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What goes around comes around: How large are spillbacks from US monetary policy?

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What goes around comes around: How large are spillbacks from US monetary policy?*

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Abstract

We quantify spillbacks from US monetary policy based on structural scenario analysis and minimum relative entropy methods applied in a Bayesian proxy structural vector-autoregressive model for the time period from 1990 to 2019. We find that spillbacks account for up to half of the overall slowdown in domestic real activity in response to a contractionary US monetary policy shock. Moreover, spillbacks materialise as stock market wealth effects impinge on US consumption, and as Tobin's q effects impinge on US investment. In particular, a contractionary US monetary policy shock depresses global equity prices, weighing on the value of US households' portfolios; and it depresses earnings of US firms through declines in foreign sales inducing them to cut back investment. Net trade does not contribute to spillbacks because US monetary policy shocks affect exports and imports similarly. Finally, spillbacks materialise through advanced rather than through emerging market economies, consistent with their relative importance in US foreign equity holdings and US firms' foreign demand.

Keywords: US monetary policy, spillovers, spillbacks, Bayesian proxy structural VAR models.
JEL-Classification: F42, E52, C50.

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1 Introduction

A large empirical literature as well as anecdotal discussions in policy and media suggest that US monetary policy spillovers are large and constitute an important driver of business cycles and financial conditions in the rest of the world (Dedola et al., 2017; Iacoviello and Navarro, 2019; Vicondoa, 2019; Degasperi et al., 2020). At the same time, the Federal Reserve has been argued to have been exhibiting "benign neglect" regarding its international effects (Eichengreen, 2013, p. 87). In particular after the Global Financial Crisis, some policymakers complained that US monetary policy measures aimed at stabilising the domestic economy elicited waves of capital flows and financial market volatility in the rest of the world (Rajan, 2013). Some have even argued that the global effects of US monetary policy inhibit control of fundamentals by monetary policy in small open and emerging economies and jeopardise local financial stability (Rey, 2016; Miranda-Agrippino and Rey, forthcoming).

Against this background, some policymakers have argued that US monetary policy should internalise its effects on the rest of the world (Rajan, 2016a,b). The Federal Reserve has responded that it already does so implicitly, as spillovers *spill back* to the US economy: "Actions taken by the Federal Reserve influence economic conditions abroad. Because these international effects in turn spill back on the evolution of the US economy, we cannot make sensible monetary policy choices without taking them into account" (Fischer, 2014). Another example is Yellen (2019): "The Fed recognizes that its own policies do have international spillovers, and, in turn because they affect global performance, they are going to have spillbacks to US economic performance". The view that spillbacks are large extends beyond the Federal Reserve, as Carney (2019) states: "Advanced economies' monetary policies will increasingly need to take account of spillbacks". And Shin (2015): "There is much talk of 'headwinds' from emerging markets buffeting advanced economies, [which] are the result of monetary policy actions taken some time ago (...) by precisely those advanced economies". However, to the best of our knowledge, no rigorous assessment of the magnitude of spillbacks from US monetary policy exists in the literature. In this paper we fill this gap.

Our analysis suggests that spillbacks from Federal Reserve monetary policy to the US economy are indeed large. According to our estimates based on data spanning the time period from 1990 to 2019, up to half of the slowdown in US real activity in the US in response to a contractionary monetary policy shock can be accounted for by spillbacks. For US consumer prices, spillbacks are somewhat smaller across specifications but can still account for up to half of the overall effect of a contractionary monetary policy shock. Regarding transmission channels, we find that spillbacks from US monetary policy materialise as stock market wealth effects impinge on consumption, and as Tobin's q effects underpinned by a decline in

US firms' foreign sales impinge on investment. In particular, contractionary US monetary policy depresses global equity prices, weighing on the value of US households' portfolios; that wealth effects contribute to the domestic effects of monetary policy is consistent with recent research on heterogeneous-agent New Keynesian models (Kaplan et al., 2018; Auclert, 2019; Caramp and Silva, 2020). Moreover, contractionary US monetary policy depresses earnings and equity prices of US sectors through declines in foreign sales, inducing them to cut back investment. Net exports do not contribute to spillbacks because US monetary policy affects exports and imports to a similar degree. Regarding geographic transmission we find that spillbacks materialise through advanced economies (AEs) rather than through emerging market economies (EMEs). This is consistent with the relative exposure of US foreign equity holdings and exports across AEs and EMEs. An important caveat to the latter finding is that it is based on the time period from 1990 to 2019; looking ahead, the already large and further growing role of EMEs in the world economy and their integration in global financial markets may overturn this finding. Finally, for US consumer prices we find that spillbacks materialise as a US monetary policy contraction slows down real activity in the rest of the world and thereby weakens price pressures in US imports.

We obtain our results by carrying out counterfactual analyses in two-country vector-autoregressive (VAR) models for the US and the rest of the world. In particular, our estimates of spillbacks are given by the difference between the impulse responses of US variables to a US monetary policy shock obtained from an unrestricted baseline and a counterfactual in which the spillovers to rest-of-the-world real activity are nil. We build on the Bayesian proxy structural VAR framework of Arias et al. (2018, forthcoming) and explore monthly data for the time period from 1990 to 2019. We identify a US monetary policy shock using the intra-daily interest rate surprises on Federal Open Market Committee (FOMC) meeting dates of Gürkaynak et al. (2005) as proxy variable as in Gertler and Karadi (2015) as well as Caldara and Herbst (2019), but cleansed from central bank information effects as in Jarocinski and Karadi (2020). We consider two approaches to construct impulse responses for a counterfactual in which the real activity spillovers from US monetary policy to the rest of the world are nil: (i) Structural scenario analysis (SSA); (ii) minimum relative entropy (MRE).

In SSA we first identify two shocks that represent a convolution—but together capture the universe—of rest-of-the-world structural shocks by combinations of zero, sign and magnitude restrictions. We use combinations of these two rest-of-the-world shocks to undo the real activity spillovers from US monetary policy to obtain the counterfactual. Intuitively, the SSA indicates how US variables would evolve if current and future shocks materialised that happened to undo the effect of the monetary policy shock on rest-of-the-world output. This approach to counterfactual analysis is a point of contact with existing literature and provides a natural benchmark (Sims and Zha, 2006; Kilian and Lewis, 2011; Bachmann and Sims, 2012; Wong, 2015; Epstein et al., 2019). We also consider a more general version of SSA using all shocks in the VAR model to undo the real activity spillovers from US monetary policy to obtain the counterfactual (Antolin-Diaz et al., 2021). In contrast, in MRE we determine the minimum 'tilt' of the posterior distribution of the baseline impulse responses to a US monetary policy shock that satisfies the constraint that the mean real activity spillovers from US monetary policy are nil. Intuitively, MRE indicates how US variables would evolve in a counterfactual world in which the effect of US monetary policy on rest-of-the-world real activity is nil but which is otherwise minimally different from the actual world in an information-theoretic sense (Cogley et al., 2005; Robertson et al., 2005; Giacomini and Ragusa, 2014). SSA and MRE are conceptually distinct, which we argue is an important advantage given the challenge of defining a counterfactual and hence spillbacks.

To the best of our knowledge no work exists that focuses on quantifying spillbacks from US monetary policy. In the context of network effects in the spillovers of US monetary policy Dees and Galesi (2019) compare the impulse responses to a US monetary policy shock in a global VAR model across an unconstrained baseline and an alternative specification in which small open economies' VAR models only include US but no other rest-of-the-world foreign variables, and in which the US VAR model does not include any foreign variable. Dees and Galesi (2019) argue that the difference between the impulse responses of the small open economies' variables across the two specifications of the global VAR model represents the network effects in the spillovers from US monetary policy. In a side note, they remark that the differences in the impulse responses for the US variables represent the spillbacks from US monetary policy. The problem with this approach is that the estimation constraining to zero the reduced-form VAR coefficients pertaining to rest-of-the-world variables in the US and the small open economies' VAR models in general entails inconsistent parameter estimates, given that this constraint is not valid in the data. As noted in Georgiadis (2017), it is in general not the case that the sign and the size of the bias in the coefficient estimates from the constrained model is related to the quantitative importance of a particular transmission channel, such as the spillbacks from US monetary policy.[1]

Our finding that spillbacks from US monetary policy are large but that these materialise primarily through AEs suggests there may be a case for international monetary policy co-ordination (Taylor, 2013; Engel, 2016; Ostry and Ghosh, 2016). In particular, in additional

[1] Degasperi et al. (2020) pursue a related but different approach in order to assess the role of different transmission channels for the spillovers—but not the spillbacks—from US monetary policy shocks. In a first step they estimate two-country VAR models with a US and a rest-of-the-world block. In a second step, they construct a counterfactual impulse response by setting to zero *after* estimation the reduced-from coefficients pertaining to rest-of-the-world variables in the US block. While immune to estimation bias, this approach is subject to the Lucas critique. See Vicondoa (2019) for a similar application.

estimations we find that while real activity spillovers from US monetary policy have the same sign in AEs and EMEs, consumer prices tend to fall in AEs but rise in EMEs. Moreover, we find that while AE monetary policy is loosened in response to a contractionary US monetary policy shock it is tightened in EMEs, consistent with fear-of-floating due to high exchange rate pass-through to consumer prices and adverse financial spillovers through foreign-currency exposures (Hausmann et al., 2001; Calvo and Reinhart, 2002). In other words, the evidence suggests that while US monetary policy spillovers do not elicit trade-offs between output stabilisation on the one hand and inflation stabilisation and financial stability on the other hand in AEs, they do so in EMEs. Against this background, our finding that the spillbacks that materialise through EMEs are very small suggests global welfare may benefit if US monetary policy internalised those spillovers that are not associated with spillbacks. Interestingly, there is evidence that the Federal Reserve is doing precisely that already. In particular, Ferrara and Teuf (2018) construct an indicator that measures the number of references to the international environment in FOMC minutes. They then estimate a Taylor-rule with standard domestic variables augmented with their international environment indicator, and find that the Federal Reserve responds to global developments even conditional on US real activity and inflation developments.

The rest of the paper is organised as follows. Section 2 provides a brief conceptual discussion of the notion of counterfactuals in the context of the assessment of spillbacks. Section 3 provides a short description of the Bayesian proxy SVAR model. Section 4 lays out our specification of the Bayesian proxy SVAR model. Section 5 explains how we construct counterfactuals and presents our results. Section 6 concludes.

2 Assessing spillbacks from monetary policy: Conceptual considerations

The discussion about monetary policy spillbacks has so far taken place at the policy level and has not been underpinned by structural or empirical analysis. In order to inject more rigor in the debate, we first conceptualise the notion of spillbacks and counterfactuals in a structural model. The insights motivate the approach we pursue in the rest of the paper.

Consider a standard two-country New Keynesian dynamic stochastic general equilibrium (NK DSGE) model for the US and the rest of the world. The model allows for different relative country sizes and degrees of home bias in consumption (see, for example, Banerjee et al., 2016). The black solid lines in Figure 1 depict the impulse responses to a contractionary US monetary policy shock: US interest rates rise, while output and consumer-price inflation drop; output in the rest of the world rises as the depreciation against the US dollar stimulates net exports.[2]

An intuitive definition of spillbacks is the difference between the domestic effects of a US monetary policy shock in the baseline version of the model and a counterfactual version in which spillovers are absent: The intuition is that when spillovers from US monetary policy are absent, then spillbacks to the US must be absent as well.

A straightforward way to modify the baseline version of the model so that there are no spillovers from US monetary policy is to assume consumers only value domestic goods, that is to raise home bias in consumption to unity. The red lines with circles in Figure 1 present the impulse responses for this counterfactual version of the model. The responses of US variables to the US monetary policy shock are different from the baseline. In particular, as the negative contribution of net exports in the baseline version of the model vanishes when trade is precluded, US output falls by less. Hence, we conclude that in the baseline version of the model spillbacks amplify the domestic effects of US monetary policy.

However, precluding spillovers from US monetary policy can be achieved in various, potentially equally intuitive and plausible ways. For example, we could assume the US is very small relative to the rest of the world. The blue dashed lines with squares in Figure 1 depict the impulse responses for this alternative counterfactual version of the model. While spillovers from a US monetary policy shock are precluded as much as in the counterfactual version of the model in which home bias is raised to unity, the implied spillbacks are different. While both US exports and imports fall more strongly, the amplification is more pronounced for the former as expenditure switching and expenditure reducing effects push in opposite directions.

In fact, assuming the US is very small rather than raising home bias to unity is not the only alternative counterfactual in which spillovers from US monetary policy are precluded. In general, the number of alternative counterfactual versions of the model is very large, also because these need not be based on modifying only a single deep parameter. And it should be clear that in general each of these counterfactual versions of the model implies a different magnitude of spillbacks from US monetary policy. Importantly, there is no rigorous metric that would guide the selection of the counterfactual version of the model. Hence, the choice of the counterfactual version of the model is far from obvious.[3]

[2]In the data US monetary policy spillovers are typically found to be large (Georgiadis, 2016; Dedola et al., 2017; Dees and Galesi, 2019; Iacoviello and Navarro, 2019; Vicondoa, 2019; Degasperi et al., 2020). For simplicity we consider a deliberately simple structural two-country model that lacks empirically relevant transmission channels such as foreign-currency mismatches and dominant-currency pricing, which are believed to be the main conduit for large and negative spillovers from US monetary policy in the data (see, e.g., Aoki et al., 2018; Akinci and Queralto, 2019; Gopinath et al., 2020). The gist of the argument we put forth in this section is the same if we consider a model that produces more realistic spillovers from US monetary policy.

[3]The multiplicity of alternative counterfactual versions of the model is exacerbated further when we relax

Against this background, in the rest of the paper we do not focus on a specific counterfactual version of a structural model but instead consider the class of models in which spillovers from US monetary policy to rest-of-the-world real activity are precluded. While we believe this is an intuitive and plausible class of counterfactual models, the discussion in this section should have made clear that it is not the only one.

Our approach to counterfactual analysis is based on VAR models. In particular, we consider two different approaches—SSA and MRE—that address the issue of the multiplicity of the set of relevant counterfactual models in different ways. Under SSA the counterfactual model is not different from the baseline model. Instead, spillovers from US monetary policy are precluded by assuming that additional shocks materialise in a given model and that they happen to be such that they offset the spillovers from US monetary policy to rest-of-the-world real activity. SSA does not reflect variation in the values of deep parameters to produce a counterfactual such as those discussed in Figure 1. Nevertheless, we deem this a useful approach as it is used in an established literature on evaluating the role of particular transmission channels (Kilian and Lewis, 2011; Bachmann and Sims, 2012; Wong, 2015; Epstein et al., 2019). Under MRE, the counterfactual is different from the baseline as it represents a model with different values of the deep parameters as in Figure 1. An appealing feature of MRE is that it reduces the multiplicity of alternative counterfactual models by determining the one which is as similar as possible—in an information-theoretic sense—to the baseline model except for the absence of real activity spillovers from US monetary policy. We discuss SSA and MRE in more detail in Section 5.

Apart from the multiplicity of alternative counterfactual models we opt for an empirical approach also because we believe structural models are subject to several pitfalls that complicate counterfactual analysis. First, in structural models in general one cannot assume policy behaviour would be unchanged in the counterfactual model. This is especially so if the counterfactual model features substantially different dynamics compared to the baseline model. Hence, in general it is not admissible to modify deep parameters so that spillovers are precluded without also adjusting policy parameters. And of course it is not clear how policy would behave in the counterfactual model, except for special cases such as when one assumes that policy is always—including in the baseline—optimal. Second, the baseline model would have to be parameterised to reflect the actual world, for example based on an estimation using actual data. However, Fernandez-Villaverde and Rubio-Ramirez (2008) show that con-

the requirement that spillovers from US monetary policy shall be absent. One might want to do so because there exist counterfactual versions of the model in which there are no spillbacks even though spillovers are not precluded. For example, when we assume the US is very large relative to the rest of the world, then there are spillovers from US monetary policy but no spillbacks; similarly when we assume that a fraction of prices of domestic sales in the rest of the world is sticky in US dollar. See Figure D.1 for the impulse responses for these cases.

ventional medium-scale structural models lack many empirically relevant elements and are hence mis-specified, implying that their deep parameters do not really have a structural interpretation. To be sure, we are not saying that counterfactual analysis should never be done in structural models. Our point is that it is more helpful to understand the mechanics of a particular structural model rather than the properties of a counterfactual world.

3 The Bayesian proxy SVAR framework

We provide a description of the Bayesian proxy SVAR (BPSVAR) framework of Arias et al. (forthcoming) before discussing our model specification and identifying assumptions. Because we identify a global uncertainty shock in addition to a US monetary policy shock using proxy variables, we discuss the BPSVAR model for the general case with k proxy variables.

Following the notation of Rubio-Ramirez et al. (2010), consider without loss of generality the structural VAR model with one lag and without deterministic terms

$$\boldsymbol{y}_t'\boldsymbol{A}_0 = \boldsymbol{y}_{t-1}'\boldsymbol{A}_1 + \boldsymbol{\epsilon}_t', \tag{1}$$

where $\boldsymbol{y}_t$ is an $n \times 1$ vector of endogenous variables and $\boldsymbol{\epsilon}_t$ an $n \times 1$ vector of structural shocks. The BPSVAR framework builds on the following assumptions in order to identify k structural shocks of interest: There exists a $k \times 1$ vector of proxy variables $\boldsymbol{m}_t$ that are (i) correlated with the k structural shocks of interest $\boldsymbol{\epsilon}_t^*$, and (ii) orthogonal to the remaining structural shocks $\boldsymbol{\epsilon}_t^o$. Formally, the identifying assumptions are

$$E[\boldsymbol{m}_t\boldsymbol{\epsilon}_t^{*\prime}] = \underset{(k\times k)}{\boldsymbol{V}}, \tag{2a}$$

$$E[\boldsymbol{m}_t\boldsymbol{\epsilon}_t^{o\prime}] = \underset{(n-k\times k)}{\boldsymbol{0}}, \tag{2b}$$

and are known as the relevance and the exogeneity condition, respectively.

Given Equation (1) as well as Equations (2a) and (2b), Arias et al. (forthcoming) augment the model in Equation (1) with k proxy equations. In particular, denote by $\tilde{\boldsymbol{y}}_t' \equiv (\boldsymbol{y}_t', \boldsymbol{m}_t')$ the vector of endogenous variables augmented with the $k \times 1$ vector of proxy variables, by $\tilde{\boldsymbol{A}}_\ell$ the corresponding coefficient matrices of dimension $\tilde{n} \times \tilde{n}$ with $\tilde{n} = n + k$, by $\tilde{\boldsymbol{\epsilon}} \equiv (\boldsymbol{\epsilon}_t', \boldsymbol{v}_t')' \sim N(\boldsymbol{0}, \boldsymbol{I}_{n+k})$, where $\boldsymbol{v}_t$ is a $k \times 1$ vector of measurement errors that affect the proxy variables (see below). The augmented model is then given by

$$\tilde{\boldsymbol{y}}_t'\tilde{\boldsymbol{A}}_0 = \tilde{\boldsymbol{y}}_{t-1}'\tilde{\boldsymbol{A}}_1 + \tilde{\boldsymbol{\epsilon}}_t'. \tag{3}$$

To ensure that augmenting the model with equations for the proxy variables does not affect the dynamics of the endogenous variables, restrictions are imposed on the matrices $\tilde{\boldsymbol{A}}_\ell$ such that

$$\tilde{\boldsymbol{A}}_\ell = \begin{pmatrix} \underset{(n\times n)}{\boldsymbol{A}_\ell} & \underset{(n\times k)}{\boldsymbol{\Gamma}_{\ell,1}} \\ \underset{(k\times n)}{\boldsymbol{0}} & \underset{(k\times k)}{\boldsymbol{\Gamma}_{\ell,2}} \end{pmatrix}, \qquad \ell = 0, 1. \tag{4}$$

The zero restrictions on the lower left-hand side block imply that the proxy variables do not enter the equations of the endogenous variables. The reduced form of the model is

$$\tilde{\boldsymbol{y}}_t' = \tilde{\boldsymbol{y}}_{t-1}' \tilde{\boldsymbol{A}}_1 \tilde{\boldsymbol{A}}_0^{-1} + \tilde{\boldsymbol{\epsilon}}_t{}' \tilde{\boldsymbol{A}}_0^{-1}. \tag{5}$$

Because the inverse of $\tilde{\boldsymbol{A}}_0$ is given by

$$\tilde{\boldsymbol{A}}_0^{-1} = \begin{pmatrix} \boldsymbol{A}_0^{-1} & -\boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1} \\ 0 & \boldsymbol{\Gamma}_{0,2}^{-1} \end{pmatrix}, \tag{6}$$

the last k equations of Equation (5) read as

$$\boldsymbol{m}_t' = \tilde{\boldsymbol{y}}_{t-1}' \tilde{\boldsymbol{A}}_1 \begin{pmatrix} -\boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1} \\ \boldsymbol{\Gamma}_{0,2}^{-1} \end{pmatrix} - \boldsymbol{\epsilon}_t' \boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1} + \boldsymbol{v}_t' \boldsymbol{\Gamma}_{0,2}^{-1}, \tag{7}$$

which shows that the proxy variables may be serially correlated, affected by past values of the endogenous variables and by measurement error.

