises

Having established this paper's core results, this section now briefly discusses a series of robustness exercises. Full results are reported in the Appendix. The main results are robust to several alternative first-stage specifications, different estimators, as well as different weighting matrices. For example, Appendix A reports results for overidentified models using $\boldsymbol{W}^2\boldsymbol{X}$ and $\boldsymbol{W}^3\boldsymbol{X}$ as instruments in the first stage. These overidentified models yield qualitatively similar, albeit somewhat smaller, estimates of the strategic spillover coefficient.[19]

Another way to examine the robustness of first-stage specifications is to choose the identifying instruments using some type of data-driven criteria. This is especially desirable in the context of a spatial/network model since the reduced form solution (7) implies, in principle, the existence of an infinite number of valid instruments (corresponding to increasingly higher-order spatial lags). Therefore, as an additional robustness check, Appendix C reports results applying high-dimensional IV methods proposed by Chernozhukov et al. (2015). Intuitively, this approach uses LASSO (or related sparse-selection algorithms) to select the relevant set of instruments by penalizing more complex models.[20] Reassuringly, high-dimensional estimates of the strategic spillover coefficient are broadly comparable to my benchmark results.

[19] This is likely due a weak instruments problem, which may bias the coefficient estimates towards OLS. See Appendix A for more details.

[20] See Appendix C for a detailed discussion.

Additionally, I assess the role of alternative network structures. While I have argued that financial linkages are the relevant channel for the transmission of monetary policy spillovers, it is useful to consider alternative weighting matrices. Appendix D estimates the benchmark models assuming two alternative network structures: (1) gross bilateral trade linkages, and (2) relative output sizes. The latter matrix captures the idea that relatively larger economies may have a disproportionate impact on global financial markets and therefore impose greater spillovers on smaller economies.

Finally, network structure misspecification is a general concern and it is therefore desirable to understand what type of bias this may introduce. As such, I also carry out a simple placebo simulation test to assess potential bias arising from specifying the wrong weighting matrix or measurement errors in the strength of the bilateral linkages. The idea behind this exercise is to randomly reshuffle the links in the weighting matrix $\boldsymbol{W}$, re-estimate the model using the observed data, and thus obtain the distribution of $\hat{\delta}$ using a large number of "placebo networks." The placebo exercise suggest that the probability of obtaining the observed benchmark results from network misspecification alone is extremely low.

6 Conclusion

This paper has investigated the existence and magnitude of strategic spillovers from monetary policy across countries. By treating monetary policy in every country as potentially endogenous and taking into account the network structure of financial linkages, I have presented evidence that strategic spillovers are sizable and depend, in part, on a country's capital account policies. These results are robust to several alternative network weighting matrices, common factors, and sets of identifying instruments.

The existence of large and significant strategic spillovers suggests that one potentially important channel for the international transmission of country-specific shocks are the endogenous reactions of central banks in neighboring economies. Significant strategic spillovers also convey useful information about the relative magnitude of the underlying transmission channels. In particular, from the perspective of a domestic monetary authority, macroeconomic spillovers must pose meaningful threats to the achievement of domestic objectives in so far as monetary policy in one country compels a policy adjustment in another.

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A Overidentified models

This appendix reports results for overidentified models using multiple instruments in the first-stage. Specifically, every model in Table A.7 instruments $\boldsymbol{Wr}$ using second-order and third-order spatial lags of real growth and inflation forecast errors. The overidentified estimates of $\hat{\delta}$ are qualitatively similar to those reported above, albeit somewhat smaller. This is likely due to a weak instruments problem, as the overidentified models exhibit substantially smaller first-stage F-statistics.

Table A.7: Estimates of strategic spillovers $\hat{\delta}$ with overidentified models

(a) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral bank positions						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.804***	0.731***	0.731***	0.693***	0.637***	0.638***
	(0.133)	(0.141)	(0.194)	(0.191)	(0.117)	(0.162)
Observations	1008	966	1008	1008	1008	950
Kleibergen-Paap F-stat	2.400	1.978	3.408	3.378	5.114	6.937
Overidentification test	0.182	0.673	0.129	0.347	0.240	0.517
Anderson-Rubin test (χ^2)	3.476	4.609	5.633	5.518	3.971	5.189
p-value	0.482	0.330	0.228	0.238	0.410	0.268
(b) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral investment						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.838***	0.814***	0.720***	0.628***	0.672***	0.632***
	(0.117)	(0.114)	(0.216)	(0.182)	(0.123)	(0.174)
Observations	1715	1647	1715	1715	1715	1540
Kleibergen-Paap F-stat	2.962	2.631	3.894	4.269	4.227	5.144
Overidentification test	1.631	1.451	1.704	2.125	2.361	1.296
Anderson-Rubin test (χ^2)	5.420	7.970	6.105	5.049	5.848	5.561
p-value	0.247	0.093	0.191	0.282	0.211	0.234
Common factors?	No	Yes	No	No	No	No
Common GFC effects?	No	No	Yes	No	No	No
Country-specific GFC effects?	No	No	No	Yes	No	No
Time FE?	No	No	No	No	Yes	Yes
Additional covariates?	No	No	No	No	No	Yes
Drop outliers?	No	No	No	No	No	Yes