Ordering the structural shocks as $\boldsymbol{\epsilon}_t = (\boldsymbol{\epsilon}_t^{o\prime}, \boldsymbol{\epsilon}_t^{*\prime})'$ we have

$$E\left[\boldsymbol{m}_t \boldsymbol{\epsilon}_t'\right] = -\boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1} = \begin{pmatrix} \underset{(k\times(n-k))}{\boldsymbol{0}} & \underset{(k\times k)}{\boldsymbol{V}} \end{pmatrix}, \tag{8}$$

where the first equality is obtained using Equation (7) and because the structural shocks $\boldsymbol{\epsilon}_t$ are by assumption orthogonal to $\boldsymbol{y}_{t-1}$ and $\boldsymbol{v}_t$, and the second equality is due to the exogeneity and relevance conditions in Equations (2a) and (2b). Equation (8) shows that the identifying assumptions imply restrictions on the last k columns of the contemporaneous structural impact coefficients in $\tilde{\boldsymbol{A}}_0^{-1}$. In particular, if the exogeneity condition in Equation (2b) holds, the first $n-k$ columns of the upper right-hand side sub-matrix $\boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1}$ of $\tilde{\boldsymbol{A}}_0^{-1}$ in Equation (6) are zero. From Equation (5) it can be seen that this implies that the first $n-k$ structural shocks do not impact contemporaneously the proxy variables. In turn, if the relevance condition in Equation (2a) holds, the last k columns of the upper right-hand side sub-matrix $\boldsymbol{A}_0^{-1}\boldsymbol{\Gamma}_{0,1}\boldsymbol{\Gamma}_{0,2}^{-1}$ of $\tilde{\boldsymbol{A}}_0^{-1}$ are different from zero. From Equation (5) it can be seen that this implies that the last k structural shocks impact the proxy variables contemporaneously. In the algorithm of Arias et al. (forthcoming) the estimates of $\boldsymbol{A}_0$ and

$\boldsymbol{\Gamma}_{0,\ell}$ are obtained such that the restrictions on $\tilde{\boldsymbol{A}}_0^{-1}$ implied by Equations (2a) and (2b) are satisfied, and hence the estimation identifies the structural shocks of interest in $\boldsymbol{\epsilon}_t^*$.

If the number of structural shocks identified by the proxy variables is larger than one, the proxy SVAR model is only set identified: Rotations of the structural shocks $\boldsymbol{Q}\boldsymbol{\epsilon}_t^*$ satisfy the exogeneity and relevance conditions in Equations (2a) and (2b). In this case, additional restrictions are needed in order to point-identify the structural shocks in $\boldsymbol{\epsilon}_t^*$. An important advantage of the BPSVAR framework over the traditional proxy SVAR framework is that the additional identifying assumptions can be restrictions on the relevance condition in Equation (2a) reflected in the matrix $\boldsymbol{V}$. One may, for example, impose the restriction that a particular structural shock does not affect a particular proxy variable. Restrictions on the relationship between structural shocks and proxy variables are arguably less controversial than exogeneity restrictions between the endogenous variables in the contemporaneous structural impact matrix $\boldsymbol{A}_0^{-1}$, such as for example those imposed in Mertens and Ravn (2013).

Another appealing feature of the BPSVAR model is that it allows to incorporate a prior belief about the strength of the proxy variables as instruments based on the notion that "researchers construct proxies to be relevant" (Caldara and Herbst, 2019, p. 165). A convenient metric is the 'reliability matrix' $\boldsymbol{R}$ derived in Mertens and Ravn (2013) given by

$$\boldsymbol{R} = \left(\boldsymbol{\Gamma}_{0,2}^{-1\prime}\boldsymbol{\Gamma}_{0,2} + \boldsymbol{V}\boldsymbol{V}'\right)^{-1}\boldsymbol{V}\boldsymbol{V}'. \tag{9}$$

Intuitively, $\boldsymbol{R}$ indicates the share of variance of the proxy variables that is accounted for by the structural shocks $\boldsymbol{\epsilon}_t^*$ in their total variance (see Equation (7)). Specifically, the minimum eigenvalues of $\boldsymbol{R}$ can be interpreted as the share of the variance of (any linear combination of) the proxy variables explained by the structural shocks $\boldsymbol{\epsilon}_t^*$ (Gleser, 1992).

Finally, yet another appealing feature of the BPSVAR model is that it allows to identify additional structural shocks using zero, sign and magnitude restrictions. These additional restrictions are imposed on the contemporaneous structural impact matrix $\boldsymbol{A}_0^{-1}$, as would be done in a traditional SVAR framework. Importantly, the BPSVAR framework of Arias et al. (forthcoming) allows rigorous inference for specifications that mix identification with zero, sign, and magnitude restrictions as well as proxy variables.

4 Empirical framework

In this section we explain how we specify the BPSVAR model, how we identify US monetary policy, global uncertainty and rest-of-the world shocks.

4.1 VAR model specification

Our point of departure is the closed-economy US VAR model in Gertler and Karadi (2015), which includes as endogenous variables monthly (log) US industrial production (IP), the (log) US consumer-price index (CPI), the excess bond premium (EBP) and the one-year Treasury Bill (TB) rate as a monetary policy indicator. We augment the model with the (log) VXO, (log) rest-of-the-world (non-US) real industrial production, and the (log) nominal effective exchange rate (NEER) of the dollar. Variable descriptions and data sources are provided in Table E.1. The sample spans the time period from February 1990 to June 2019.

4.2 Identifying assumptions

We identify a US monetary policy shock using a proxy variable and—for the purpose of the SSA counterfactuals—two rest-of-the-world shocks using a mixture of sign, magnitude and zero restrictions. In addition, we identify a global uncertainty shock to preclude that the two rest-of-the-world shocks are contaminated by common shocks to the US and the rest of the world. We identify the global uncertainty shock using a proxy variable.

4.2.1 US monetary policy and global uncertainty shocks

As in Gertler and Karadi (2015) as well as Caldara and Herbst (2019) we consider the intra-daily interest rate changes around narrow time windows on FOMC meeting days of Gürkaynak et al. (2005) as proxy variable for the US monetary policy shock. We in addition cleanse these interest rate surprises from central bank information effects using the poor-man's approach of Jarocinski and Karadi (2020): When the interest rate surprise has the same sign as the equity price surprise, this is classified as a central bank information effect; when the interest rate and the equity price surprises have the opposite sign, this is classified as a 'pure' monetary policy surprise.[4]

We consider the intra-daily gold price changes of Piffer and Podstawski (2018a) around narrow time windows on narratively selected days as proxy variable for the global uncertainty shock. In particular, Piffer and Podstawski (2018a) first extend the list of dates selected by Bloom (2009) on which the VXO increased arguably due to exogenous uncertainty shocks. Second, they calculate the change in the price of gold between the last auction before and the first auction after the news about the event representing the uncertainty shock became available

[4]An alternative approach to cleanse high-frequency interest rate surprises from central bank information effects is proposed in Miranda-Agrippino and Ricco (forthcoming).

to markets. The original data on gold price surprises of Piffer and Podstawski (2018b) cover the time period until 2015; we use the update of Bobasu et al. (2020) that spans until 2019.[5]

Consider the notation from Section 3 and define $\boldsymbol{\epsilon}_t^* \equiv (\epsilon_t^{mp}, \epsilon_t^u)'$, where ϵ_t^{mp} denotes the US monetary policy shock and ϵ_t^u the global uncertainty shock. Furthermore, define $\boldsymbol{m}_t \equiv (p_t^{\epsilon,mp}, p_t^{\epsilon,u})'$ as the vector containing the proxy variables for the US monetary policy and the global uncertainty shock. Our identifying assumptions are

$$E[\boldsymbol{m}_t \boldsymbol{\epsilon}_t^{*\prime}] = \begin{pmatrix} E[p_t^{\epsilon,mp}\epsilon_t^{mp}] & E[p_t^{\epsilon,mp}\epsilon_t^{u}] \\ E[p_t^{\epsilon,u}\epsilon_t^{mp}] & E[p_t^{\epsilon,u}\epsilon_t^{u}] \end{pmatrix} = \boldsymbol{V}, \tag{10a}$$

$$E[\boldsymbol{m}_t \boldsymbol{\epsilon}_t^{o\prime}] = \begin{pmatrix} E[p_t^{\epsilon,mp}\boldsymbol{\epsilon}_t^{o}] & E[p_t^{\epsilon,u}\boldsymbol{\epsilon}_t^{o}] \end{pmatrix} = \boldsymbol{0}. \tag{10b}$$

First, in the relevance condition in Equation (10a) we assume that US monetary policy shocks drive the interest rate surprises on FOMC meeting days, $E[p_t^{\epsilon,mp}\epsilon_t^{mp}] \neq 0$. This is the standard instrument relevance assumption maintained in the literature (Gertler and Karadi, 2015; Caldara and Herbst, 2019). The exogeneity condition $E[p_t^{\epsilon,mp}\boldsymbol{\epsilon}_t^{o}] = 0$ in Equation (10b) cannot be tested as none of the other structural shocks $\boldsymbol{\epsilon}_t^{o}$ is observed, but it seems plausible that in a narrow time window around FOMC meetings monetary policy shocks are the only systematic drivers of interest rate surprises cleansed from central bank information effects.

Second, in the relevance condition in Equation (10a) we assume that global uncertainty shocks drive the gold price surprises on the narratively selected dates, $E[p_t^{\epsilon,u}\epsilon_t^{u}] \neq 0$. Intuitively, as gold is widely seen as a safe haven asset, demand increases when uncertainty rises (Baur and McDermott, 2010, 2016). Piffer and Podstawski (2018a) provide evidence that gold price surprises are relevant instruments for uncertainty shocks based on F-tests and Granger-causality tests with the VXO and the macro uncertainty measure constructed in Jurado et al. (2015). Ludvigson et al. (forthcoming) also use gold price changes as a proxy variable for uncertainty shocks. Regarding the exogeneity condition $E[p_t^{\epsilon,u}\boldsymbol{\epsilon}_t^{o}] = 0$ in Equation (10b), Piffer and Podstawski (2018a) document that gold price surprises are uncorrelated with a range of non-uncertainty shocks.[6]

As discussed in Section 3, when multiple proxy variables are used to identify multiple structural shocks, the relevance and exogeneity conditions are not sufficient for point identification.

[5] We aggregate the daily changes in the proxy variables to monthly frequency as in Gertler and Karadi (2015).

[6] The exogeneity condition for the gold price surprises might be questioned as on some of the dates also non-uncertainty shocks may have materialised. However, note that the events considered by Bloom (2009) and Piffer and Podstawski (2018a) are very diverse, meaning that even if on each and every event it was not only a global uncertainty shock that materialised, the non-uncertainty shock is likely to have been of a different nature across events. For example, while the collapse of Lehmann Brothers may have been more a financial than a global uncertainty shock, the 9/11 attacks or the start of Gulf War I were arguably no financial shocks. Therefore, we believe the only structural shock that has been *systematically* related to gold price surprises across all dates selected by Bloom (2009) and Piffer and Podstawski (2018a) are global uncertainty shocks.

In this case, additional restrictions need to be imposed on $\boldsymbol{A}_0^{-1}$ or—arguably less restrictive and an important advantage of the BPSVAR framework over the traditional proxy SVAR framework (see Section 3)—on $\boldsymbol{V}$. A natural idea is to impose that $\boldsymbol{V}$ is a diagonal matrix, implying that US interest rate surprises on FOMC meeting days are not driven by global uncertainty shocks and that gold price surprises on days with prominent global economic, political or natural events are not driven by US monetary policy shocks. Technically, these additional restrictions imply an over-identified system, which cannot be handled by the algorithm of Arias et al. (forthcoming). We therefore impose a *weaker* set of additional restrictions on $\boldsymbol{V}$, namely only that US interest rate surprises on FOMC meeting days are not driven by global uncertainty shocks, $E[p_t^{\epsilon,mp}\epsilon_t^u] = 0$. Note that this assumption is implicitly maintained and crucial for the validity of much work in the literature. For example, if this assumption was not satisfied then the analyses of Gertler and Karadi (2015), Caldara and Herbst (2019) as well as Jarocinski and Karadi (2020) would be invalid as the identified US monetary policy shocks would be contaminated by global uncertainty shocks.

Finally, it is worthwhile to point out that when two proxy variables are used to identify two structural shocks, a single additional zero restriction on $\boldsymbol{V}$ is sufficient for point-identification (Giacomini et al., forthcoming).[7]

4.2.2 Rest-of-the-world shocks

Existing literature using SSA has considered neutralising shocks that are as 'close' as possible to the transmission channel being evaluated (see Section 5.1 below for a discussion of SSA). To establish a point of contact with this literature, we identify rest-of-the-world shocks and then use them to neutralise the real activity spillovers from US monetary policy in SSA. We 'identify' two reduced-form shocks that nest the universe of rest-of-the-world structural shocks. We label these two shocks as rest-of-the-world 'depreciating' and 'appreciating' shocks. We argue below in Section 5.1 that while using neutralising shocks as 'close' as possible to the transmission channel of interest may seem intuitive, it is not compelling from a conceptual point of view. We therefore also consider a more general version of SSA in which only the US monetary policy shock needs to be identified.

Table 1 reports the sign and relative magnitude restrictions we impose in order to identify the two rest-of-the-world shocks. Both shocks are normalised to be contractionary, and we assume it takes some time until they transmit to the US. We impose that rest-of-the-world real activity decelerates on impact, and that it decelerates more than US real activity. The

[7]This is appealing also because under set-identification results may depend on the choice of the prior distribution for the construction of the rotation matrices in the estimation (Baumeister and Hamilton, 2015).

latter magnitude restriction helps to distinguish US and rest-of-the-world shocks.[8]

For the 'depreciating' rest-of-the-world shock we assume that it appreciates the US dollar NEER and that it slows down rest-of-the-world and US real activity; we assume US real activity slows down as expenditure reducing and expenditure switching effects in the US point in the same direction: In response to a rest-of-the-world 'depreciating'—e.g. contractionary demand—shock US exports decline as rest-of-the-world real activity slows down. Moreover, because the US dollar NEER appreciates the rest-of-the-world switches away from imports towards domestically produced goods, pushing further downward pressure on US real activity.

For the 'appreciating' rest-of-the-world shock we assume that it depreciates the US dollar NEER. We do not assume that US real activity slows down, as expenditure reducing and expenditure switching effects in the US move in opposite directions: While demand for US exports decline as rest-of-the-world real activity slows down in response to a rest-of-the-world 'appreciating'—e.g. contractionary monetary policy shock—in the US the depreciation of the US dollar NEER induces expenditure switching away from US imports towards domestically produced goods; the overall effect on US net exports and hence US real activity is ambiguous.

While we do not take a stand on the response of the exchange rate to rest-of-the-world productivity, financial and fiscal policy shocks, it should be clear that they are subsumed in one of the two rest-of-the-world reduced-form shocks.

4.3 Priors

We use flat priors for the VAR parameters. We follow Caldara and Herbst (2019) as well as Arias et al. (forthcoming) and impose a 'relevance threshold' to express our prior belief that the proxy variables are relevant instruments. In particular, we require that at least a share $\gamma = 0.1$ of the variance of the proxy variables is accounted for by the US monetary policy and global uncertainty shocks, respectively; this is weaker than the relevance threshold of $\gamma = 0.2$ used by Arias et al. (forthcoming), and—although hard to compare conceptually—lies below the 'high-relevance' prior of Caldara and Herbst (2019).

4.4 Baseline impulse responses

Our findings for the US monetary policy shock in Figure 2 are consistent with the literature (see Gertler and Karadi, 2015; Caldara and Herbst, 2019). A contractionary US monetary policy shock is accompanied by a rise in the one-year Treasury Bill rate, tightens financial

[8]Consistent with the exogeneity restriction in Equation (10b) we also assume that the proxy variables are not driven by the rest-of-the-world shocks using zero restrictions.

conditions by raising the excess bond premium, increases the VXO, appreciates the US dollar NEER, temporarily reduces US industrial production and persistently US consumer prices. Our findings are also consistent with the literature on spillovers (see, e.g., Georgiadis, 2016; Dedola et al., 2017; Dees and Galesi, 2019; Iacoviello and Navarro, 2019; Vicondoa, 2019; Degasperi et al., 2020): Rest-of-the-world real activity slows down considerably, essentially mirroring the US.

The 'depreciating' rest-of-the-world—e.g. contractionary demand—shock slows down real activity globally. US consumer prices fall, the VXO and the excess bond premium drop somewhat on impact, and the US dollar NEER appreciates. The 'appreciating' rest-of-the-world—e.g. contractionary monetary policy—shock also slows down real activity globally. Overall, rest-of-the-world shocks have a non-trivial impact on the US. This suggests that spillovers from US monetary policy may entail non-trivial spillbacks.

Finally, the global uncertainty shock appreciates the US dollar NEER, raises the VXO and the excess bond premium, causes a slowdown in global real activity, lowers US consumer prices, and is followed by a fall in the one-year Treasury Bill rate. Overall, the impulse responses of the global uncertainty shock are consistent with the literature on the importance of US safe assets and the implications for the US dollar exchange rate (Bianchi et al., 2020; Jiang et al., forthcoming) as well as the global economy and financial markets (Epstein et al., 2019).

5 Quantifying spillbacks from US monetary policy

We define spillbacks as the difference between the impulse responses of domestic variables to a US monetary policy shock across the baseline in Figure 2 and a counterfactual. It will be useful to think of an impulse response as a conditional forecast of the endogenous variables for periods $T+1, T+2, \ldots, T+h$. In the baseline, the conditional forecast assumes that the US monetary policy shock equals unity in period $T+1$. In the counterfactual, the conditional forecast additionally assumes that rest-of-the-world real activity does not change. We consider two approaches for constructing this counterfactual: SSA and MRE.

5.1 SSA counterfactuals

5.1.1 Conceptual considerations

Under SSA the path of rest-of-the-world real activity under the counterfactual conditional forecast is achieved by allowing additional shocks to materialise over periods $T+1, T+$

$2, \ldots, T+h$. The shocks are calibrated so that their effects offset the impact of the US monetary policy shock in period $T+1$ on rest-of-the-world real activity in periods $T+1, T+2, \ldots, T+h$. Antolin-Diaz et al. (2021; henceforth ADPRR) describe how to implement conditional forecasts with constraints on the paths of the endogenous variables together with constraints on the set of offsetting shocks. Earlier applications of SSA such as Kilian and Lewis (2011), Bachmann and Sims (2012), Wong (2015) as well as Epstein et al. (2019) can be viewed as special cases of the general framework described in ADPRR in the sense that they only consider a single offsetting shock. In these applications, the offsetting shock is chosen so as to be as 'close' as possible to the transmission channel being evaluated. To establish a point of contact with these applications, we first use the rest-of-the-world 'depreciating' and 'appreciating' shocks for the offsetting of the real activity spillovers from US monetary policy, but then also consider a more general version of SSA in which we do not restrict the set of offsetting shocks. We only sketch the SSA framework of ADPRR here, but provide a more detailed description in Appendix C.

Assuming the structural parameters of the VAR model are known, the $nh \times 1$ vector of future values of the endogenous variables $\boldsymbol{y}_{T+1,T+h} \equiv [\boldsymbol{y}'_{T+1}, \boldsymbol{y}'_{T+2}, \ldots, \boldsymbol{y}'_{T+h}]'$ over an horizon of h periods is given by

$$\boldsymbol{y}_{T+1,T+h} = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\boldsymbol{\epsilon}_{T+1,T+h}, \tag{11}$$

where the $nh \times 1$ vector $\boldsymbol{b}_{T+1,T+h}$ represents the deterministic component of the forecast that is due to initial conditions and the autoregressive dynamics of the system, and the $nh \times nh$ matrix $\boldsymbol{M}'$ the effects of the structural shocks. The object of interest of SSA is

$$\widetilde{\boldsymbol{y}}_{T+1,T+h} \sim N(\boldsymbol{\mu}_y, \boldsymbol{\Sigma}_y), \tag{12}$$

where the $nh \times 1$ vector $\widetilde{\boldsymbol{y}}_{T+1,T+h}$ contains all endogenous variables—i.e. both those whose paths are constrained and those whose paths are unconstrained. A conditional forecast involves

(i) 'conditional-on-observables forecasting', i.e. specifying paths for a subset of endogenous variables that deviate from the unconditional forecast

(ii) 'conditional-on-shocks forecasting', i.e. specifying the subset of structural shocks that may deviate from their unconditional distribution to produce the path of the endogenous variables specified in (i)

Given Equation (11) 'conditional-on-observables forecasting' under (i) can be written as

$$\overline{\boldsymbol{C}}\widetilde{\boldsymbol{y}}_{T+1,T+h} = \overline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h} + \overline{\boldsymbol{C}}\boldsymbol{M}'\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\overline{\boldsymbol{f}}_{T+1,T+h}, \overline{\boldsymbol{\Omega}}_f), \tag{13}$$

where $\overline{\boldsymbol{C}}$ is a $k_o \times nh$ selection matrix, the $k_o \times 1$ vector $\overline{\boldsymbol{f}}_{T+1,T+h}$ is the mean of the distribution of the endogenous variables that are constrained under the conditional forecast and the $k_o \times k_o$ matrix $\overline{\boldsymbol{\Omega}}_f$ reflects the associated uncertainty. In turn, 'conditional-on-shocks forecasting' under (ii) can be written as

$$\boldsymbol{\Xi}\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\boldsymbol{g}_{T+1,T+h}, \boldsymbol{\Omega}_g), \tag{14}$$

where $\boldsymbol{\Xi}$ is a $k_s \times nh$ selection matrix, the $k_s \times 1$ vector $\boldsymbol{g}_{T+1,T+h}$ the mean of the distribution of the shocks $\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}$ in the conditional forecast, and the $k_s \times k_s$ matrix $\boldsymbol{\Omega}_g$ reflects the associated uncertainty. ADPRR show how $\boldsymbol{\mu}_y$ and $\boldsymbol{\Sigma}_y$ in Equation (12) can be determined such that the constraints under (i) and (ii) are satisfied simultaneously.

We conceive as conditional forecasts that depart from an unconditional forecast both the baseline and the counterfactual impulse responses to a US monetary policy shock. In particular, our baseline is given by the forecast $\widetilde{\boldsymbol{y}}^{bl}_{T+1,T+h}$ conditional on a US monetary policy shock materialising in period $T+1$. Our SSA counterfactual is given by the forecast $\widetilde{\boldsymbol{y}}^{cf}_{T+1,T+h}$ conditional on a US monetary policy shock materialising in period $T+1$ and the additional constraint that rest-of-the-world industrial production does not change over the forecast horizon. The latter is achieved through the materialisation of the two rest-of-the-world shocks that offset the real activity spillovers from the US monetary policy shock.[9]

5.1.2 Results from SSA

The left-hand side panel in Figure 3 presents the baseline impulse response of domestic industrial production to the US monetary policy shock from Figure 2 (black solid line) and the SSA counterfactual in which rest-of-the-world shocks materialise so that real activity spillovers to the rest-of-the-world are offset (green line with squares). In the counterfactual in which real activity spillovers are precluded the drop in US industrial production is reduced substantially compared to the baseline. This implies that spillbacks amplify the domestic effects of US monetary policy. Spillbacks account for about 50% of the overall domestic effect of US monetary policy on industrial production.

While from a conceptual perspective it is intuitive to consider rest-of-the-world shocks to offset real activity spillovers from US monetary policy shocks in line with earlier literature using SSA counterfactuals (Kilian and Lewis, 2011; Bachmann and Sims, 2012; Wong, 2015; Epstein et al., 2019), we believe this is not compelling. In principle, one could argue there should not be any constraint on the set of shocks that may materialise to offset the real activity spillovers in our counterfactual. The middle panel in Figure 3 presents the results

[9] See Appendix C for further technical details and the specification of the matrices $\overline{\boldsymbol{C}}$, $\overline{\boldsymbol{f}}_{T+1,T+h}$, $\boldsymbol{\Xi}$, $\overline{\boldsymbol{g}}_{T+1,T+h}$, $\boldsymbol{\Omega}_g$ and $\overline{\boldsymbol{\Omega}}_f$ under the baseline and the counterfactual conditional forecast.

for this more general version of SSA, which turn out to be similar to those based only on the rest-of-the-world shocks.

Figure 4 presents the posterior distribution of the difference between the response of domestic industrial production to a US monetary policy shock in the baseline and the SSA counterfactuals from Figure 3. Our estimation assigns a high probability to spillbacks being different from zero. The posterior distribution of the SSA spillback estimates is tighter if all shocks are allowed to materialise. This is because in this case only the US monetary policy shock needs to be identified, and hence uncertainty stemming from the set identification of the rest-of-the-world shocks is absent.[10]

The validity of SSA depends on the characteristics of the offsetting shocks, i.e. $\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}$ in Equation (14). If these are exceptionally large or persistent, then agents are likely to update their beliefs about the policy regime and the structure of the economy more generally; recall that the rest-of-the-world shocks include—even if we do not disentangle them—policy shocks. As a consequence, SSA might be subject to the Lucas critique. However, the 'modesty statistic' of Leeper and Zha (2003) displayed in the top row in Figure 5 does not indicate that the offsetting shocks are unusually large or persistent. Similarly, the q-divergence proposed by ADPRR and displayed in the bottom row in Figure 5 does not indicate that the distribution of shocks in the counterfactual is notably different from the baseline.

Figure 6 documents that our findings regarding spillbacks are robust to different approaches for aggregating the daily interest rate surprises on FOMC meetings dates (as well as the gold price surprises) to monthly frequency. In particular, the left-hand side panel presents results for the case in which we do not consider FOMC inter-meeting announcements as suggested by Caldara and Herbst (2019). The middle panel presents results for the case in which we do not consider the temporal aggregation approach of Gertler and Karadi (2015) but simply take the average of the daily surprises in a given month. And the right-hand side column considers simple averages of surprises on non-inter-meeting FOMC announcement dates only. While there is some variation in the magnitude of spillbacks, they are consistently estimated to be non-trivial.

[10] As our two rest-of-the-world shocks are set identified we acknowledge that inference on the identified set may depend on the choice of our prior over the rotation matrix. In particular we sample from the set of orthonormal matrices using the uniform prior discussed in Rubio-Ramirez et al. (2010). As pointed out by Baumeister and Hamilton (2015) this uniform prior might influence the posterior of the impulse responses, although the practical relevance of this concern is still up for debate (Inoue and Kilian, 2020).

5.2 MRE counterfactuals

5.2.1 Conceptual considerations

In the existing empirical literature MRE is used to incorporate restrictions derived from economic theory in order to improve a forecast. For example, Robertson et al. (2005) improve their forecasts of the Federal Funds rate, US inflation and the output gap by imposing the constraint that the mean three-year-ahead inflation forecast must equal 2.5% through MRE.[11] Similar in spirit, we use MRE to generate a counterfactual conditional forecast based on our baseline conditional forecast that represents the impulse responses to a US monetary policy shock. In contrast to SSA, in the MRE approach the counterfactual conditional forecast is based on the *same* shocks as in the baseline but reflects a *counterfactual world* in the spirit of Section 2, i.e. some alternatively parameterised structural model as data generating process.

For consistency of exposition with SSA again conceive of an impulse response as a conditional forecast $\widetilde{\boldsymbol{y}}_{T+1,T+h}$ under which in $\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}$ we have $\widetilde{\epsilon}^{mp}_{T+1} = 1$, $\widetilde{\epsilon}^{mp}_{T+s} = 0$ for $s = 2, 3, \ldots, h$ and $\widetilde{\epsilon}^{j}_{T+s} = 0$ for $s = 1, 2, \ldots, h$ and $j \neq mp$. Furthermore, consider the posterior belief about the effects of a US monetary policy shock based on the actual data

$$f(\widetilde{\boldsymbol{y}}_{T+h}|\boldsymbol{y}_{1,T}, \mathcal{I}_a, \widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}) \propto p(\boldsymbol{\psi}) \times \ell(\boldsymbol{y}_{1,T}|\boldsymbol{\psi}, \mathcal{I}_a) \times \nu, \tag{15}$$

where $p(\cdot)$ is the prior about the structural VAR parameters $\boldsymbol{\psi}$, $\mathcal{I}_a$ our identifying assumptions, and ν the volume element of the mapping from the posterior distribution of $\boldsymbol{\psi}$ to the posterior distribution of the conditional forecast $\widetilde{\boldsymbol{y}}_{T+h}$; the mean of f is plotted in the first column in Figure 2. MRE determines the posterior beliefs about the effects of a US monetary policy shock in a counterfactual world by

$$\begin{gathered} Min_{\boldsymbol{\psi}}\ \mathcal{D}(f^*||f) \quad s.t. \\ \int f^*(\widetilde{\boldsymbol{y}})\widetilde{y}^{ip^*} d\widetilde{\boldsymbol{y}} = E(\widetilde{y}^{ip^*}) = 0, \quad \int f^*(\widetilde{\boldsymbol{y}}) d\widetilde{\boldsymbol{y}} = 1, \quad f^*(\widetilde{\boldsymbol{y}}) \geq 0, \end{gathered} \tag{16}$$

where $\mathcal{D}(\cdot)$ is the Kullback-Leibler divergence—the 'relative entropy'—between the counterfactual and actual posterior beliefs (we drop the subscripts in $\widetilde{y}^{ip*}_{T+h}/\widetilde{\boldsymbol{y}}_{T+h}$ in Equation (16) for simplicity). In general, there is an infinite number of counterfactual worlds about which given the data $\boldsymbol{y}_{1,T}$ we could construct beliefs f^* that satisfy the constraint $E(\widetilde{y}^{ip^*}_{T+h}) = 0$. The MRE approach in Equation (16) disciplines the choice of the counterfactual world in an arguably plausible way by requiring that it is associated with beliefs f^* that are minimally different from the baseline posterior beliefs f in an information-theoretic sense. Intuitively,

[11] See Cogley et al. (2005) and Giacomini and Ragusa (2014) for similar applications.

MRE determines the counterfactual world in which real activity spillovers from US monetary policy are nil but which is minimally different from the actual world in all other regards.[12]

It turns out that in order to determine the posterior beliefs f^* about the effects of a US monetary policy shock in Equation (16) MRE optimally updates the baseline posterior beliefs f by incorporating the information represented by the constraint that real activity spillovers in the counterfactual world are nil according to

$$f^*\left(\widetilde{\boldsymbol{y}}_{T+h}|\boldsymbol{y}_{1,T}, \mathcal{I}_a, \widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}, E(\widetilde{y}^{ip^*}_{T+h}) = 0\right) \propto \\ f(\widetilde{\boldsymbol{y}}_{T+h}|\boldsymbol{y}_{1,T}, \mathcal{I}_a, \widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}) \times \tau\left(\widetilde{y}^{ip^*}_{T+h}(\boldsymbol{\psi})\right), \tag{17}$$

where τ is a 'tilt' function (see Robertson et al., 2005).[13] Intuitively, τ down-weights the baseline posterior for VAR parameter values $\boldsymbol{\psi}$ that are associated with large deviations from the constraint that real activity spillovers from US monetary policy shall be nil. In practice, Robertson et al. (2005) as well as Giacomini and Ragusa (2014) show that MRE boils down to adjusting the weights of the draws of the approximated baseline posterior distribution. Once the counterfactual weights are obtained, importance sampling techniques[14] can be used to estimate the mean and percentiles of the counterfactual posterior distribution.[15]

[12] Proposition 1 in ADPRR establishes a connection between SSA and MRE. In particular, when the distribution of a constrained forecast is determined by minimising its relative entropy relative to a baseline forecast, the solutions for the mean and the variance turn out to coincide with those of SSA. However, the solution of a generic MRE problem as in Proposition 1 in ADPRR is silent about what underpins the departure of the mean and the variance of the constrained forecast from the baseline. As in the context of ADPRR a change in the distribution of future shocks is one possibility. But another possibility—not mentioned by ADPRR because it is not relevant in their context—is an alternatively parameterised VAR model, with the distribution of future shocks being unchanged relative to the baseline. In any case, the equivalence of the solutions of MRE and SSA established in Proposition 1 in ADPRR does not hold in our context, as (i) the baseline posterior distribution f in Equation (15) is in general not normal, (ii) we do not consider forecasts with uncertainty in the conventional sense but rather paths reflecting impulse responses without any uncertainty, and (iii) in our SSA with all shocks we actually do restrict some shocks (namely the US monetary policy shock in $T+1$).

[13] Beliefs can be updated not only based on data but based on any form of new information. Optimally updating beliefs based on data refers to Bayes' rule. In case of other information—such as the constraint that real activity spillovers in the counterfactual world are expected to be nil—it can be shown that MRE updating as in Equation (17) is optimal in an axiomatic sense (see for example Shore and Johnson, 1980, 1981). Also note that there is nothing dubious using data from the actual world and MRE to form beliefs about a counterfactual world. For example Giffin (2008, pp. 25-26) writes: "The distribution that we get in the end is based on our information, not what is or is not true".

[14] Importance sampling is only feasible and efficient if the baseline density—in our case the posterior distribution of the impulse responses—spans the target density. As shown in Arias et al. (2018) the posterior of the impulse responses follows a Generalized-Normal distribution, which (in theory) has infinite support. Hence, theoretically any counterfactual posterior distribution of conditional forecasts can be obtained using MRE updating. However, in practice when the posterior distribution is approximated by a finite number of draws and when the target density is very different from the baseline density, importance sampling might perform poorly. In this case, other samplers can be used, for instance the one-block tailored Metropolis–Hastings algorithm of Chib et al. (2018).

[15] Andrle and Plasil (2018) propose a 'system priors' approach for estimation of structural and VAR models in which priors for model-implied moments can be specified. Their approach first updates the priors of the model parameters given the 'system priors', and then uses the actual data to update the updated parameter priors to obtain the posterior. There are two differences between the 'system priors' and the MRE approach. First, while the 'system priors' approach updates the priors, the MRE approach updates the posterior. Second,

5.2.2 Results from MRE counterfactuals

The right-hand side column in Figure 3 presents the baseline impulse response of US industrial production to the contractionary US monetary policy shock (black solid line) together with the MRE counterfactual (blue line with triangles). The results are very similar to those from SSA: When real activity spillovers are precluded US industrial production drops by much less during the first year following a contractionary US policy shock.

5.2.3 Spillbacks for US consumer prices

The upper left-hand side panel in Figure 7 presents results for US consumer prices.[16] Similar to industrial production, in the counterfactual in which real activity spillovers from US monetary policy are precluded, US consumer prices fall by less. Spillbacks again account for up to 50% of the overall domestic effect of US monetary policy on consumer prices.[17]

5.3 Transmission channels for spillbacks

To shed light on the channels through which spillbacks from US monetary policy materialise we first examine the responses of GDP components. Throughout this subsection we augment the VAR model by one additional endogenous variable at a time, unless otherwise mentioned.

5.3.1 GDP components

Figure 8 displays the responses of US real exports and imports as well as US real consumption and investment to a domestic monetary policy shock under the baseline and the counterfactual.[18] All GDP components decline in response to a contractionary US monetary policy shock in the baseline. In the counterfactual in which real activity spillovers from US monetary policy are precluded the decline is weaker for all GDP components. The results in the top row suggest that net exports cannot account for spillbacks to the US: Exports and

while in the MRE approach the final posterior will by design satisfy the counterfactual constraint—in our case that real activity spillovers from US monetary policy are nil—this is in general not the case for the posterior in the 'system priors' approach.

[16] Figure D.2 presents the posterior distribution of the spillbacks to US consumer prices as well as the 'modesty statistic' of Leeper and Zha (2003), and Figure D.3 documents the spillbacks when we use alternative approaches to aggregate the high-frequency surprises on a monthly frequency, analogous to Figures 4, 5 and 6 for industrial production.

[17] Analogous to Figure 6, Figure D.3 documents that our findings regarding spillbacks to consumer prices are robust to different approaches for temporal aggregation of daily interest rate and gold price surprises.

[18] The results are all based on quarterly data interpolated to monthly frequency. Figure D.4 documents that results are very similar if we use monthly data for consumption, exports and imports.

imports decline by less to roughly the same degree in the counterfactual. The panels in the bottom row suggest that spillbacks instead arise through consumption and investment. We next explore the associated transmission channels in detail.

5.3.2 Consumption

The main channel through which monetary policy affects consumption in the traditional representative agent NK (RANK) model centers on interest rates and inter-temporal substitution. As US inflation falls less strongly in the counterfactual (see Figure 7) while the nominal policy rate responds very similarly as shown in the first panel in Figure 9, the *ex post* real interest rate rises by less in the counterfactual. This would be consistent with a smaller drop in US consumption in the counterfactual, and would suggest real activity spillbacks from US monetary policy materialise through spillbacks to US inflation, real interest rates, and eventually inter-temporal adjustments in consumption. However, the second panel in Figure 9 documents that the one-year ahead *ex ante* real interest rate—obtained from the Cleveland Fed/Haubrich et al. (2012) term-structure model—responds very similarly in the baseline and the counterfactual. Overall, we judge the evidence on the role of real interest rates and inter-temporal substitution for spillbacks from US monetary policy to be weak.

Recent research highlights that indirect channels may be quantitatively much more important for monetary transmission than direct channels centered on inter-temporal substitution. Kaplan et al. (2018) propose a heterogeneous-agent NK (HANK) framework in which the effect of monetary policy on consumption that materialises through indirect channels involving labour demand, wages and wealth is large relative to direct channels (see also Auclert, 2019).[19] In light of this work, the prediction from traditional RANK models that stock market wealth effects contribute little to the effects of US monetary policy seems questionable.[20]

The bottom row in Figure 9 documents that global equity prices fall considerably less in response to a US monetary policy shock in the counterfactual. This is qualitatively consistent with stock market wealth effects accounting for the spillbacks to consumption. To assess whether the differences in the equity price responses can account for the spillbacks also quantitatively, we next review the composition of US household portfolios at the micro level

[19] Stock market wealth effects are small in the model of Kaplan et al. (2018) because profits fall after a monetary expansion. As this is in contrast to the data, Kaplan et al. (2018, p. 732) remark “the design of a HANK model that is consistent with the evidence should be a priority for future research”. Caramp and Silva (2020) propose a HANK model with rich asset-pricing dynamics in which wealth effects play an important role for the transmission of monetary policy.