Note: This table reports Two-Step GMM estimates of the SAR model in (4). The dependent variable is the first difference of the monetary policy interest rate. The vector of exogenous observables $\boldsymbol{X}_t$ includes lags of quarterly real GDP growth, the change in inflation, as well as country-specific forecasts of growth and inflation. Common factors refers to the inclusion of the VIX index and indices for the global price of oil and commodities. Additional covariates refers to the inclusion of lagged unemployment and changes in the real exchange rate. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

B CUE estimates

Table B.8: CUE estimates of strategic spillover $\hat{\delta}$

(a) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral bank positions						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	0.882^{***}	0.767^{***}	0.782^{***}	0.781^{***}	0.666^{***}	0.733^{***}
	(0.236)	(0.195)	(0.242)	(0.244)	(0.143)	(0.201)
Observations	1008	966	1008	1008	1008	948
Kleibergen-Paap F-stat	6.801	7.783	12.384	12.493	10.669	15.369
Anderson-Rubin test (χ^2)	2.473	3.783	5.018	4.769	3.363	4.914
p-value	0.116	0.052	0.025	0.029	0.067	0.027
Common factors?	No	Yes	No	No	No	No
Common GFC effects?	No	No	Yes	No	No	No
Country-specific GFC effects?	No	No	No	Yes	No	No
Time FE?	No	No	No	No	Yes	Yes
Additional covariates?	No	No	No	No	No	Yes
Drop outliers?	No	No	No	No	No	Yes

Note: This table reports CUE estimates of the SAR model in (4). The dependent variable is the first difference of the monetary policy interest rate. The vector of exogenous observables $\boldsymbol{X}_t$ includes lags of quarterly real GDP growth, the change in inflation, as well as country-specific forecasts of growth and inflation. Common factors refers to the inclusion of the VIX index and indices for the global price of oil and commodities. Additional covariates refers to the inclusion of lagged unemployment and changes in the real exchange rate. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

C High-dimensional controls and instruments

While the reduced form solution of the empirical model provides a clear rationale for instrumenting the endogenous foreign monetary policy rates using higher-order spatial lags of the macroeconomic observables $\boldsymbol{X}$, it does not provide obvious guidance on which instruments to choose. In fact, as expression (7) makes clear, one could in principle use an infinite number of spatial lags in the first-stage. While this is clearly not feasible in practice, it does raise the question of whether it is possible to improve the performance of our estimator by "optimally" choosing the instruments in the first-stage through a data-driven approach.

I now present an additional robustness exercise where the set of instruments in the first-stage are selected using the approach proposed by Chernozhukov et al. (2015), which applies high-dimensional estimation techniques to an IV setting with many instruments and potentially high-dimensional controls. The essence of the CHS approach is to conduct LASSO (or a similar high-dimensional sparse selection estimator) on the first and second stages separately in order to construct orthogonalized versions of the dependent variable and the endogenous treatment variable and to obtain optimal instruments from the variables selected by LASSO. These the orthogonalized variables and optimal instrument can then be used with the 2SLS estimator. Another related approach is to use the control variables and instruments selected by the CHS routine in a conventional 2SLS or GMM estimator.

Results for both of these approaches are presented in Table C.9. Orthogonalized 2SLS refers to the CHS approach, while post-LASSO GMM refers to the conventional two-step GMM estimator using the LASSO selected instruments and controls. I consider penalty loadings for the LASSO models that are robust to heteroskedasticity and two alternative-forms of clustering. I allow LASSO to select among every possible instrument suggested by (7) up to the third-order spatial lag for every observable $\boldsymbol{X}$. Taking full advantage of the CHS approach, I also include in the selection process a rich set of alternative specifications to account for unobserved heterogeneity, including polynomials of country-specific trends, heterogeneous effects from the global financial crisis, and large a set of additional macroeconomic observables.

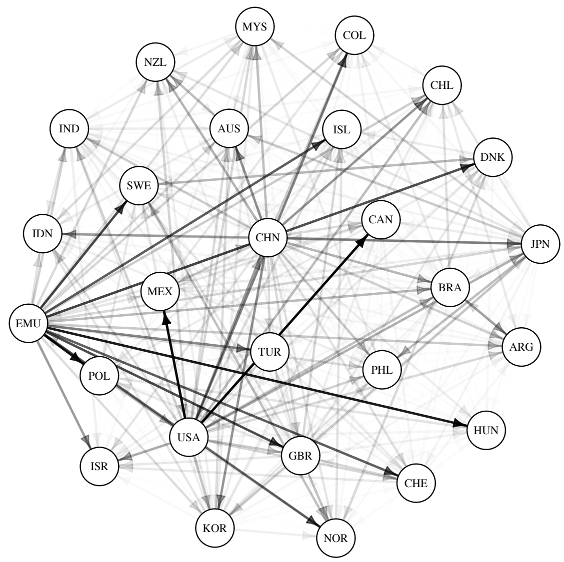
As can be seen in the table, the main results are robust to these LASSO selection methods. In particular, the estimates of the strategic spillover coefficient are broadly comparable to the benchmark estimates and are statistically significant at standard confidence levels.