[20] In the 1979 movie “Manhatten” Woody Allan’s character laments:
My stocks are down. I’m cash poor or something. I got no cash flow. I’m not liquid, something’s not flowing. (...) You know, I gotta cut down. I’ll have to give up my apartment. I’m not gonna be able to play tennis, pick checks up at dinner, or take the Southampton house. Plus I’ll probably have to give my parents less money.

and of the US external balance sheet at the macro level; then, we review elasticities of US aggregate consumption with respect to equity prices estimated in the literature.

The composition of US household portfolios suggests stock market wealth effects may play a non-trivial role for spillbacks from US monetary policy. From a micro perspective, around 50% of US households hold equity, and almost 25% of their total assets is accounted for by direct and indirect equity holdings (Bricker et al., 2019). And equity holdings are quantitatively important for households across all percentiles of the wealth distribution (Christelis et al., 2013). While direct holdings of *foreign* stocks might be limited (Christelis and Georgarakos, 2013), US households may be diversified internationally through holdings of mutual fund shares and retirement accounts. Unfortunately, very limited data on the share of US households' mutual funds or retirement accounts allocated to non-US equity exists. Some administrative information on the composition of mutual funds via tax records exists for Sweden, and Calvet et al. (2007) document that household portfolios are well diversified internationally. From a macro perspective, the US has been termed the 'world venture capitalist' investing great amounts in risky assets in the rest of the world (Gourinchas and Rey, 2007). Indeed, US foreign portfolio investment equity holdings have amounted to a non-trivial 25% of US annual GDP since 1990 on average (see Figure 10).

Estimates of the elasticity of US aggregate consumption to equity prices in the literature are consistent with stock market wealth effects accounting for the spillbacks from US monetary policy. In particular, in the counterfactual consumption declines less by about 0.05pp (0.025pp in the non-interpolated monthly data in Figure D.4) and global equity prices decline less by about 0.5pp in Figure 9.[21] Therefore, for stock market wealth effects to *fully* account for the spillbacks from US monetary policy, we would need an elasticity of aggregate consumption to equity prices of about 10% (5% in case of non-interpolated monthly data). This is close to estimates in the literature. For example, Lettau and Ludvigson (2004) estimate an elasticity of about 5%. And Lettau et al. (2002, p. 124) find that stock market wealth effects play an important role in US monetary transmission as "the decline of total private consumption expenditures in response to a Federal Funds rate shock is about 0.1 percentage points less at its trough [of 0.25% below baseline] with the wealth channel shut off".[22]

Figure D.5 documents that other possible channels—through precautionary savings, debt revaluation and house prices—do not appear to account for spillbacks to consumption.

[21] As foreign equity are denominated in foreign currency, the appreciation of the US dollar caused by the US monetary policy shock implies a negative exchange rate valuation effect (see Georgiadis and Mehl, 2016). However, Figure 7 shows that the appreciation of the oUS dollar is not less pronounced in the counterfactual.

[22] In the context of the interaction between US monetary policy and stock prices Bjornland and Leitemo (2009) estimate an elasticity of the output gap to exogenous equity price changes of about 10%.

5.3.3 Investment

The key determinant of investment from a theoretical perspective is Tobin's q, i.e. the ratio of the market price of capital—future expected profits discounted by a relevant interest rate—and its replacement price. A slowdown in rest-of-the-world real activity in response to a contractionary US monetary policy shock might reduce US firms' profits and hence their valuations, inducing them to cut back investment. Indeed, US firms are exposed to developments in the rest of the world to a non-trivial degree, as more than 40% (30%) of total sales (revenues) of S&P 500 firms are accounted for by the rest of the world (Brzenk, 2018; Silverblatt, 2019). The first panel in Figure 11 documents that US equity prices fall by less in the counterfactual, and the second panel that this is at least in part due to a weaker decline in earnings expectations. Moreover, the panels in the bottom row in Figure 11 document that valuations of sectors which are more exposed to the rest of the world exhibit greater differences in their responses to a US monetary policy shock across the baseline and the counterfactual. Overall, our results are consistent with spillbacks from US monetary policy arising through cutbacks in investment by US firms whose profits fall as they experience a decline in foreign demand.[23]

Figure D.5 documents that other possible channels—through probabilities of default, risk premia and uncertainty—do not appear to contribute to the spillbacks to investment.

5.3.4 Transmission channels for the spillbacks to US consumer prices

In the counterfactual US import prices drop by less.[24] Because the last panel in Figure 7 documents that the US dollar NEER appreciates very similarly in the baseline and the counterfactual, the weaker drop in US import prices may be solely due to the weaker slowdown in rest-of-the-world real activity and hence price pressures. Of course, part of the smaller drop in US consumer prices in the counterfactual may also be due weaker pressures on domestic prices given the weaker slowdown of US real activity.

[23]Investment cutbacks may also be driven by US multinationals experiencing negative balance sheet effects as the valuation of their foreign acquisitions drops along with the slowdown in rest-of-the-world real activity in response to a contractionary US monetary policy shock. In principle, this may be quantitatively important as well: US foreign direct investment equity holdings have amounted to about 25% of US annual GDP since 1990 (see Figure 10). However, most of these assets are not listed in stock exchanges and are not marked-to-market.

[24]The response of US import prices is not inconsistent with dominant-currency pricing (DCP; Gopinath et al., 2020). In particular, under DCP US import prices are sticky in US dollar in the *short* run, but exporters can adjust prices in US dollar terms in the medium term. Indeed, although we estimate that the US dollar NEER appreciates on impact US import prices only fall gradually over time.

5.4 Spillbacks through AEs vs. EMEs

We next explore if spillbacks arise through spillovers to AEs or EMEs or both. To this end, we re-estimate the VAR model replacing rest-of-the-world industrial production with the corresponding AE and EME analogues. We then repeat the counterfactual analysis, imposing that the responses of AE and EME industrial production to a US monetary policy shock are nil. In order to assess the contribution of spillovers to AEs and EMEs for spillbacks to the US, we consider two variations of the counterfactual: First we only preclude spillovers from US monetary policy to AEs while constraining spillovers to EMEs to coincide with those in the baseline; hence, in this variation we shut down spillbacks through AEs but allow spillbacks through EMEs. In the second variation of the counterfactual we do the reverse.

The left-hand side panel in Figure 12 presents the results for the counterfactual in which we shut down spillbacks from AEs but not from EMEs based on SSA with all shocks; results for MRE are shown in Figure D.6 and are very similar. The blue line with triangles depicts the domestic real activity response to a US monetary policy shock when spillovers to the entire rest of the world—i.e. both AEs and EMEs—are precluded, and the dark blue line with crosses when only spillovers to AEs are precluded. The domestic real activity effect of a US monetary policy shock is estimated to be almost identical when spillbacks from the entire rest of the world or only from AEs are shut down. This suggests that spillbacks from US monetary policy arise through AEs rather than EMEs. Indeed, the right-hand side panel shows that the domestic real activity effect of a US monetary policy shock is almost identical when spillovers to the entire rest of the world are unconstrained (black solid line) and when only spillbacks from EMEs are precluded (dark blue line with crosses). An important caveat to the finding that spillbacks from US monetary policy arise through AEs rather than EMEs is that it is based on data for the time period from 1990 to 2019; at the current juncture and looking ahead, the already large and further growing role of EMEs in the world economy and their integration in global financial markets may overturn this finding.

One may wonder if the relative importance of AEs and EMEs is consistent with our findings on the channels in Section 5.3. Recall that the evidence suggests spillbacks materialise through stock market wealth effects rooted in US households' holdings of global equity as well as Tobin's q effects rooted in the exposure of US firms' to foreign demand. The top panel in Figure 13 documents that since 2003 the share of US foreign portfolio investment equity accounted for by AEs and EMEs on average amounted to about 63% and 26%, respectively.[25] Because the share accounted for by AEs has been falling over time along with the integration of EMEs in global financial markets, the dominant role of AEs as a destination for US foreign

[25]The data are taken from Bertaut et al. (2019) and account for measurement problems related to multinationals, financial centers and mutual funds.

portfolio investment equity over our sample period would stand out even more prominently if data prior to 2003 was available. In addition to the compositional perspective, Figure 14 documents that also the difference in the equity price spillovers from US monetary policy across the baseline and the counterfactual is larger in AEs than in EMEs.[26] Finally, using the country composition of exports as a proxy for the share of US firms' revenues/sales accounted for by AEs and EMEs in the bottom panel in Figure 13 again suggests a more important role of AEs. Overall, the country composition of the exposure of US foreign equity holdings and exports in Figure 13 is consistent with our interpretation of Figure 12 that spillbacks from US monetary policy materialise primarily through AEs.

These findings have important implications for the notion that the existence of large spillbacks from US monetary policy weakens the case for more extensive forms of international monetary policy coordination (Fischer, 2014; Yellen, 2019). In particular, Figure 15 presents estimates of the spillovers from US monetary policy to consumer prices and policy rates in AEs and EMEs. While real activity spillovers have the same sign in AEs and EMEs, consumer prices fall in AEs but tend to rise in EMEs. The latter is a common finding usually ascribed to greater exchange rate pass-through to consumer prices in EMEs (Hausmann et al., 2001). Hence, while US monetary policy spillovers do not imply trade-offs between output and inflation stabilisation in AEs, they may do so in EMEs. Indeed, our estimates suggest that consistent with fear-of-floating EME monetary policy is tightened in response to a contractionary US monetary policy shock (Calvo and Reinhart, 2002); the latter could also point to trade-offs between output stabilisation and financial stability due to foreign-currency exposures on EME balance sheets (Georgiadis and Zhu, 2021). The tightening in EME monetary policy may contain exchange rate depreciation and hence prevent spikes in import prices as well as risks to financial stability, but comes at the cost of exacerbating the slowdown in real activity. Our findings that (i) US monetary policy does not take into account its spillovers to EMEs as there are no associated spillbacks and that (ii) these spillovers give rise to trade-offs in EMEs together suggest the case for international monetary policy coordination may have to be reconsidered. In particular, global welfare may benefit from US monetary policy internalising also those spillovers that are not associated with spillbacks. Further research on this issue seems warranted as it may be that US monetary policy actually already internalises those spillovers that do are not associated with spillbacks (Ferrara and Teuf, 2018).

[26] Figure D.7 shows that US foreign direct investment equity holdings are largely accounted for by financial centers, and so it is not obvious whether the US—in particular through multinationals—is more exposed to AEs or EMEs. However, financial centers include Ireland, Luxembourg and the Netherlands, which are important entry points to AEs in Europe (Damgaard et al., 2020). Therefore, to the extent that spillbacks materialise through negative valuation effects in US multinationals' foreign acquisitions that dampen their domestic investment this also appears to be mediated primarily through AEs rather than EMEs.

5.5 Placebo tests

As a placebo test for our counterfactual analysis we check what we obtain when we use SSA and MRE to estimate spillbacks from some small open economy (SOE) rather than from the entire rest of the world. We expect the SSA and MRE counterfactuals to indicate that spillbacks from US monetary policy from an individual SOE are small. The top row in Figure 16 presents results for estimations in which we constrain real activity spillovers from US monetary policy to some individual SOEs to be nil while those to the rest of the world to be identical to our baseline. The impulse responses of US industrial production (crossed orange lines) are very different from the baseline counterfactuals (squared blue lines) from Figure 3. In fact, the impulse responses of US industrial production are very similar to the unconstrained baseline (black solid lines) when only spillovers to individual SOEs are shut down. SSA and MRE thus estimate spillbacks from US monetary policy through individual SOEs alone are essentially zero. A related check for the plausibility of SSA and MRE counterfactual analysis is to explore how large spillbacks from US monetary policy are if we constrain spillovers to the rest of the world to be nil but leave those to individual SOEs unconstrained. The impulse responses of US industrial production for this specification (crossed orange lines) in the bottom row in Figure 16 are hardly distinguishable from the baseline counterfactuals (blue squared lines) from Figure 3. Again, this suggests that spillbacks through individual SOEs are very small. Figures D.8 and D.9 provide results for SSA with rest-of-the-world shocks and for MRE. Overall, the results from these exercises bolster the plausibility of the counterfactual analysis based on SSA and MRE.

6 Conclusion

In this paper we quantify spillbacks from US monetary policy using the SSA and MRE approach in a state-of-the-art Bayesian proxy structural VAR model. Our results suggest that spillbacks from US monetary policy are large: Up to about half of the slowdown in US real activity in response to a contractionary US monetary policy shock can be accounted for by spillbacks. Moreover, we find that spillbacks materialise as stock market wealth effects impinge on US consumption, and as Tobin's q effects impinge on US investment. In particular, a contractionary US monetary policy shock depresses global equity prices, weighing on the value of US households' portfolios; and it depresses earnings of US firms through declines in foreign sales, inducing them to cut back investment. Net trade does not contribute to spillbacks because US monetary policy affects exports and imports similarly. Finally, we find that spillbacks materialise through AEs rather than through EMEs, consistent with the composition of US foreign equity holdings and exports.

Our findings suggest that US monetary policy internalises through spillbacks only some of the spillovers it emits to the rest of the world. Moreover, our evidence also suggests that while US monetary policy spillovers do not give rise to trade-offs between output stabilisation on the one hand and inflation stabilisation as well as financial stability on the other hand in AEs, they do so in EMEs. Against this background, our result that spillbacks to the US economy that materialise through EMEs are small suggests global welfare may benefit from US monetary policy internalising those spillovers that are not associated with spillbacks. Further research on this issue seems warranted as it may be that US monetary policy already internalises these spillovers (Ferrara and Teuf, 2018).

A natural extension of our work in this paper would be to consider spillbacks from monetary policy in other systemic economies such as the euro area (Draghi, 2018; Coeure, 2019).

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A Tables

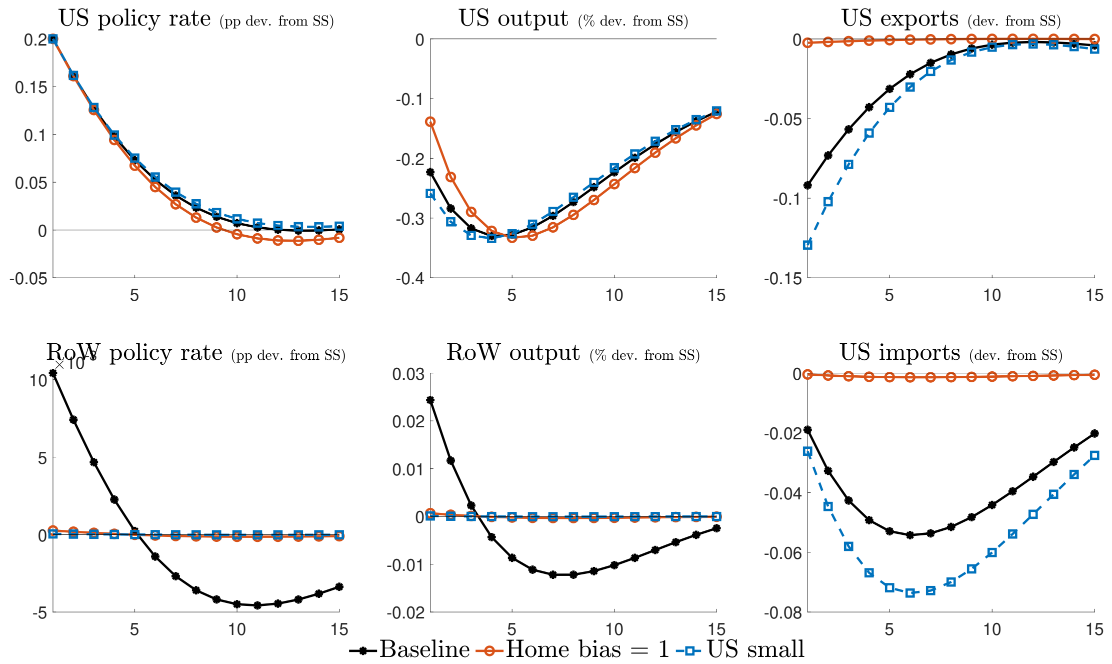
Table 1: Identification restrictions of the rest-of-the-world shocks

Variable / Shock	RoW ‘depreciating’ shock	RoW ‘appreciating’ shock
US 1-year T-bill rate		
US industrial production	$< 0^{\triangle}$	$\lozenge$
US CPI		
US excess bond premium		
US dollar NEER	> 0	< 0
VXO		
RoW industrial production	< 0 & $<^{\triangle}$	< 0 & $<^{\lozenge}$

Notes: The table presents the sign and magnitude restrictions we impose in order to identify the rest-of-the world shocks. We additionally impose the exogeneity restrictions $E[p_t^{\epsilon,mp} \boldsymbol{\epsilon}_t^o] = 0$ in Equation (10b) that the proxy variables are not driven by the rest-of-the-world shocks.

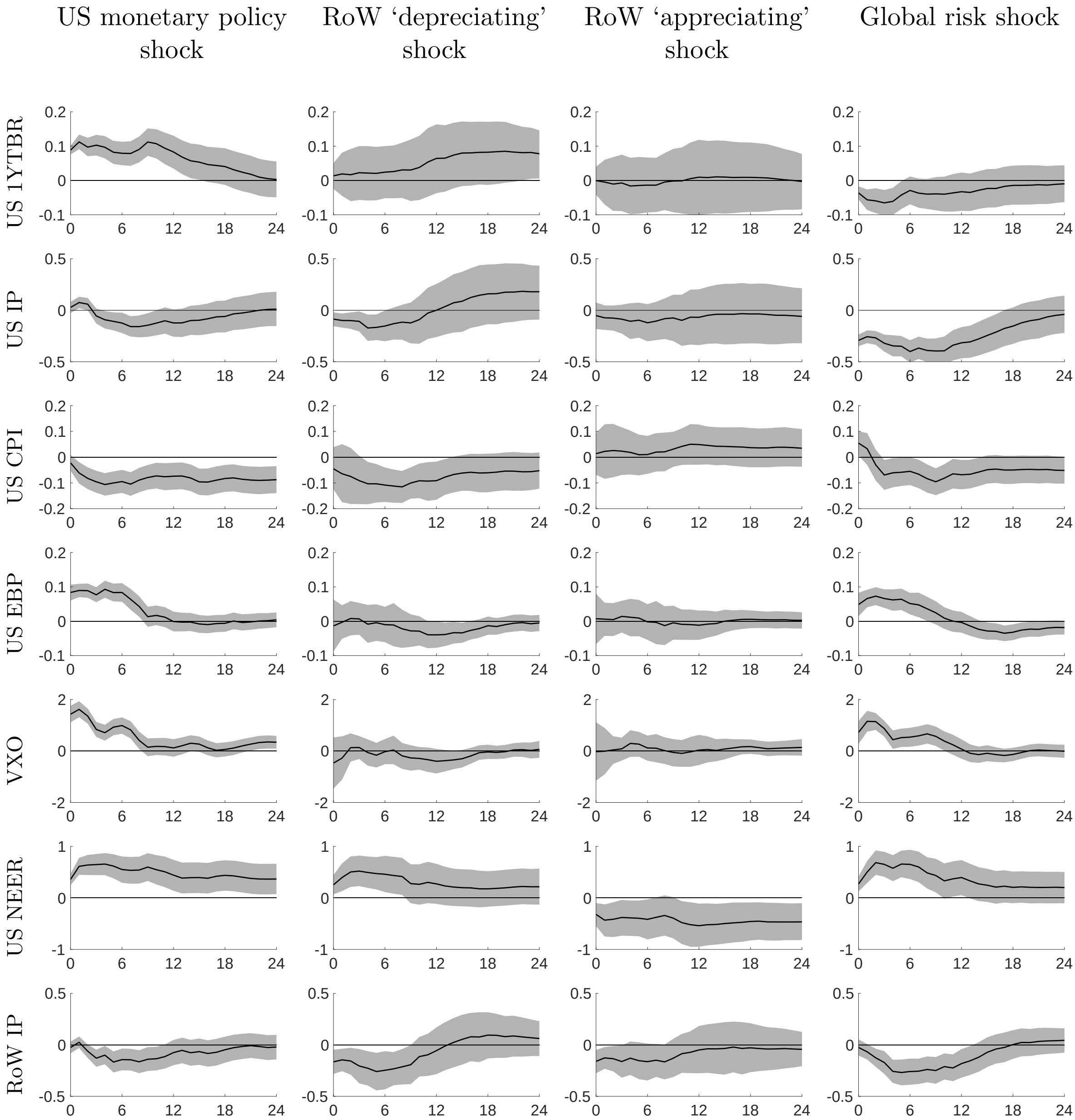
B Figures

Figure 1: Impulse responses to a US monetary policy shock in a structural two-country model



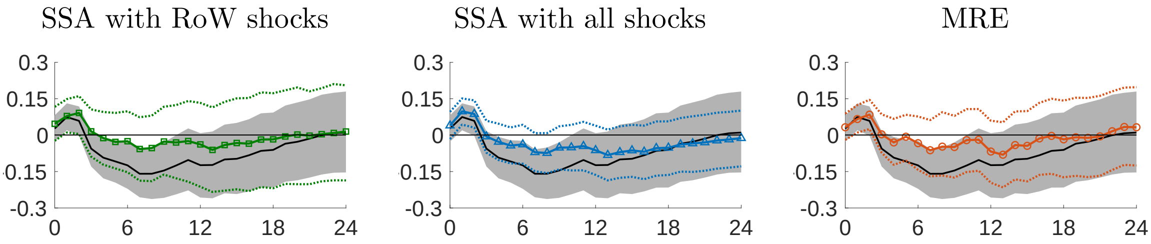
Notes: The figure displays the responses of policy interest rates and output of the US and the res of the world, as well as US exports/import to a contractionary US monetary policy shock from a structural two country model. The black solid lines show the impulse responses for the baseline specification, the red solid lines with circles when home bias is set to unity, and the blue dashed lines with squares for the specification in which the US is very small relative to the rest of the world. Interest rates are plotted in percentage points deviations from steady state, output in percent deviations from steady state, and exports/imports in absolute deviations from steady state (in order to avoid complications in specifications in which their steady-state values are zero).