Table C.9: High dimensional models

Penalty Loading Cluster:	*Year*		*Country*	
Estimator:	LASSO	S-LASSO	LASSO	S-LASSO
	(1)	(2)	(3)	(4)
(a) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral bank positions				
Orthogonalized 2SLS	0.571^{*}	0.437	0.765^{***}	0.663^{**}
	(0.310)	(0.267)	(0.258)	(0.286)
Post-LASSO GMM	0.667^{**}	0.475^{**}	0.557^{***}	0.530^{***}
	(0.331)	(0.207)	(0.119)	(0.140)
Anderson-Rubin Weak Inst. Test (χ^2)	2.863	3.007	7.967	7.037
AR (p-value)	0.091	0.083	0.019	0.030
(b) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral trade				
Orthogonalized 2SLS	0.983^{**}	0.790^{**}	1.087^{***}	1.069^{***}
	(0.390)	(0.372)	(0.339)	(0.361)
Post-LASSO GMM	1.058^{***}	0.767^{***}	0.588^{***}	0.724^{***}
	(0.328)	(0.195)	(0.174)	(0.181)
Anderson-Rubin Weak Inst. Test (χ^2)	5.902	6.745	8.093	10.365
AR (p-value)	0.015	0.009	0.017	0.006

Note: *Orthogonalized 2SLS* refers to the CHS "post-regularization" estimator proposed by Chernozukhov, Hansen, and Splinder (2015). *Post-LASSO GMM* refers to two-step GMM using the instruments and controls selected by the CHS estimator. *S-LASSO* refers to the square-root LASSO estimator.

Figure D.7: Gross bilateral trade



D Alternative weighting matrices

Gross bilateral banking positions

Source: BIS Locational Banking Statistics.

Time-varying?: Yes.

Gross bilateral trade

Source: IMF Direction of Trade Statistics.

Time-varying?: Yes.

Gross bilateral investment positions

Source: Hobza and Zeugner (2014).

Time-varying?: No.

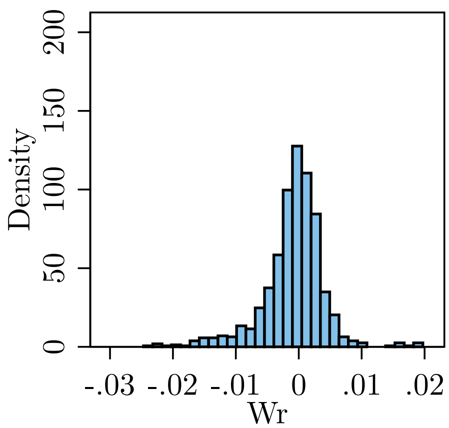
Relative GDP

Source: IMF World Economic Outlook.

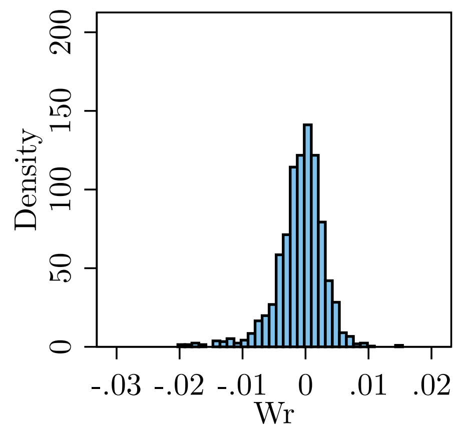
Time-varying?: Yes.

Figure D.8: Distribution of spatial lag $\boldsymbol{Wr}$

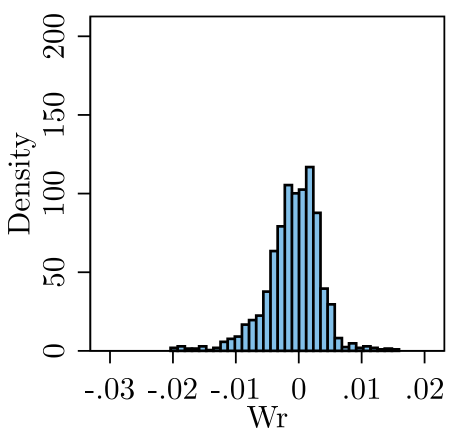
(a) $\boldsymbol{W}$ = Bilateral bank positions



(b) $\boldsymbol{W}$ = Bilateral trade



(c) $\boldsymbol{W}$ = Bilateral investment positions



(d) $\boldsymbol{W}$ = Relative GDP

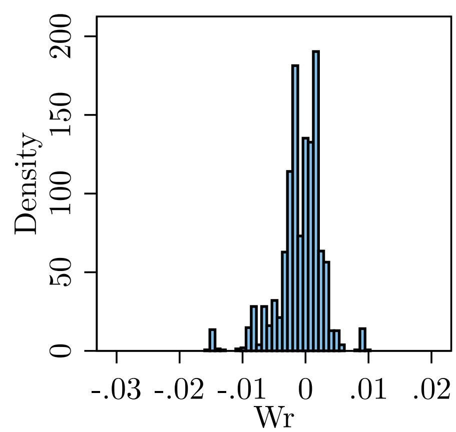


Table D.10: Estimates of strategic spillover $\hat{\delta}$ with alternative weighting matrices

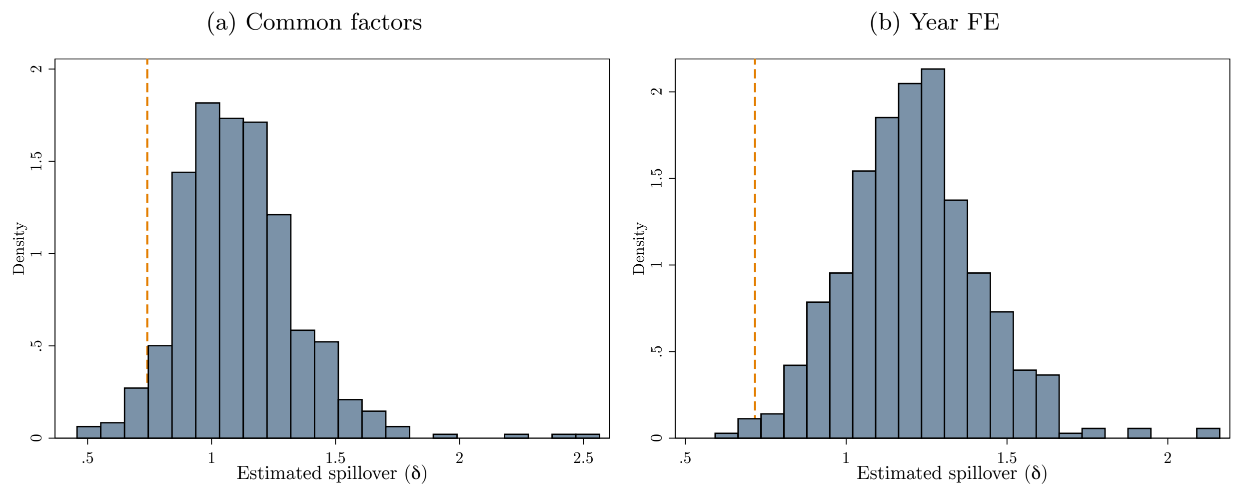
(a) Weighting Matrix ($\boldsymbol{W}$): Gross bilateral trade						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	1.078***	0.980***	1.046***	1.034***	0.881***	0.898***
	(0.201)	(0.186)	(0.270)	(0.264)	(0.136)	(0.207)
Observations	1757	1693	1757	1757	1757	1589
Kleibergen-Paap F-stat	9.747	10.790	15.259	15.732	9.853	11.360
Anderson-Rubin test (χ^2)	3.819	5.810	8.585	8.214	4.279	4.342
p-value	0.051	0.016	0.003	0.004	0.039	0.037
(b) Weighting Matrix ($\boldsymbol{W}$): Relative output size						
	(1)	(2)	(3)	(4)	(5)	(6)
$\boldsymbol{Wr}$	1.144***	1.070***	1.116***	1.092***	0.893***	0.664***
	(0.216)	(0.202)	(0.357)	(0.351)	(0.161)	(0.237)
Observations	1757	1693	1757	1757	1757	1568
Kleibergen-Paap F-stat	6.647	8.919	7.497	7.324	8.393	5.730
Anderson-Rubin test (χ^2)	3.691	5.069	5.489	4.973	3.912	3.765
p-value	0.055	0.024	0.019	0.026	0.048	0.052
Common factors?	No	Yes	No	No	No	No
Common GFC effects?	No	No	Yes	No	No	No
Country-specific GFC effects?	No	No	No	Yes	No	No
Time FE?	No	No	No	No	Yes	Yes
Additional covariates?	No	No	No	No	No	Yes
Drop outliers?	No	No	No	No	No	Yes

Note: This table reports Two-Step GMM estimates of the SAR model in (4). The dependent variable is the first difference of the monetary policy interest rate. The vector of exogenous observables $\boldsymbol{X}_t$ includes lags of quarterly real GDP growth, the change in inflation, as well as country-specific forecasts of growth and inflation. Common factors refers to the inclusion of the VIX index and indices for the global price of oil and commodities. Additional covariates refers to the inclusion of lagged unemployment and changes in the real exchange rate. Driscoll-Kraay standard-errors are reported in parenthesis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

E Placebo networks

In this section, I report results from a "placebo exercise" intended to shed light on the resilience of the estimates to misspecification of the weighting matrix. This is potentially important for two reasons. First, data on bilateral financial positions and trade likely contain some degree of measurement error, which introduces noise into the network structure of interlinkages and, consequently, the spatial lag as well. Second, although I have argued that bilateral financial linkages and trade are the relevant linkages for the transmission of international spillovers, it is possible to conceive of alternative weighting schemes. More generally, it would be reassuring to be able to place approximate bounds on the direction and magnitude of the bias introduced by misspecification of the network.