Figure 2: Baseline impulse responses to US monetary policy, rest-of-the-world 'appreciating' and 'depreciating', and global risk shocks



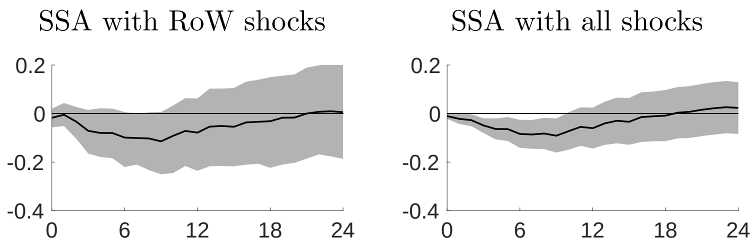
Notes: The figure shows point-wise posterior mean impulse responses (black solid lines) and 68 percent centered point-wise probability bands (grey areas). '1YTBR' stands for the 1-year Treasury bill rate, 'IP' for industrial production, 'CPI' for consumer-price index, 'EBP' for excess bond premium, 'VXO' is the stock market volatility index, and 'NEER' the nominal effective exchange rate.

Figure 3: Baseline and counterfactual impulse responses of US industrial production to a US monetary policy shock



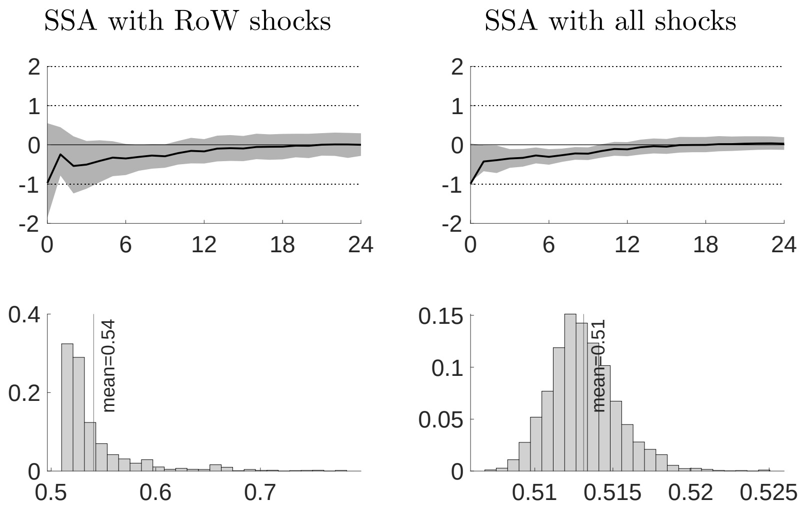
Notes: The black solid lines depict the baseline impulse responses of US industrial production to a US monetary policy shock and the coloured lines with markers depict the counterfactual impulse responses based on point-wise posterior mean SSA with rest-of-the-world shocks (left column, green lines with squares), based on point-wise posterior mean SSA with all shocks (middle column, blue lines with triangles), and based on point-wise posterior mean MRE (right column, red lines with circles). The grey shaded areas represent 68% centered point-wise probability bands.

Figure 4: Distribution of SSA spillback estimates



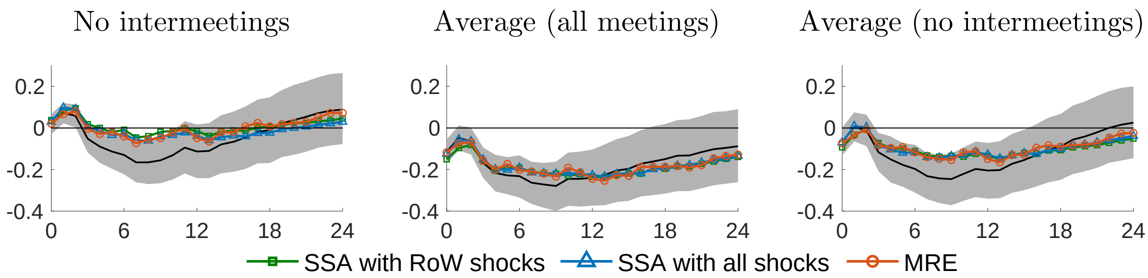
Notes: The figure presents the point-wise mean of the differences between the baseline and counterfactual effects of US monetary policy on domestic industrial production together with 68% centered point-wise probability bands.

Figure 5: Modesty statistic of Leeper and Zha (2003) and distribution of the q-divergence of ADPRR for SSA counterfactuals



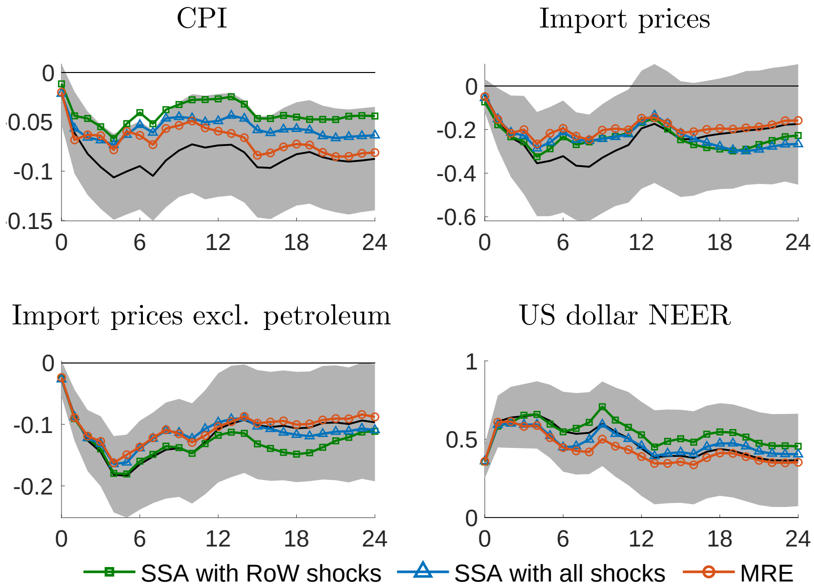
Notes: The top panels show the 'modesty statistic' of Leeper and Zha (2003) for the implied neutralising effects needed to impose the counterfactual path of rest-of-the-world industrial production (point-wise mean and 68% centered point-wise probability bands). The neutralising effect is 'modest'—meaning it would be unlikely to induce agents to adjust their expectations formation—if the statistic is smaller than two in absolute value. The bottom panels show the distribution of the q-divergence of ADPRR for the SSA; the left-hand side panel presents results for the case in which only the rest-of-the-world shocks are driving shocks, while the right-hand side panel for the case in which all shocks are used as driving shocks. The q-divergence indicates how unlikely a conditional forecast is in terms of comparing the implied distributions of shocks with their unconditional distributions, translated into a comparison of the binomial distributions of a fair and a biased coin. See Appendix C.1 for a description how we implement the q-divergence in the context of our paper.

Figure 6: Spillbacks from US monetary policy using alternatively aggregated high-frequency surprises



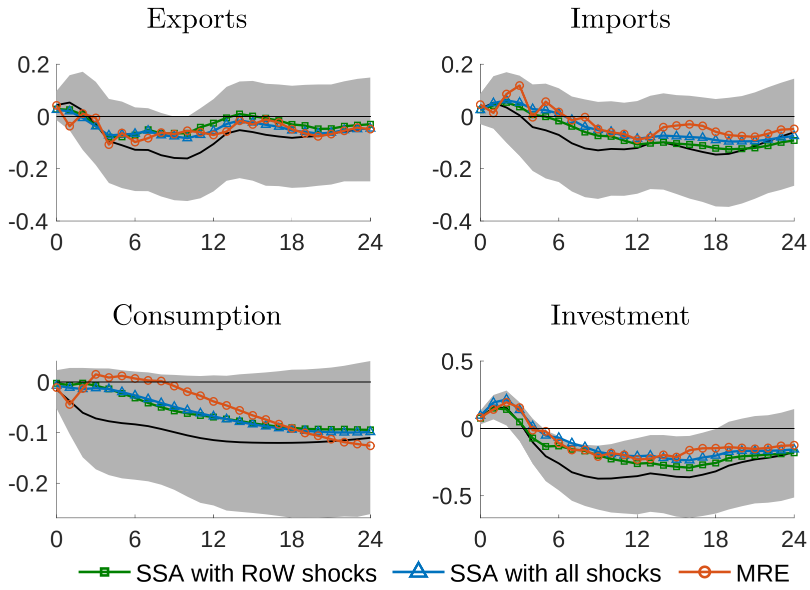
Notes: The black solid lines depict the baseline impulse responses of US industrial production to a US monetary policy shock and the coloured lines with markers depict the counterfactual impulse responses based on point-wise posterior mean SSA with rest-of-the-world shocks (green lines with squares), based on point-wise posterior mean SSA with all shocks (blue lines with triangles), and based on point-wise posterior mean MRE (red lines with circles). In the first column we aggregate the daily policy and uncertainty surprises as in Gertler and Karadi (2015) but exclude FOMC inter-meeting announcements; in the second column we take monthly averages of all meetings, and in the third column we use monthly averages of non inter-meetings only. The grey shaded areas represent 68% centered point-wise probability bands.

Figure 7: Spillbacks for US consumer prices



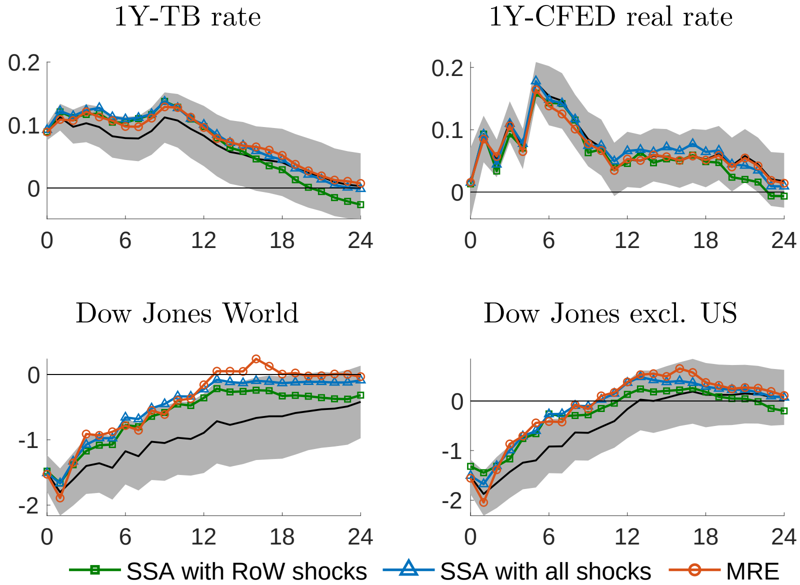
Notes: The figure presents the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for US CPI, import prices with and without petroleum as well as the US dollar NEER. The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure 8: Responses of GDP components to US monetary policy shock for the baseline and the counterfactual



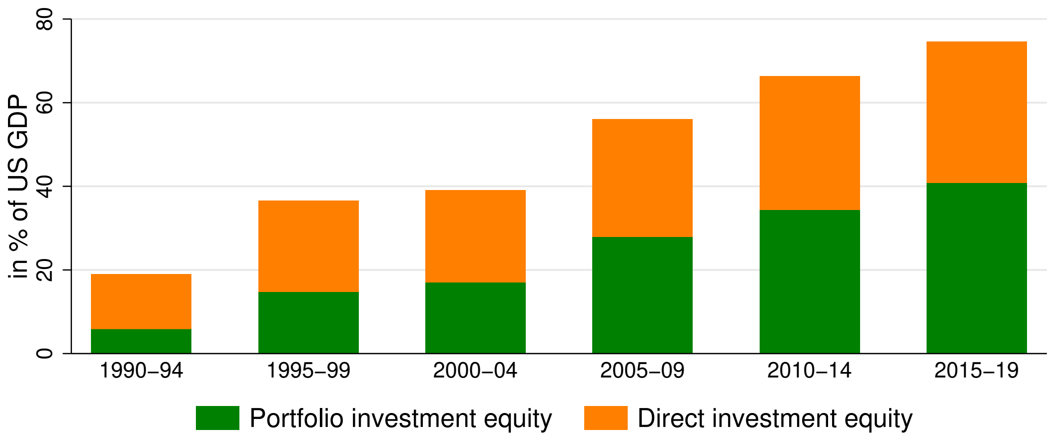
Notes: The figure presents the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for real exports, real imports, real private consumption expenditures and real private gross fixed capital investment to a US monetary policy shock. The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure 9: Channels of transmission for spillbacks from US monetary policy to consumption



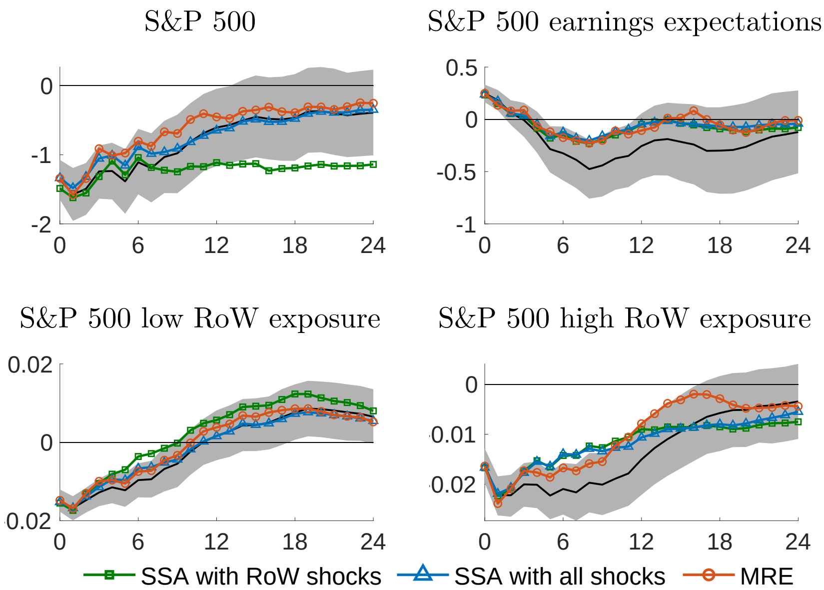
Notes: The figure shows the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for the the 1-year Treasury rate, the Cleveland Fed/Haubrich et al. (2012) interest rate-term structure-based 1-year real rate, the S&P 500 index, the Dow Jones World index, and the Dow Jones World excl. US index. The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure 10: US foreign equity holdings



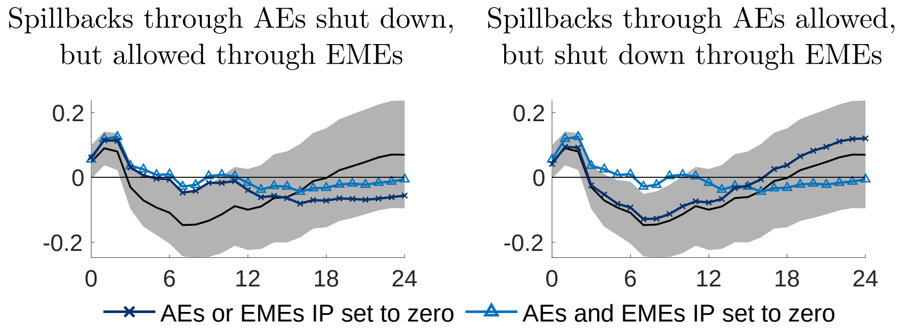
Notes: The figure shows the evolution of the US international investment position in terms of portfolio and direct investment equity assets relative to GDP. The data are taken from the Bureau of Economic Analysis.