Figure E.9: Distribution of placebo network effects vs. actual estimate



Note: This figure compares $\hat{\delta}$ to the distribution of $P = 500$ placebo estimates. The dashed orange line denotes $\hat{\delta}$ using the empirically observed network $\boldsymbol{W}$. Panel (a) considers a specification controlling for common factors, while the specification in panel (b) includes year fixed effects.

To understand this potential bias, I draw a large sample of random "placebo networks" and combine these with the observed data to obtain placebo estimates of the spillover coefficient. The networks are randomized by reshuffling the links in the observed matrix of bilateral financial stocks so as to preserve the original distribution of edges. The reshuffled weight matrix $\tilde{\boldsymbol{W}}$ can then be used to construct a placebo spatial lag using the observed policy rates, $\tilde{\boldsymbol{r}} = \tilde{\boldsymbol{W}}\boldsymbol{r}$, and obtain placebo estimates of the spillover coefficient. The placebo exercise can be summarized by the following simple algorithm:

1. Reshuffle weight matrix $\boldsymbol{W}$ to obtain $\tilde{\boldsymbol{W}}$

2. Construct placebo spatial lag of the policy rate $\tilde{\boldsymbol{r}} = \tilde{\boldsymbol{W}}\boldsymbol{r}$

3. Estimate $\boldsymbol{r} = \delta\tilde{\boldsymbol{r}} + \boldsymbol{\beta X} + \boldsymbol{u}$ to obtain placebo spillover $\tilde{\delta}$

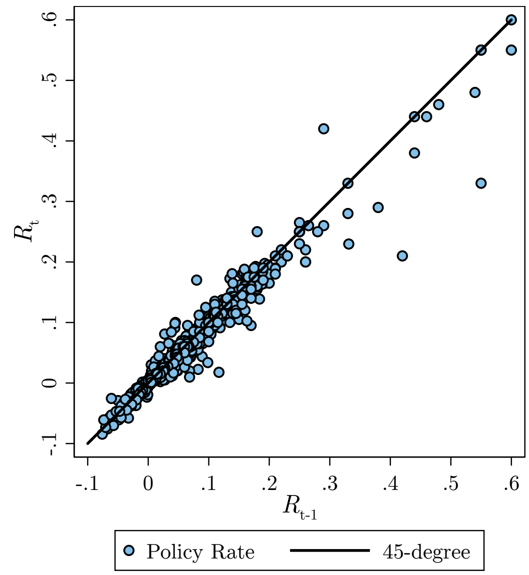
4. Repeat P times

I consider two different simulations with $P = 500$ random draws. The first is a specification controlling for common factors analogous to model (2) in Table 3. The second includes year fixed effects as in (3) in Table 3. The simulation results are reported in Figure E.9, which depicts the distribution of placebo estimates (in dark blue) and compares them to the observed spillover coefficient (indicated by the dashed orange line). As can be seen in the figure, misspecification of the network tends to bias the estimated coefficient upwards and therefore overstates the size of the strategic spillover. Misspecification of the network therefore implies a considerable obstacle for inference, although, reassuringly the probability of actually observing our estimated spillovers from a randomized network is low. Indeed, for both specifications the probability of observing the estimated spillover is less than one percent.

This exercise also may help explain why using the bilateral trade weighting matrix tends to yield somewhat larger spillover estimates relative to those weighted by capital flows. If we assume that financial linkages are the most important channel for the transmission of spillovers, bilateral trade linkages could be seen as a noisy proxy expected to bias the spillover upward.

F Unit Root Tests

Figure F.10: Policy rate persistence



This appendix presents tests for the stationarity properties of the monetary policy rate R_{it}. Figure F.10 plots the policy rate against its lagged level. As the figure illustrates, the policy rate exhibits substantial persistence and indicates the possibility of the existence of a unit root, with significant amount of data clustered around the 45-degree line. Formal country-specific and panel-based unit root tests are presented in Tables F.11 and F.12, respectively. As the country-specific tests indicate, we fail to reject the unit root null for well over half of the countries in the sample.

Panel tests, which provide additional power, yield similarly mixed results. While a majority of homogenous tests that impose a common autoregressive parameter on each panel are able to reject the null, they do so at only a 10 percent significance level. In contrast, a majority of heterogeneous tests allowing for panel-specific AR parameters fail to reject the null. It is worth highlighting that the one heterogeneous test that rejects the null hypothesis, Pesaran's Cross-sectionally Augmented Dickey-Fuller (CADF) test, is robust to cross-sectional dependence and therefore may have greater power in a setting where spatial dependence is important. Nevertheless, the alternative hypothesis in the CADF test is that a *fraction* of the panels are stationary, consistent with the mixed results provided by country-specific tests.

Finally, the Hadri Lagrange-multiplier test, in Table F.12, rejects the null hypothesis that all panels are *stationary*. This indicates that, consistent with the previous tests, a non-zero fraction of the panels are non-stationary. Together, the country-specific and panel-based unit root tests indicate that non-stationarity is likely a valid concern.