Figure 11: Channels of transmission for spillbacks from US monetary policy to investment



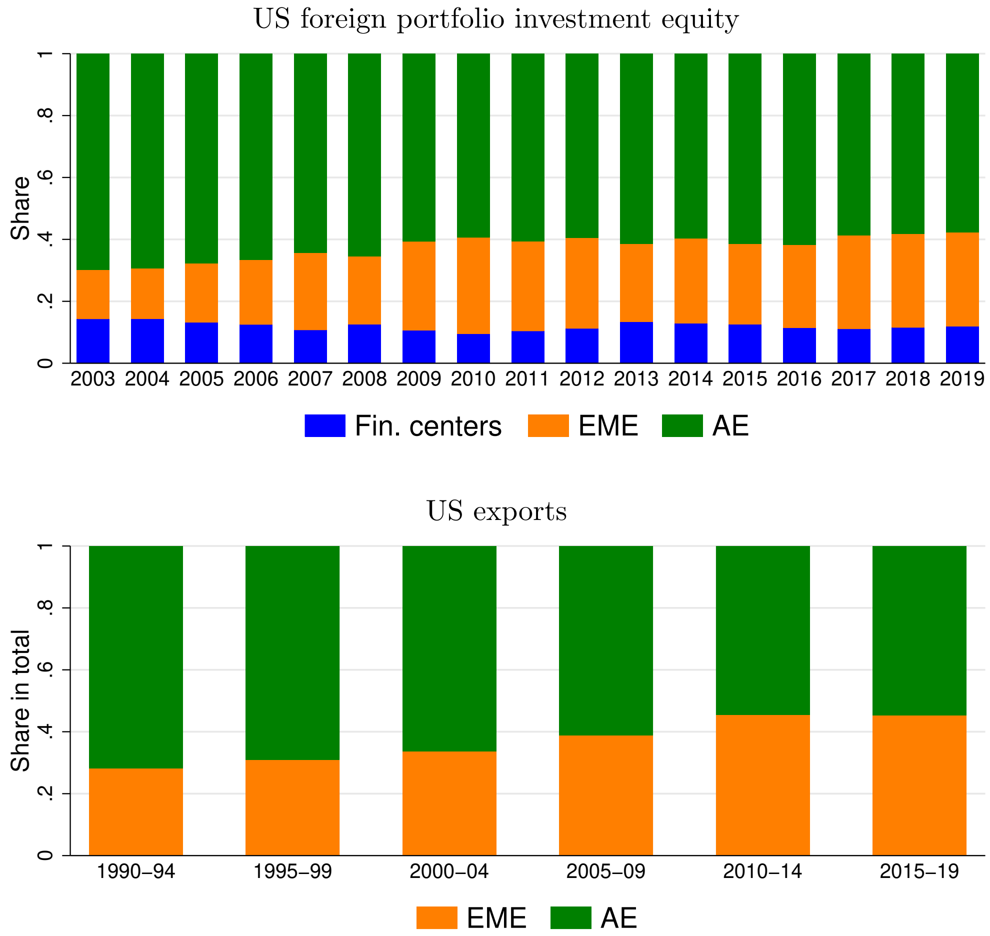
Notes: The figure shows the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for the S&P 500 Composite, the 12-months forward S&P 500's earnings per share, and the S&P 500 index for high and low US sales exposure. The S&P 500 indices for low and high rest-of-the-world exposures are constructed as market capitalisation weighted averages of sectoral S&P indices. The low rest-of-the-world exposure sectors are utilities, telecommunication services, health care and financials, and the high rest-of-the-world exposure sectors are energy, materials, industrials and information technology; see Brzenk (2018) for data and a discussion of US exposures in the S&P 500. The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure 12: Spillbacks from US monetary policy through AEs and EMEs (SSA all shocks counterfactuals)



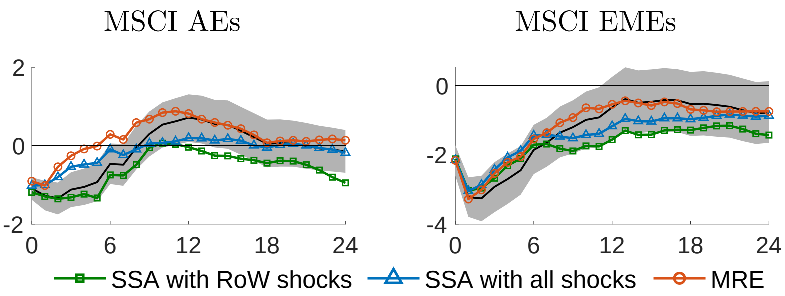
Notes: The black solid lines depict the response of US industrial production to a US monetary policy shock from VAR models in which rest-of-the-world industrial production is replaced with separate measures for AEs and EMEs industrial production and their impulse responses to a US monetary policy shock are not constrained, and the grey shaded areas represent 68% centered point-wise probability bands. The blue lines with triangles show results from a counterfactual in which spillovers to the rest-of-the-world are precluded, meaning that both AEs and EMEs industrial production are constrained to not respond to a US monetary policy shock. In the left-hand side panel the dark blue line with crosses depicts the counterfactual response of US industrial production when AEs industrial production is constrained to not respond while the response of EMEs industrial production is set to respond as in the unconstrained case. In the right-hand side panel the dark blue line with crosses depicts the counterfactual response when AEs industrial production is constrained to respond as in the unconstrained case while the response of EMEs industrial production is constrained to not respond to a US monetary policy shock. All counterfactuals shown are based on SSA with all shocks. Figure D.6 presents the counterfactuals based on SSA with rest-of-the-world shocks and MRE.

Figure 13: Country composition of US foreign portfolio investment equity holdings and US exports



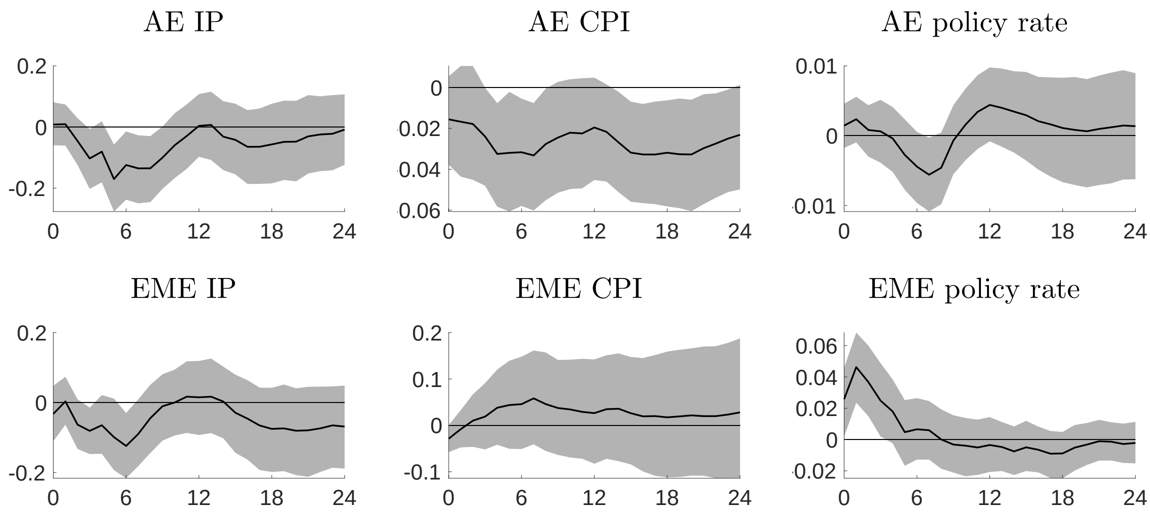
Notes: The top panel shows the country composition of US foreign portfolio equity holdings through common stocks and mutual funds based on the analysis in Bertaut et al. (2019). The total underlying the shares does not include cross-border equity of firms that primarily operate in the US (for details see Bertaut et al., 2019). The list of financial centers is taken from Bertaut et al. (2019). The bottom panel shows the country composition of US exports of goods obtained from the IMF Direction of Trade Statistics

Figure 14: US monetary policy spillovers to AE and EME equity prices



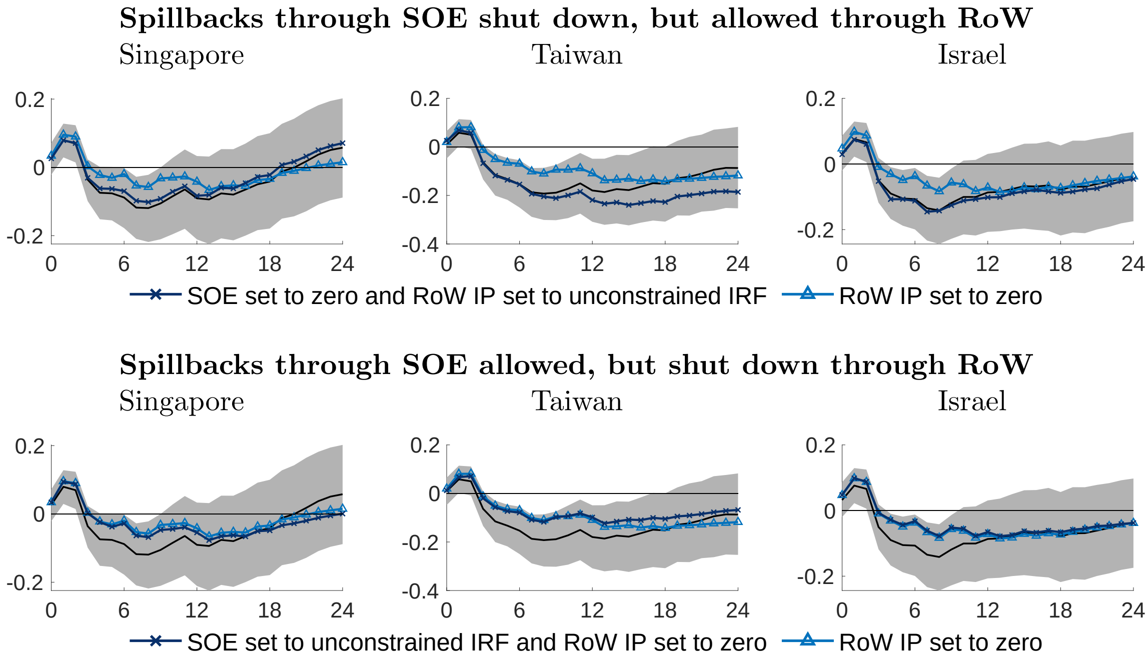
Notes: The figure shows the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for the MSCI AEs index and the MSCI EME index. The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure 15: US monetary policy spillovers to AEs and EMEs



Notes: The figure shows point-wise posterior mean impulse responses (black solid lines) and 68% centered point-wise probability bands (grey areas).

Figure 16: SSA all shocks placebo test responses of US industrial production



Notes: The black solid lines depict the response of US industrial production from VAR models in which SOE industrial production is added to the vector of observables and their impulse responses to a US monetary policy shock are not constrained, and the grey shaded areas represent 68% centered point-wise probability bands. The blue lines with triangles show results from the baseline counterfactual in which spillovers to rest-of-the-world industrial production are precluded. In the top row, the dark blue lines with crosses depict the counterfactual response of US industrial production when SOE industrial production is constrained to not respond to a US monetary policy shock, and rest-of-the-world industrial production is constrained to respond as in the unconstrained case. In the bottom row, the dark blue lines with crosses depict the response of US industrial production when the response of SOE industrial production is constrained to respond as in the unconstrained case, and rest-of-the-world industrial production is constrained to not respond to a US monetary policy shock. Figure D.8 and Figure D.9 document the placebo tests based on SSA with rest-of-the-world shocks and MRE.

C The SSA framework of ADPRR

The SSA framework of ADPRR provides a rigorous and general treatment on how to impose specific paths on observables in a VAR model as conditional forecasts with and without constraints on the set of driving shocks. Denoting by $\boldsymbol{y}'_{T+1,T+h} \equiv [\boldsymbol{y}'_{T+1}, \boldsymbol{y}'_{T+2}, \ldots, \boldsymbol{y}'_{T+h}]$ the $1 \times nh$ vector that stacks the future values of the observables over an horizon of h periods, the SSA framework of ADPRR consists of obtaining the distribution of the observables

$$\widetilde{\boldsymbol{y}}_{T+1,T+h} \sim N(\boldsymbol{\mu}_y, \boldsymbol{\Sigma}_y), \tag{C.1}$$

where the $nh \times 1$ vector vector $\widetilde{\boldsymbol{y}}_{T+1,T+h}$ contains the values of all observables—i.e. both those whose paths are constrained and those whose paths are unconstrained—under the conditional forecast. The $nh \times 1$ vector $\boldsymbol{\mu}_y$ contains the corresponding means of the distribution of the observables in $\widetilde{\boldsymbol{y}}_{T+1,T+h}$ under the conditional forecast, and the $nh \times nh$ matrix $\boldsymbol{\Sigma}_y$ the associated uncertainty.

In the framework of ADPRR, structural scenarios involve

(i) 'conditional-on-observables forecasting', i.e. specifying paths for a subset of observables in $\boldsymbol{y}_{T+1,T+h}$ that depart from their unconditional forecast, and/or

(ii) 'conditional-on-shocks forecasting', i.e. specifying the subset of (and potentially a path for) the structural shocks $\boldsymbol{\epsilon}_{T+1,T+h}$ that are allowed to depart from the unconditional distribution to produce the specified path of the observables in (i);

Both the case in which the path of observables under (i) and the case in which the path of structural shocks under (ii) is constrained can be laid out based on Equation (C.1). The goal is to determine $\boldsymbol{\mu}_y$ and $\boldsymbol{\Sigma}_y$ such that the constraints under (i) and (ii) are satisfied simultaneously.

Assume the structural parameters of the VAR model are known. The future values of the observables are given by

$$\boldsymbol{y}_{T+1,T+h} = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\boldsymbol{\epsilon}_{T+1,T+h}, \tag{C.2}$$

where the $nh \times 1$ vector $\boldsymbol{b}_{T+1,T+h}$ represents the deterministic component due to initial conditions and the autoregressive dynamics of the VAR model, and the $nh \times nh$ matrix $\boldsymbol{M}'$ the impact of future structural shocks.

Under (i), 'conditional-on-observables forecasting' can be written as

$$\overline{\boldsymbol{C}}\widetilde{\boldsymbol{y}}_{T+1,T+h} = \overline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h} + \overline{\boldsymbol{C}}\boldsymbol{M}'\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\overline{\boldsymbol{f}}_{T+1,T+h}, \overline{\boldsymbol{\Omega}}_f). \tag{C.3}$$

where $\overline{\boldsymbol{C}}$ is a $k_o \times nh$ selection matrix, the $k_o \times 1$ vector $\overline{\boldsymbol{f}}_{T+1,T+h}$ is the mean of the distribution of the observables constrained under the conditional forecast and the $k_o \times k_o$ matrix $\overline{\boldsymbol{\Omega}}_f$ the associated uncertainty. In turn, under (ii), 'conditional-on-shocks forecasting' can be written as

$$\boldsymbol{\Xi}\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\boldsymbol{g}_{T+1,T+h}, \boldsymbol{\Omega}_g), \tag{C.4}$$

where $\boldsymbol{\Xi}$ is a $k_s \times nh$ selection matrix, the $k_s \times 1$ vector $\boldsymbol{g}_{T+1,T+h}$ the mean of the distribution of the shocks constrained under the conditional forecast and the $k_s \times k_s$ matrix $\boldsymbol{\Omega}_g$ the associated uncertainty.[27] Under invertibility we have

$$\begin{aligned}
\boldsymbol{M}'^{-1}\widetilde{\boldsymbol{y}}_{T+1,T+h} &= \boldsymbol{M}'^{-1}\boldsymbol{b}_{T+1,T+h} + \widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}, \\
\boldsymbol{\Xi}\boldsymbol{M}'^{-1}\widetilde{\boldsymbol{y}}_{T+1,T+h} &= \boldsymbol{\Xi}\boldsymbol{M}'^{-1}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{\Xi}\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}, && \text{(C.5)} \\
\underline{\boldsymbol{C}}\widetilde{\boldsymbol{y}}_{T+1,T+h} &= \underline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{\Xi}\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}, && \text{(C.6)}
\end{aligned}$$

and hence

$$\underline{\boldsymbol{C}}\widetilde{\boldsymbol{y}}_{T+1,T+h} = \underline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{\Xi}\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\underline{\boldsymbol{f}}_{T+1,T+h}, \underline{\boldsymbol{\Omega}}_f), \tag{C.7}$$

with $\underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g$.

Based on Equations (C.3) and (C.7), we can combine the k_o constraints on the observables under 'conditional-on-observables forecasting' and the k_s constraints on the structural shocks under 'conditional-on-shocks forecasting' by defining the $k \times nh$, $k = k_o + k_s$, matrices $\boldsymbol{C} \equiv [\overline{\boldsymbol{C}}', \underline{\boldsymbol{C}}']'$ and $\boldsymbol{D} \equiv [\boldsymbol{M}\overline{\boldsymbol{C}}', \boldsymbol{\Xi}']'$ to write

$$\boldsymbol{C}\widetilde{\boldsymbol{y}}_{T+1,T+h} \;=\; \boldsymbol{C}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{D}\widetilde{\epsilon}_{T+1,T+h} \sim N(\boldsymbol{f}_{T+1,T+h}, \boldsymbol{\Omega}_f), \tag{C.8}$$

where the $k \times 1$ vector $\boldsymbol{f}_{T+1,T+h} \equiv [\overline{\boldsymbol{f}}'_{T+1,T+h}, \underline{\boldsymbol{f}}'_{T+1,T+h}]'$ stacks the means of the distributions under the 'conditional-on-observables forecasting' ($\overline{\boldsymbol{f}}_{T+1,T+h} = \overline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h}$) and the 'conditional-on-shocks forecasting' ($\underline{\boldsymbol{f}}_{T+1,T+h} = \underline{\boldsymbol{C}}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{g}_{T+1,T+h}$), and the $k \times k$ matrix $\boldsymbol{\Omega}_f \equiv diag(\overline{\boldsymbol{\Omega}}_f, \underline{\boldsymbol{\Omega}}_f)$.[28]

Based on the combination of 'conditional-on-shocks observables forecasting' and 'conditional-on-shocks forecasting' in Equation (C.8), we can derive the solutions for $\boldsymbol{\mu}_y$ and $\boldsymbol{\Sigma}_y$. Define

$$\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h} \sim N(\boldsymbol{\mu}_\epsilon, \boldsymbol{\Sigma}_\epsilon), \quad \boldsymbol{\Sigma}_\epsilon = \boldsymbol{I} + \boldsymbol{\Psi}_\epsilon, \tag{C.9}$$

[27] Viewing an impulse response function to the i-th shock in period $T+1$ as a conditional forecast we have

$$\boldsymbol{\Xi} = \boldsymbol{I}_{nh}, \quad \boldsymbol{g}_{T+1,T+h} = [\boldsymbol{e}'_i, \boldsymbol{0}'_{n(h-1)\times 1}]'_{nh\times 1}, \quad \boldsymbol{\Omega}_g = \boldsymbol{0}_{nh\times nh},$$

where $\boldsymbol{e}_i$ is an $n \times 1$ vector of zeros with unity at the i-th position.

[28] Note that $\underline{\boldsymbol{f}}_{T+1,T+h}$ refers to the mean of $\underline{\boldsymbol{C}}\widetilde{\boldsymbol{y}}_{T+1,T+h} = \boldsymbol{\Xi}\boldsymbol{M}'^{-1}\widetilde{\boldsymbol{y}}_{T+1,T+h}$ and hence not just of a path of some observable(s). Instead, $\boldsymbol{\Xi}\boldsymbol{M}'^{-1}\widetilde{\boldsymbol{y}}_{T+1,T+h}$ are the values of the observables that are implied by a specific path of the structural shocks assumed under 'conditional-on-shocks forecasting'.

so that the $nh \times 1$ vector $\boldsymbol{\mu}_\epsilon$ and the $nh \times nh$ matrix $\boldsymbol{\Psi}_\epsilon$ represent the deviation of the mean and the variance of the structural shocks under the conditional forecast from the unconditional forecast. Given Equations (C.8) and (C.9), we have

$$\begin{aligned} \boldsymbol{f}_{T+1,T+h} &= \boldsymbol{C}\boldsymbol{b}_{T+1,T+h} + \boldsymbol{D}\boldsymbol{\mu}_\epsilon, && \text{(C.10)} \\ \boldsymbol{\Omega}_f &= \boldsymbol{D}(\boldsymbol{I} + \boldsymbol{\Psi}_\epsilon)\boldsymbol{D}'. && \text{(C.11)} \end{aligned}$$

The solutions for $\boldsymbol{\mu}_\epsilon$ and $\boldsymbol{\Sigma}_\epsilon$ are given by

$$\begin{aligned} \boldsymbol{\mu}_\epsilon &= \boldsymbol{D}^*(\boldsymbol{f}_{T+1,T+h} - \boldsymbol{C}\boldsymbol{b}_{T+1,T+h}), && \text{(C.12)} \\ \boldsymbol{\Sigma}_\epsilon &= \boldsymbol{D}^*\boldsymbol{\Omega}_f\boldsymbol{D}^{*\prime} + (\boldsymbol{I} - \boldsymbol{D}^*\boldsymbol{D}\boldsymbol{D}'\boldsymbol{D}^{*\prime}), && \text{(C.13)} \end{aligned}$$

where the $nh \times k$ matrix $\boldsymbol{D}^*$ is the Moore-Penrose inverse of $\boldsymbol{D}$.[29] Equation (C.12) shows that the path of the implied future structural shocks under the conditional forecast depends on its deviation from the unconditional forecast. In turn, Equation (C.13) shows that the variance of the implied future structural shocks depends on the uncertainty the researcher attaches to the conditional forecast; if the uncertainty is zero, then $\boldsymbol{\Omega}_f = \boldsymbol{0}$ as $\overline{\boldsymbol{\Omega}}_f = \underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g = \boldsymbol{0}$, and hence $\boldsymbol{\Sigma}_\epsilon = 0$, meaning that a unique, certain path $\boldsymbol{\mu}_\epsilon$ for the structural shocks is implied by the conditional forecast.[30]

Finally, as

$$\widetilde{\boldsymbol{y}}_{T+1,T+h} = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h}, \tag{C.14}$$

and given Equations (C.12) and (C.13) we have that

$$\begin{aligned} \boldsymbol{\mu}_y &= \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\boldsymbol{D}^*(\boldsymbol{f}_{T+1,T+h} - \boldsymbol{C}\boldsymbol{b}_{T+1,T+h}), && \text{(C.15)} \\ \boldsymbol{\Sigma}_y &= \boldsymbol{M}'\boldsymbol{M} - \boldsymbol{M}'\boldsymbol{D}^*(\boldsymbol{\Omega}_f - \boldsymbol{D}\boldsymbol{D}')\boldsymbol{D}^{*\prime}\boldsymbol{M}. && \text{(C.16)} \end{aligned}$$

Again, when $\boldsymbol{\Omega}_f = \boldsymbol{0}$ then $\boldsymbol{\Sigma}_y = \boldsymbol{0}$, and there is no uncertainty about the path of the observables under the conditional forecast.