Table F.11: Country-specific unit root tests for the monetary policy rate

		Phillips-Perron		***Augmented DF***	
Country name	***ISO code***	Zt	p-value	Zt	p-value
Australia	AUS	-1.058	(0.732)	-1.482	(0.542)
Brazil	BRA	-2.906	(0.045)	-1.341	(0.610)
Canada	CAN	-1.793	(0.384)	-1.848	(0.357)
Chile	CHL	-3.310	(0.014)	-2.892	(0.046)
China	CHN	-1.893	(0.335)	-2.164	(0.220)
Colombia	COL	-5.985	(0.000)	-3.259	(0.017)
Croatia	HRV	-3.262	(0.017)	-2.840	(0.053)
Czech Republic	CZE	-4.302	(0.000)	-1.961	(0.304)
Denmark	DNK	-1.112	(0.710)	-1.088	(0.720)
Eurozone	EMU	-0.404	(0.909)	-0.232	(0.935)
Hungary	HUN	-1.988	(0.292)	-1.895	(0.335)
Iceland	ISL	-1.522	(0.523)	-1.474	(0.546)
India	IND	-2.841	(0.053)	-2.606	(0.092)
Israel	ISR	-2.675	(0.078)	-2.474	(0.122)
Japan	JPN	1.073	(0.995)	1.002	(0.994)
Korea, Rep.	KOR	-1.373	(0.595)	-1.586	(0.490)
Malaysia	MYS	-2.995	(0.035)	-2.236	(0.194)
Mexico	MEX	-6.465	(0.000)	-3.210	(0.019)
New Zealand	NZL	-1.217	(0.666)	-1.203	(0.673)
Norway	NOR	-2.052	(0.264)	-1.642	(0.461)
Philippines	PHL	-2.887	(0.047)	-1.381	(0.591)
Poland	POL	-1.799	(0.381)	-1.701	(0.431)
Russia	RUS	-4.918	(0.000)	-5.077	(0.000)
South Africa	ZAF	-3.635	(0.005)	-2.555	(0.103)
Sweden	SWE	-1.271	(0.642)	-1.515	(0.526)
Switzerland	CHE	-1.726	(0.418)	-1.920	(0.323)
Turkey	TUR	-5.539	(0.000)	-4.011	(0.001)
United Kingdom	GBR	-1.539	(0.514)	-1.462	(0.552)
United States	USA	-1.478	(0.544)	-1.784	(0.388)

Note: This table reports standard test results that the level of the policy rate contains a unit root. All Phillips-Perron tests include 3 Newey-West lags. The Augmented Dickey-Fuller test is specified with 2 lags for every country.

Table F.12: Panel unit root tests

	Statistic	*p-value*
Homogenous tests		
Levin-Lin-Chu (adj t)	-1.486	(0.069)
Harris-Tzavalis (Z)	-1.388	(0.083)
Breitung (λ)	0.082	(0.533)
Heterogeneous tests		
Im-Pesaran-Shin ($\bar{W}_t$)	-0.956	(0.169)
Fisher (Z)	-0.998	(0.159)
Pesaran CADF ($\bar{z}_t$)	-2.239	(0.013)
Stationarity test		
Hadri LM (z)	22.368	(0.000)

Note: *Homogenous tests* refers to panel tests with a common autoregressive coefficient. These test the null hypothesis that all panels contain a unit root. *Heterogeneous tests* refers to panel tests that assume panel-specific autoregressive coefficients. In these tests, the alternative hypothesis is that *some* of the panels are stationary. The Hadri LM *stationarity test*, in contrast, tests the null hypothesis that all panels are *stationary* against the alternative hypothesis that at least some panels contain unit roots.

G Sample and Data Description

Table G.13: Full country list and weighting matrix samples

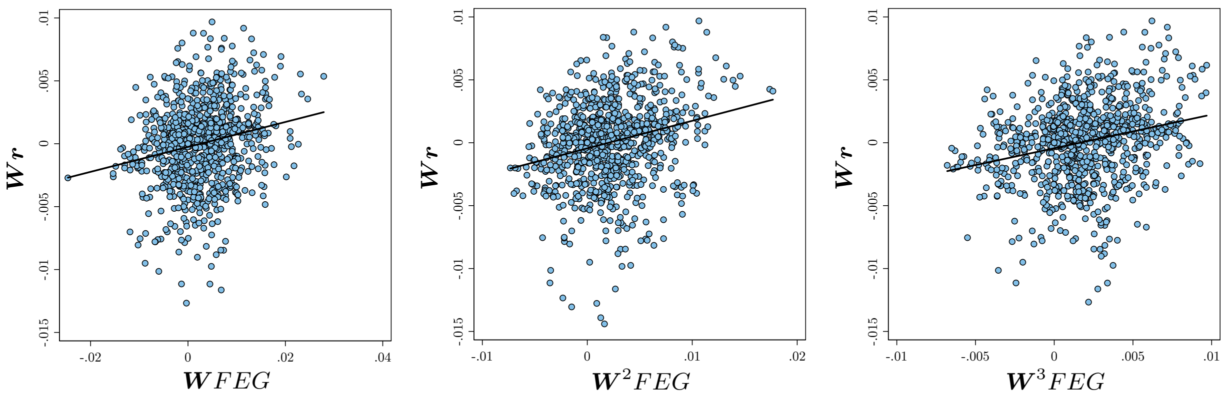
Country / Group	ISO Code	Weighting Matrix ($\boldsymbol{W}$)			
		Financial Position	Bilateral Trade	Investment Stocks	Relative GDP
Australia	AUS	Yes	Yes	Yes	Yes
Brazil	BRA	Yes	Yes	Yes	Yes
Canada	CAN	Yes	Yes	Yes	Yes
Chile	CHL	Yes	Yes	Yes	Yes
China	CHN	No	Yes	Yes	Yes
Colombia	COL	No	Yes	No	Yes
Croatia	HRV	No	No	Yes	No
Czech Republic	CZE	No	No	Yes	No
Denmark	DNK	Yes	Yes	Yes	Yes
Eurozone	EMU	Yes	Yes	Yes	Yes
Hungary	HUN	No	Yes	Yes	Yes
Iceland	ISL	No	Yes	Yes	Yes
India	IND	No	Yes	Yes	Yes
Israel	ISR	No	Yes	Yes	Yes
Japan	JPN	Yes	Yes	Yes	Yes
Korea	KOR	Yes	Yes	Yes	Yes
Malaysia	MYS	No	Yes	No	Yes
Mexico	MEX	Yes	Yes	Yes	Yes
New Zealand	NZL	No	Yes	Yes	Yes
Norway	NOR	No	Yes	Yes	Yes
Philippines	PHL	No	Yes	No	Yes
Poland	POL	No	Yes	Yes	Yes
Russia	RUS	No	Yes	No	No
South Africa	ZAF	Yes	No	No	No
Sweden	SWE	Yes	Yes	Yes	Yes
Switzerland	CHE	Yes	Yes	Yes	Yes
Turkey	TUR	No	Yes	Yes	Yes
United Kingdom	GBR	Yes	Yes	Yes	Yes
United States	USA	Yes	Yes	Yes	Yes

H Additional Figures

H.1 First Stage Results

Figure H.11: First-stage with different forecast error instruments

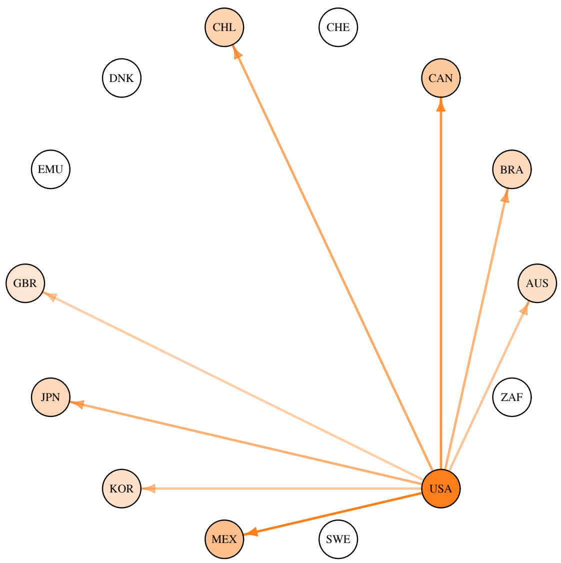
(a) 1st-order spatial lag (b) 2nd-order spatial lag (c) 3rd-order spatial lag



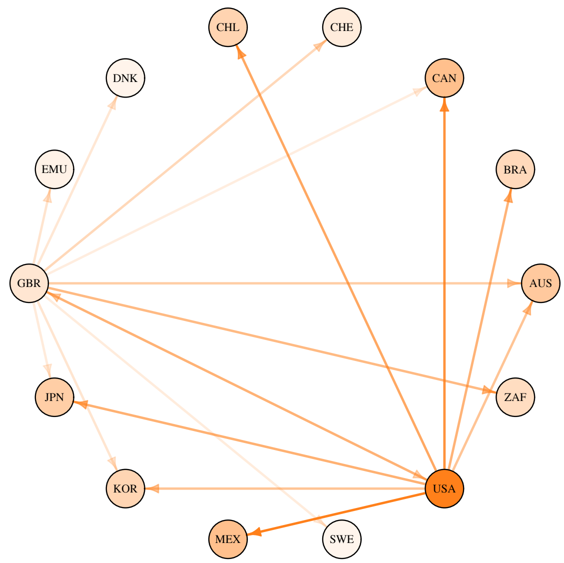
H.2 Illustration of spillover amplification

Figure H.12: Effect of a one percentage point shock in the U.S.