It is useful to discuss how the framework of ADPRR is parsed in the context of our paper. Recall that we constrain the effect of a US monetary policy shock on rest-of-the world real activity to be zero, and we assume this occurs due to two offsetting rest-of-the world shocks whose effects. Ordering rest-of-the-world output last in $\boldsymbol{y}_t$, the US monetary policy shock first and the two rest-of-the-world shocks last in $\boldsymbol{\epsilon}_t$, and denoting by $\boldsymbol{e}_i$ a $n \times 1$ vector of zeros

[29]ADPRR discuss the properties of the solutions under different values for k relative to nh.

[30]As discussed in ADPRR, the researcher could impose that the uncertainty under the conditional forecast is identical to that of the unconditional forecast, i.e. set $\boldsymbol{\Omega}_f = \boldsymbol{D}\boldsymbol{D}'$.

with unity at the i-th position, for 'conditioning-on-observables forecasting' we have

$$\begin{aligned}\overline{\boldsymbol{C}} &= \boldsymbol{I}_h \otimes \boldsymbol{e}_n', && \text{(C.17)}\\ \overline{\boldsymbol{f}}_{T+1,T+h} &= \mathbf{0}_{h\times 1}, && \text{(C.18)}\\ \overline{\boldsymbol{\Omega}}_f &= \mathbf{0}_{h\times h}. && \text{(C.19)}\end{aligned}$$

The intuition underlying Equations (C.17) and (C.18) is that we constrain rest-of-the-world output (ordered at the n-th position in $\boldsymbol{y}_t$) to be zero over all horizons $T+1, T+2, \ldots, T+h$, and Equation (C.19) indicates that we do not allow for any uncertainty. In turn, for 'conditioning-on-shocks forecasting' we have

$$\boldsymbol{\Xi} = \begin{bmatrix} \boldsymbol{e}_1' & \mathbf{0}_{1\times n(h-1)} \\ (\mathbf{0}_{n-3\times 1}, \boldsymbol{I}_{n-3}, \mathbf{0}_{n-3\times 2}) & \mathbf{0}_{n-3\times n(h-1)} \\ \mathbf{0}_{(h-1)(n-2)\times n} & \boldsymbol{I}_{h-1} \otimes (\boldsymbol{I}_{n-2}, \mathbf{0}_{n-2\times 2}) \end{bmatrix}_{h(n-2)\times nh} \quad \text{(C.20)}$$

$$\underline{\boldsymbol{f}}_{T+1,T+h} = \boldsymbol{g}_{T+1,T+h} = [1, \mathbf{0}_{1\times n-3}, \mathbf{0}_{1\times(n-2)(h-1)}]', \quad \text{(C.21)}$$

$$\underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g = \mathbf{0}_{h(n-2)\times h(n-2)}. \quad \text{(C.22)}$$

The first row in Equation (C.20) selects the US monetary policy shock ordered first in $\boldsymbol{\epsilon}_t$ and the first row in Equation (C.21) constrains it to be unity in the impact period $T+1$; the second row in Equation (C.20) selects the non-US monetary policy and the non-rest-of the world shocks ordered from position 2 to $n-3$ in $\boldsymbol{\epsilon}_t$ and the second entry in Equation (C.21) constrains them to be zero in the impact period $T+1$; the third row in Equation (C.20) selects the US monetary policy and the non-rest-of the world shocks and Equation (C.21) constrains them to be zero over horizons $T+2, T+3, \ldots, T+h$. It is furthermore interesting to consider—recalling that $\underline{\boldsymbol{C}} \equiv \boldsymbol{\Xi}\boldsymbol{M}'^{-1}$—the stacked matrices $\boldsymbol{C}$ and $\boldsymbol{D}$ in Equation (C.8)

$$\boldsymbol{C} = \begin{bmatrix} \overline{\boldsymbol{C}}_{h\times hn} \\ \underline{\boldsymbol{C}}_{h(n-2)\times hn} \end{bmatrix}_{h(n-1)\times hn}, \qquad \boldsymbol{D} = \begin{bmatrix} \overline{\boldsymbol{C}}\boldsymbol{M}' \\ \boldsymbol{\Xi} \end{bmatrix}_{h(n-1)\times nh}. \quad \text{(C.23)}$$

Note that the fact that $\boldsymbol{C}$ and $\boldsymbol{D}$ are not square and full rank reflects that at every horizon we have two rest-of-the-world shocks to impose one constraint (the absence of a rest-of-the-world real activity response to a US monetary policy shock), implying a multiplicity of solutions. ADPRR show that the solution chosen in this case—obtained using the Moore-Penrose inverse of $\boldsymbol{D}$—minimises the Frobenius norm of the deviation of the distribution of the structural shocks under the conditional forecast from the baseline, i.e. $\boldsymbol{\mu}_\epsilon$ from $\mathbf{0}$ and $\boldsymbol{\Sigma}_\epsilon$ from $\boldsymbol{I}$. Note that $\boldsymbol{C}$ and $\boldsymbol{D}$ become square and full rank if h additional constraint are imposed. For example, we could impose that the two rest-of-the-world shocks we use for the offsetting of the effects of the US monetary policy shock on rest-of-the-world output are of equal size. To do so, we would stack below $\boldsymbol{\Xi}$ in Equation (C.20) an $h \times nh$ matrix

$$\boldsymbol{\Xi}^{add} = \boldsymbol{I}_h \otimes [0, 0, \dots, 0, 1, -1]_{1\times n}, \tag{C.24}$$

and below $\underline{\boldsymbol{f}}_{T+1,T+h}$ in Equation (C.21) an $h \times 1$ vector

$$\underline{\boldsymbol{f}}^{add}_{T+1,T+h} = \boldsymbol{0}_{h\times 1}. \tag{C.25}$$

C.1 How plausible is the counterfactual?

When analysing a counterfactual using SVARs, one should be careful that the implied shocks are not so "unusual" that the analysis becomes subject to the Lucas critique. Against this background, ADPRR propose to use the Kullback-Leibler (KL) divergence $\mathcal{D}(F_{bl}||F_{cf})$ between the distributions of the implied shocks underlying conditional forecasts in the baseline F_{bl} and the counterfactual F_{cf}. While it is straightforward to compute $\mathcal{D}(F_{bl}||F_{cf})$, it is difficult to grasp whether any value for the KL divergence is large or small. In other words, the KL divergence can be easily used to rank scenarios but it is hard to understand how far away they are from the unconditional forecast. To ease the interpretation of the KL divergence, ADPRR "calibrate" the KL divergence from two generic distributions Q to P, using the KL divergence between two easily interpretable distributions. In particular, ADPRR suggest comparing $\mathcal{D}(F_{bl}||F_{cf})$ with the KL divergence between two binomial distributions Q and P, one with probability q and the other with probability $p = 0.5$. ADPRR suggest calibrating the KL divergence from Q to P to a parameter q that would solve the following equation $\mathcal{D}(B(nh; 0.5)||B(nh; q)) = \mathcal{D}(F_{bl}||F_{cf})$. The solution to the equation is $q = \frac{1}{2}\left(1 + \sqrt{1 - e^{-\frac{2z}{nh}}}\right)$ where $z = \mathcal{D}(F_{bl}||F_{cf})$. Intuitively, the value for the KL divergence $\mathcal{D}(F_{bl}||F_{cf})$ is translated into a comparison between the flip of a fair and a biased coin. For example, a value of $q = 0.501$ suggests that the distribution of the shocks under the counterfactual is not at all far from the distribution under the baseline, so that counterfactual can be considered as quite realistic relative to the baseline.

It is worthwhile noting that this measure of plausibility is similar in spirit to the concept of "modest interventions" proposed by Leeper and Zha (2003). In particular, the measure proposed by Leeper and Zha (2003) reports how unusual the path for a set of policy shocks needed to achieve some conditional forecast is relative to their size. For example, if the counterfactual implies a sequence of shocks close to their unconditional mean, the policy intervention is considered "modest", and the results of the analysis are likely to be reliable in the sense that they are unlikely to induce agents to revise their beliefs about policy rules. Instead, if the counterfactual involves an unlikely sequence of shocks the analysis is deemed unreliable and potentially subject to the Lucas critique. The q-divergence of ADPRR compares the entire distribution rather than only the path of the shocks and generalises to counterfactuals other than those involving a single shock.

ADPRR propose the KL divergence to assess the plausibility of a conditional forecast relative to an unconditional forecast. In the context of our paper, we need to slightly adjust their proposed KL divergence. In particular, while in the case of ADPRR the baseline is given by an unconditional forecast and the counterfactual by a conditional forecast both afflicted by uncertainty, in our case the baseline and the counterfactual are given by conditional forecasts both of which are *not* subject to any uncertainty. Obviously, the KL divergence is not defined in case the baseline and the counterfactual do not feature any uncertainty. For the purpose of assessing the plausibility of the shocks that materialise to produce our counterfactual, we therefore consider the following exercise. As baseline we consider a conditional forecast in which we assume that a US monetary policy shock of size 1 occurs in period $T+1$ with certainty, while all other non-US monetary policy shocks in period $T+1$ as well as all shocks in periods $T+2, T+3, \ldots, T+h$ follow their unconditional distributions. For the conditional forecast under the counterfactual, we impose the mean constraint from our main exercise (i.e. that rest-of-the-world output stays at zero and that there is a US monetary policy shock in period $T+1$) but we also allow for uncertainty.

Formally, this exercise involves setting for the baseline and the counterfactual $\ell \in \{bl, cf\}$ $\overline{\boldsymbol{C}}_\ell = \boldsymbol{I}$ and

$$\begin{aligned} \boldsymbol{f}_{bl} &= \boldsymbol{\mu}_{y,bl} = \boldsymbol{M}'(\boldsymbol{e}_i', \boldsymbol{0}_{n(h-1)\times 1})', && \text{(C.26)} \\ \boldsymbol{f}_{cf} &= \boldsymbol{\mu}_{y,cf}, && \text{(C.27)} \end{aligned}$$

where i is the position of the US monetary policy shock, Equation (C.26) states that the observables on average shall follow the impulse response to a US monetary policy shock in period $T+1$ under the baseline, and Equation (C.26) that they shall follow the path we obtained in the main SSA counterfactual exercise. Moreover, we set $\boldsymbol{\Xi}_\ell = \boldsymbol{0}$ and $\underline{\boldsymbol{C}}_\ell = \boldsymbol{0}$ so that $\boldsymbol{D}_\ell = \boldsymbol{M}'$, $\boldsymbol{\Psi}_{\epsilon,\ell} = \boldsymbol{0}$ as we allow the shocks to have their unconditional variance. Hence we have

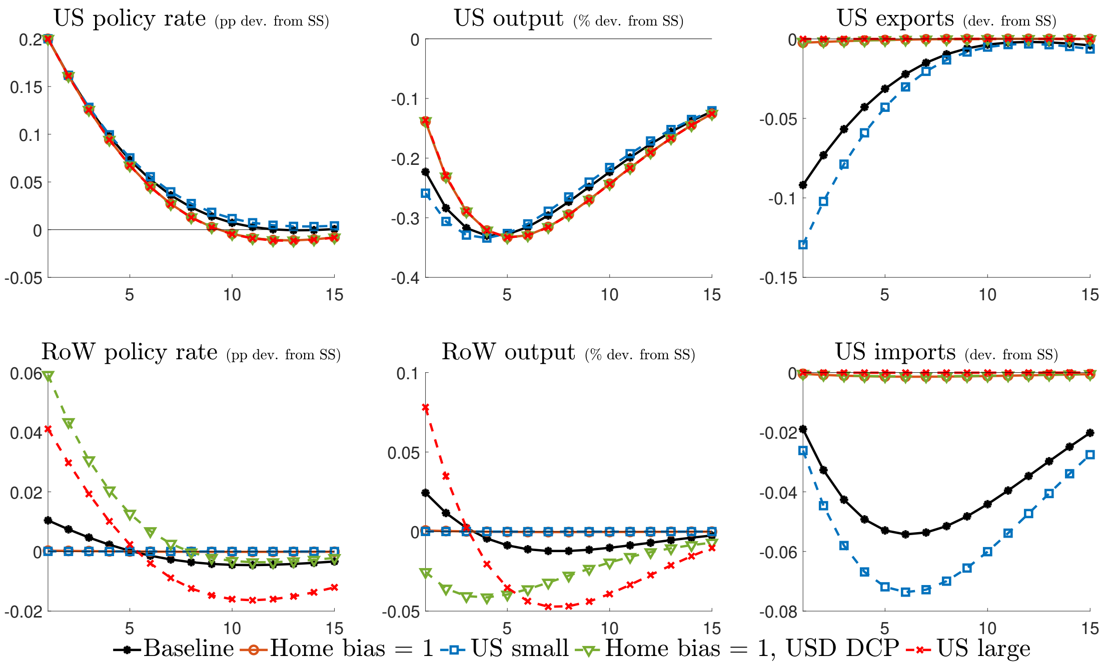
$$\begin{aligned}
\boldsymbol{\Omega}_{f,\ell} &= \boldsymbol{D}_\ell \boldsymbol{D}_\ell' = \boldsymbol{M}'\boldsymbol{M}, && \text{(C.28)}\\
\boldsymbol{\Sigma}_{\epsilon,\ell} &= \boldsymbol{D}_\ell^* \boldsymbol{\Omega}_{f,\ell} \boldsymbol{D}_\ell^{*\prime} = \boldsymbol{D}_\ell^{-1} \boldsymbol{\Omega}_{f,\ell} \boldsymbol{D}_\ell^{-1\prime} = \boldsymbol{M}'^{-1}\boldsymbol{M}'\boldsymbol{M}\boldsymbol{M}^{-1} = \boldsymbol{I}, && \text{(C.29)}\\
\boldsymbol{\mu}_{\epsilon,\ell} &= \boldsymbol{D}_\ell^* \boldsymbol{f}_\ell = \boldsymbol{D}_\ell^{-1} \boldsymbol{f}_\ell = \boldsymbol{M}'^{-1}\boldsymbol{f}_\ell, && \text{(C.30)}\\
\boldsymbol{\Sigma}_{y,\ell} &= \boldsymbol{M}'\boldsymbol{M} - \boldsymbol{M}'\boldsymbol{D}_\ell^*(\boldsymbol{\Omega}_{f,\ell} - \boldsymbol{D}_\ell \boldsymbol{D}_\ell')\boldsymbol{D}_\ell^{*\prime}\boldsymbol{M} \\
&= \boldsymbol{M}'\boldsymbol{M} - \boldsymbol{M}'\boldsymbol{D}_\ell^{-1}(\boldsymbol{\Omega}_{f,\ell} - \boldsymbol{D}_\ell \boldsymbol{D}_\ell')\boldsymbol{D}_\ell^{-1\prime}\boldsymbol{M} \\
&= \boldsymbol{M}'\boldsymbol{M} - \boldsymbol{M}'\boldsymbol{M}'^{-1}(\boldsymbol{\Omega}_{f,\ell} - \boldsymbol{M}'\boldsymbol{M})\boldsymbol{M}^{-1}\boldsymbol{M} \\
&= \boldsymbol{M}'\boldsymbol{M} - (\boldsymbol{\Omega}_{f,\ell} - \boldsymbol{M}'\boldsymbol{M}) \\
&= \boldsymbol{M}'\boldsymbol{M}. && \text{(C.31)}
\end{aligned}$$

Note that $\boldsymbol{\mu}_{\epsilon,bl}$ equals a vector of zeros with unity at the i^{th} position, where i is the position of the US monetary policy shock. The KL divergence between the distribution of the shocks under the baseline $\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h,bl}$ and the counterfactual $\widetilde{\boldsymbol{\epsilon}}_{T+1,T+h,cf}$ is then given by

$$\mathcal{D}(F_{bl}||F_{cf}) = \frac{1}{2}\left[tr\left(\boldsymbol{\Sigma}_{\epsilon,cf}^{-1}\boldsymbol{\Sigma}_{\epsilon,bl}\right) + \left(\boldsymbol{\mu}_{\epsilon,cf} - \boldsymbol{\mu}_{\epsilon,bl}\right)' \boldsymbol{\Sigma}_{\epsilon,cf}^{-1}\left(\boldsymbol{\mu}_{\epsilon,cf} - \boldsymbol{\mu}_{\epsilon,bl}\right) - nh + log\left(\frac{|\boldsymbol{\Sigma}_{\epsilon,cf}|}{|\boldsymbol{\Sigma}_{\epsilon,bl}|}\right)\right]. \tag{C.32}$$

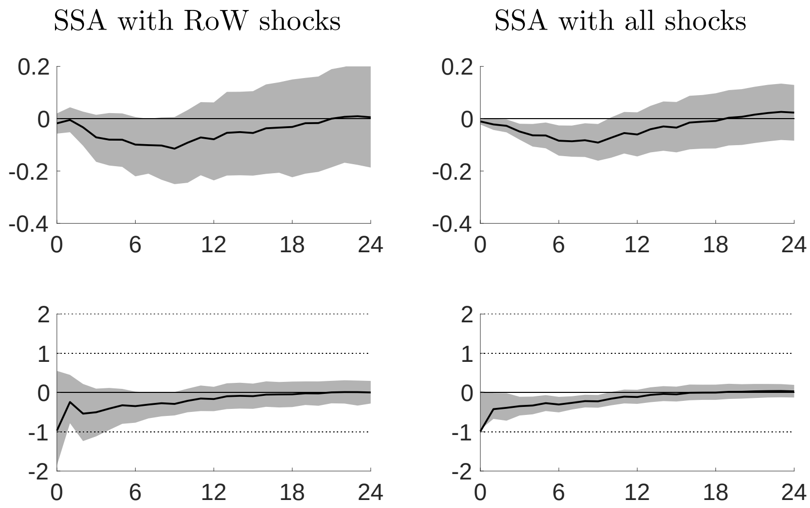
D Additional figures

Figure D.1: Impulse responses to a US monetary policy shock in a structural two-country model - additional alternative counterfactual model versions



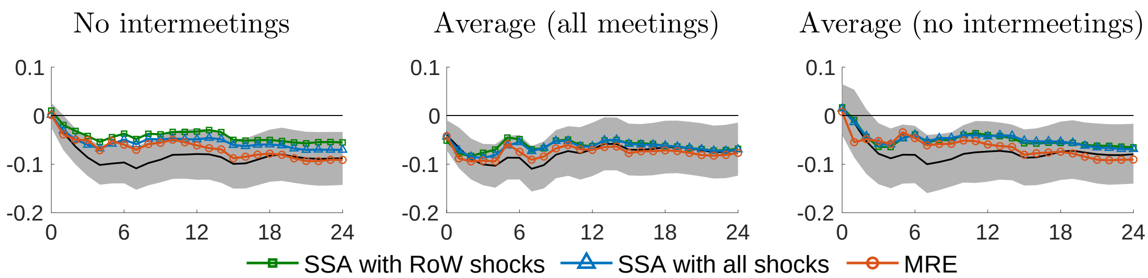
Notes: The figure displays the responses of policy interest rates and output of the US and the res of the world, as well as US exports/import to a contractionary US monetary policy shock from a structural two country model. The black solid lines show the impulse responses for the baseline specification, the red solid lines with circles when home bias is set to unity, the blue dashed lines with squares for the specification in which the US is very small relative to the rest of the world, the green dashed lines with triangles for the specification in which a fraction of prices of domestic sales in the rest of the world is sticky in US dollar and the red dashed lines with crosses for the specification in which the US is very large relative to the rest of the world. Interest rates are plotted in percentage points deviations from steady state, output in percent deviations from steady state, and exports/imports in absolute deviations from steady state (in order to avoid complications in specifications in which their steady-state values are zero).

Figure D.2: Distribution of SSA spillback estimates on CPI and Modesty statistics of Leeper and Zha (2003) for SSA counterfactuals



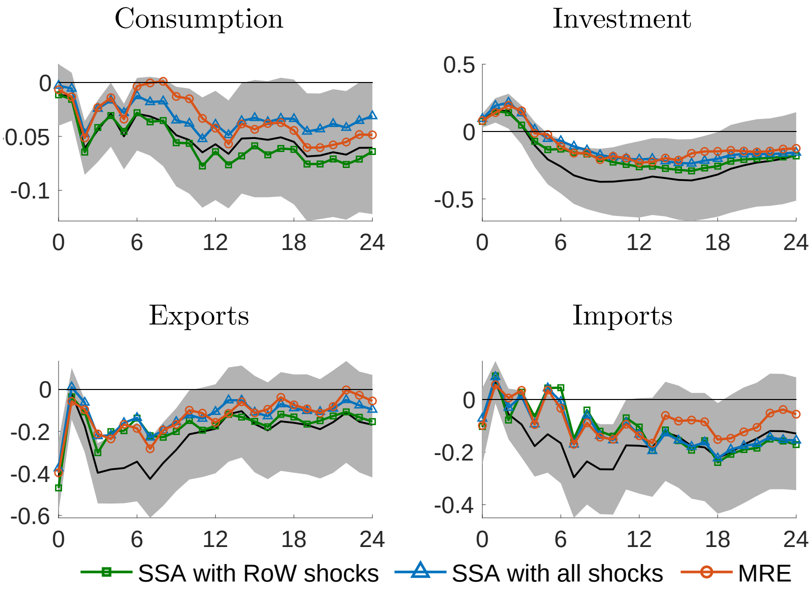
Notes: The top panels show the differences between the baseline and counterfactual effects of US monetary policy on domestic consumer prices. The bottom panels show the 'modesty statistic' of Leeper and Zha (2003) for the implied neutralising effects needed to impose the counterfactual path of rest-of-the-world industrial production. The neutralising effect is 'modest'—meaning it would be unlikely to induce agents to adjust their expectations formation—if the statistic is smaller than two in absolute value. The black solid lines depict the point-wise mean and the grey shaded areas represent 68% centered point-wise probability bands.

Figure D.3: Spillbacks from US monetary policy on CPI using alternatively aggregated high-frequency surprises



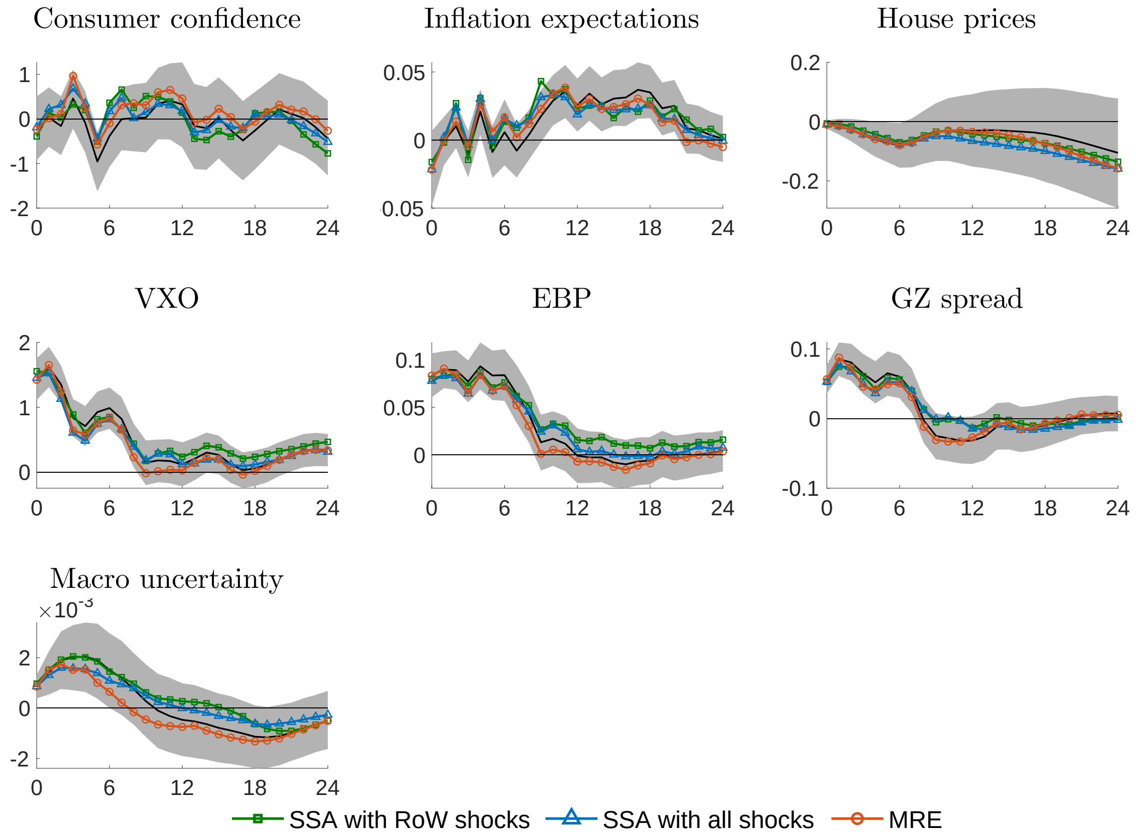
Notes: The black solid lines depict the baseline impulse responses of US consumer prices to a US monetary policy shock and the coloured lines with markers depict the counterfactual impulse responses based on point-wise posterior mean SSA with rest-of-the-world shocks (green lines with squares), based on point-wise posterior mean SSA with all shocks (blue lines with triangles), and based on point-wise posterior mean MRE (red lines with circles). In the first column we aggregate the daily policy and uncertainty surprises as in Gertler and Karadi (2015) but exclude FOMC inter-meeting announcements; in the second column we take monthly averages of all meetings, and in the third column we use monthly averages of non inter-meetings only. The grey shaded areas represent 68% centered point-wise probability bands.

Figure D.4: Responses of monthly GDP components to US monetary policy shock for the baseline and the counterfactual



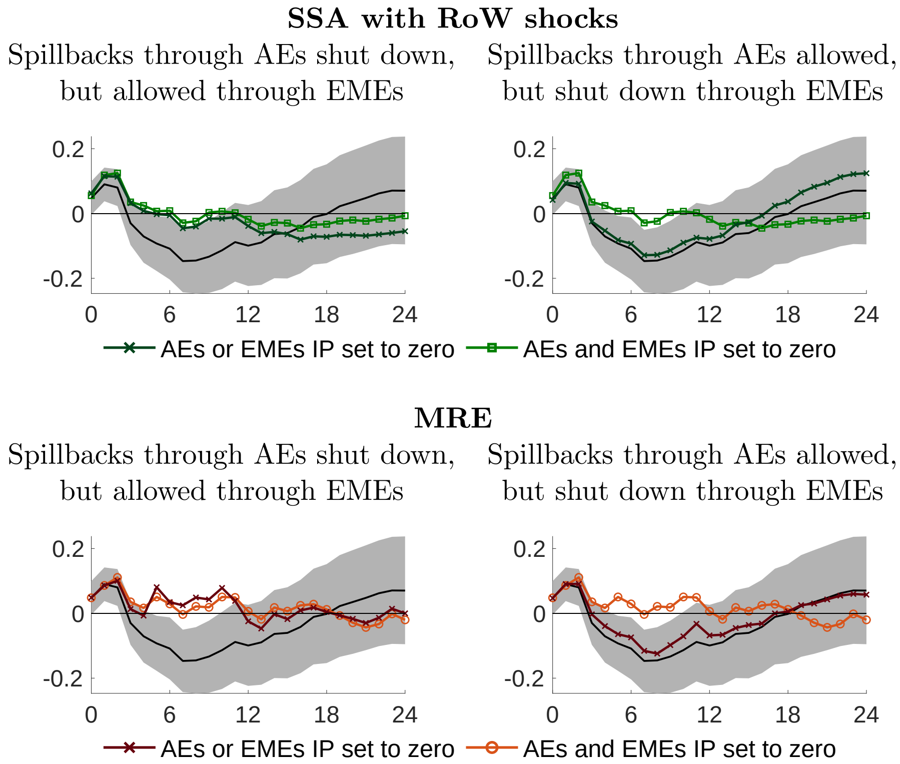
Notes: See the notes to Figure 8. The responses are based on monthly data except for investment, which is based on quarterly data interpolated to monthly frequency.

Figure D.5: Channels of transmission for spillbacks from US monetary policy - Additional variables



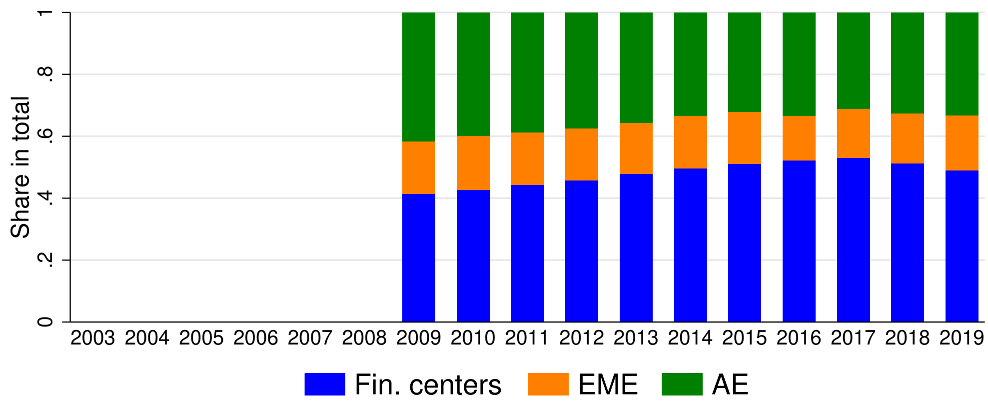
Notes: The figure shows the baseline and counterfactual impulse responses based on SSA with rest-of-the-world shocks (green lines with squares), SSA with all shocks (blue lines with triangles) and MRE (red lines with circles) for the Conference Board consumer confidence index, the Cleveland Fed/Haubrich et al. (2012) interest rate-term structure-based 1-year ahead consumer price inflation expectations, the S&P CoreLogic Case-Shiller home price index, the VXO, the excess bond premium, the Gilchrist-Zakrajsek (GZ) spread, and the macro uncertainty index of Jurado et al. (2015). The grey shaded areas represent 68% centered point-wise probability bands for the baseline impulse responses.

Figure D.6: Spillbacks from US monetary policy through AEs and EMEs (SSA RoW shocks and MRE counterfactuals)



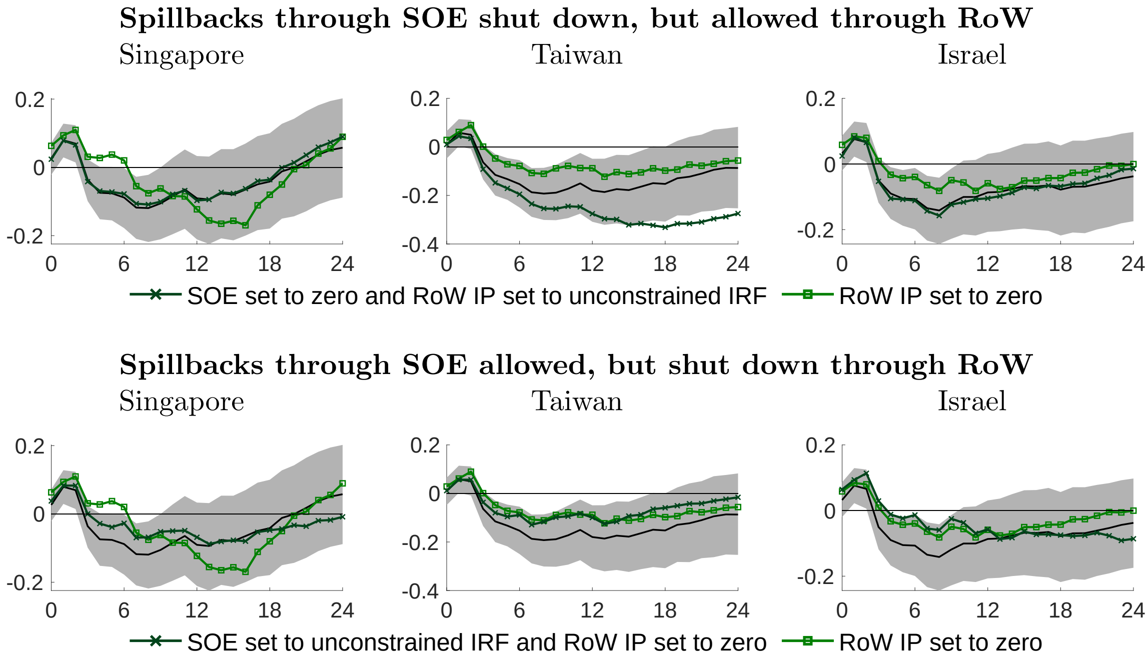
Notes: See the notes to Figure 12.

Figure D.7: Country composition of US foreign direct investment equity holdings



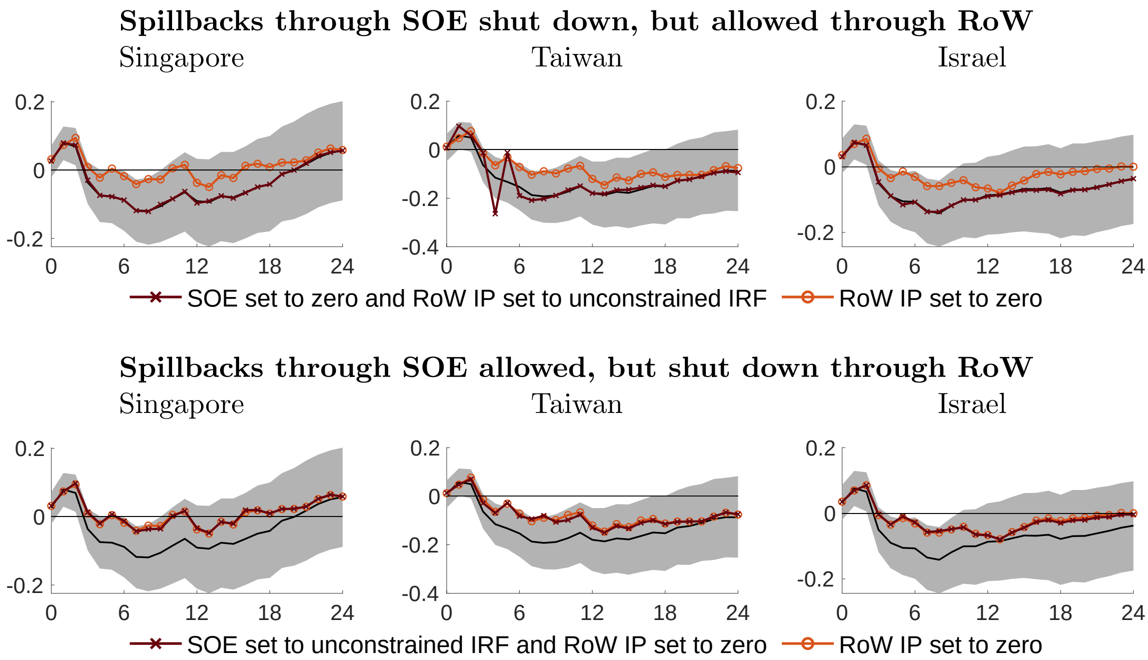
Notes: The figure shows the country composition of US direct investment equity holdings. The data are taken from the IMF Coordinated Direct Investment Survey (CDIS). The list of financial centers is taken from Bertaut et al. (2019).

Figure D.8: SSA with RoW shocks placebo test responses of US industrial production



Notes: See the notes to Figure 16.

Figure D.9: MRE placebo test responses of US industrial production



Notes: See the notes to Figure 16.

E Additional tables

Table E.1: Data description

Variable	Description	Source	Coverage
US 1-year TB rate	1-year Treasury Bill yield at constant maturity	US Treasury/Haver	1990m1 - 2019m6
US IP	Industrial production excl. construction	FRB/Haver	1990m1 - 2019m6
US CPI	US consumer price index	BLS/Haver	1990m1 - 2019m6
US EBP		See Favara et al. (2016)	
US import prices	Import price index: All imports	BLS/Haver	1990m1 - 2019m6
US import prices excl. petroleum	Import price index: Non-petroleum imports	BLS/Haver	1990m1 - 2019m6
US consumption	Personal consumption expenditures (chnd. 2012$)	BEA/Haver	1990q1-2019q2, interpolated to monthly frequency
US investment	Gross private domestic investment (chnd. 2012$)	BEA/Haver	1990q1-2019q2, interpolated to monthly frequency
US exports	Exports of goods and services (chnd. 2012$)	BEA/Haver	1990q1-2019q2, interpolated to monthly frequency
US imports	Imports of goods and services (chnd. 2012$)	BEA/Haver	1990q1-2019q2, interpolated to monthly frequency
US dollar NEER	Nominal broad trade-weighted Dollar index	FRB/Haver	1990m1-2019m6
CFED-1Y real interest rate	See Haubrich et al. (2012)	Cleveland Fed	1990m1 - 2019m6
VXO	CBOE market volatility index VXO	Wall Street Journal/Haver	1990m1 - 2019m6
S&P 500	S&P 500 Composite	S&P/Haver	1990m1 - 2019m6
Dow Jones World	Dow Jones Global Index	Dow Jones/Haver	1992m1 - 2019m6
Dow Jones excl. US	Dow Jones Global Index excl. US	Dow Jones/Haver	1992m1 - 2019m6
MSCI AEs	MSCI AEFE Index: Developed markets in Europe, Australasia, Israel and the Far East	MSCI/Bloomberg	1990m1 - 2019m6
MSCI EMEs	MSCI MXEF Index: Emerging markets with mid to large cap	MSCI/Bloomberg	1990m1 - 2019m6
S&P 500 earnings expectations	S&P 500 Composite 12-months forward earnings per share	S&P/Bloomberg	1990m1 - 2019m6
S&P 500 low/high RoW exposure	Based on sectoral S&P 500 indices	S&P/Haver	1990m1 - 2019m6
RoW, AE, EME IP	Industrial production, see Martinez-Garcia et al. (2015)	Dallas Fed Global Economic Indicators/Haver	1990m1 - 2019m6
RoW, AE, EME CPI	Consumer price index	Dallas Fed Global Economic Indicators/Haver (Martinez-Garcia et al., 2015)	1990m1 - 2019m6
RoW, AE, EME policy rate	Short-term official/policy rate, see Martinez-Garcia et al. (2015)	Dallas Fed Global Economic Indicators/Haver	1990m1 - 2019m6
Singapore IP	Industrial production: Manufacturing (excl. rubber processing)	Department of Statistics/Haver	1990m1 - 2019m6
Taiwan IP	Industrial production: Manufacturing	Ministry of Economic Affairs/Haver	1990m1 - 2019m6
Israel IP	Industrial production: Manufacturing	Central Bureau of Statistics/Haver	1990m1 - 2019m6

Notes: BLS stands for Bureau of Labour Statistics, FRB for Federal Reserve Board, and BEA for Bureau of Economic Analysis.