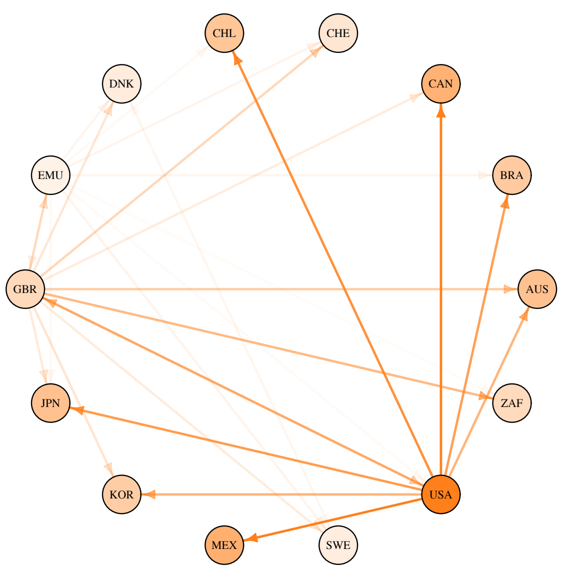
(a) First-order effects



(b) Second-order effects



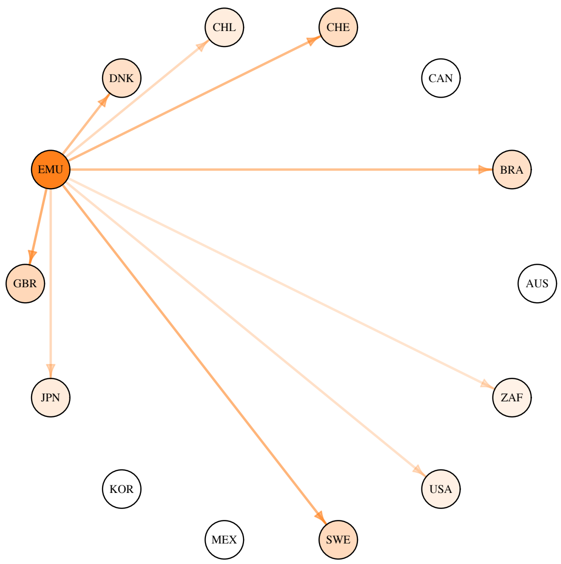
(c) Third-order effects



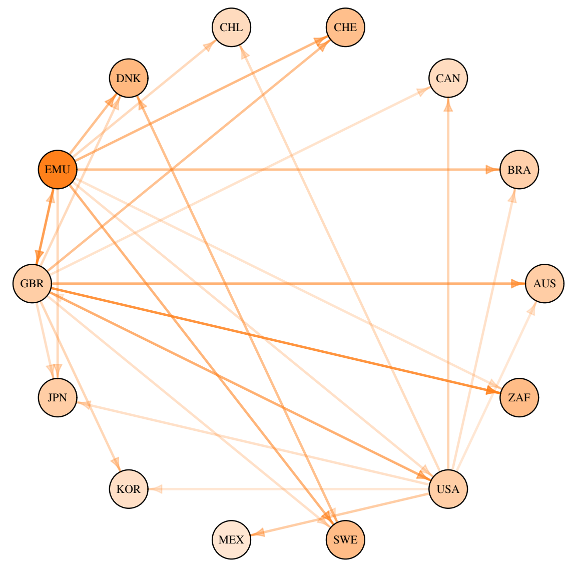
Note: This figure depicts the amplification of a one percentage point tightening of U.S. monetary policy. First-order effects refers to the immediate direct response of monetary policy in countries directly linked to the U.S. through bank financial flows. Higher-order effects include subsequent reactions by countries exposed to the immediate impact of the U.S. shock. Darker arrows denote stronger bilateral spillovers, while the shading within each node reflects the cumulative reaction after each round of effects.

Figure H.13: Effect of a one percentage point shock in the Eurozone

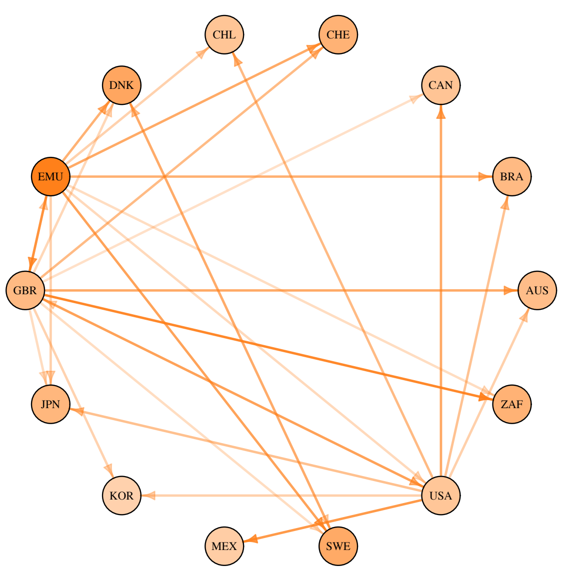
(a) First-order effects



(b) Second-order effects



(c) Third-order effects



Note: This figure depicts the amplification of a one percentage point tightening of Eurozone monetary policy. First-order effects refers to the immediate direct response of monetary policy in countries directly linked to the Eurozone through bank financial flows. Higher-order effects include subsequent reactions by countries exposed to the immediate impact of the Eurozone shock. Darker arrows denote stronger bilateral spillovers, while the shading within each node reflects the cumulative reaction after each round of effects.