Explaining time-variation in trade spillovers of US monetary policy

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- PRELIMINARY AND INCOMPLETE –

International spillovers of US monetary policy substantially change over time depending on the level of the trade elasticity. During economic downturns, as global trade collapses, trade spillovers of a US monetary policy tightening become more adverse for the foreign economy. This occurs as a decline in the trade elasticity reduces the expenditure switching effect that should otherwise shift spending towards the foreign economy, thereby making US monetary policy shocks more of a beggar-thy-neighbor policy in recessions. We come to these conclusions using a combination of empirical and theoretical tools. In a first step, we estimate a Bayesian time-varying structural VAR model with stochastic volatility to document substantial time variation in the effect of US monetary policy shocks. We find that the impact of US monetary policy shocks on exchange rates has increased substantially over time, while the trade balance response displays cyclical variation - even switching sign over time. In a second step, in order to explain this variation, we estimate key structural spillover parameters of a two-country New Keynesian DSGE model via minimum distance techniques using the empirical impulse response functions from the first step, and this for every quarter over the past four decades. Combining estimates of the structural DSGE parameters with counterfactual analysis shows that variation in the trade elasticity is key to understanding global trade spillovers of US monetary policy.

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1. Introduction

> *"In a progressively integrating world economy and financial system, a central bank cannot ignore developments beyond its country's borders, and the Fed is no exception. … The state of the U.S. economy is significantly affected by the state of the world economy. … And of course, actions taken by the Federal Reserve influence economic conditions abroad. Because these international effects in turn spill back on the evolution of the U.S. economy, we cannot make sensible monetary policy choices without taking them into account."*
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> *Stanley Fisher, "The Federal Reserve and the Global Economy", May 2015.*

In the light of the recent lift-off in US interest rates after being at the zero lower bound for several years, a key question is how US monetary policy shocks affect the global economy. Theoretically seen, and concentrating on spillovers via trade, the effect on foreign GDP will crucially depend on the strength of the expenditure switching effect versus the income absorption effect. As these two effects offset each other, the magnitude and even the sign of international GDP spillovers of a US monetary policy shock are subject to debate.

As the global economy is progressively integrating over time, however, it might be useful to assess spillovers in a dynamic instead of static framework as previous studies have mostly done. Specifically, when taking a time-varying perspective several relevant questions can be addressed. Can we observe secular trends with regard to international spillovers of monetary policy given increased global integration? Are international spillovers state-dependent? What are the key determinants of spillovers, and do these change over time?

This paper takes a time-varying perspective to assessing the global spillovers of US monetary policy. It finds that the international transmission through trade substantially differs over time; the effect on the US trade balance (as an indicator of foreign trade spillovers) of a US monetary policy shock is found to even switch sign over time. Further analyzing this variation shows that the state of the economy – being in a downturn or not – makes a crucial difference for the effects of a US monetary policy shock on the trade balance and foreign GDP. Specifically, it is found that US monetary policy becomes more of a beggar-thy-neighbor policy during recessions as the US trade balance improves following a US monetary policy tightening, despite the appreciation of the US dollar. Using the empirical time-varying estimates to estimate a theoretical model teaches us that in downturns, a decline in the trade elasticity is mainly responsible for making US monetary policy a beggar-thy-neighbor policy in recessions. This occurs as the decline in the trade elasticity reduces the expenditure switching effect, causing the spillovers of a US monetary policy tightening to the global economy to be more adverse.

2. Time-variation in the international transmission of monetary policy

2.1. The international transmission of monetary policy via trade: theory

The question of how US monetary policy shocks affect the trade balance and spill over to foreign GDP remains subject to debate. From a theoretical point of view, as pointed out by Kim (2001), the ambiguity in the international effects of monetary policy shocks is related to the fact that theoretical models provide different perspectives on how monetary policy shocks affect the global economy, and through which channels this occurs. The basic Mundell-Flemming-Dornbusch model predicts that a monetary tightening will lead to a real exchange rate appreciation that worsens the domestic trade balance and increases foreign output. This happens via the *'expenditure switching effect'*, i.e. the exchange rate appreciation causes domestic demand for foreign goods to increase as these become cheaper, leading to positive trade spillovers for the foreign economy. At the same time, however, the domestic trade balance might also improve due to the *'income-absorption effect'*, i.e. lower domestic income following the monetary tightening reduces domestic demand for imported goods. Models including intertemporal decisions, as popularized by Obstfeld and Rogoff (1995), have emphasized the forward looking behavior of economic agents and introduced additional dimensions through which a monetary policy shock can propagate internationally. For example, following a monetary tightening, the temporary decline in income might worsen the trade balance through consumption smoothing, but also improve the current account if investments decline substantially due to higher real interest rates. This ambiguity in the effects on the trade balance translates into a similar ambiguity in the predicted effects on foreign GDP. Depending on whether the expenditure switching or the income absorption effect is dominant, foreign GDP spillovers following a US monetary policy tightening can either be positive or negative. We refer to Kim (2001) for a more detailed discussion on this and the references to the relevant literature.

Accordingly, key to understanding the international transmission of monetary policy shocks is first, to know whether the expenditure switching or income absorption effect is dominant in defining the final reaction of the trade balance and foreign GDP, and second, to know which are the main determinants of these effects. Generally, the strength of the expenditure switching effect will depend on the exchange rate reaction, the pass-through of exchange rates to import prices and the elasticity of substitution between domestic and foreign goods, i.e. the trade elasticity. On the other hand, the income absorption effect is a function of the domestic demand response and the reaction in foreign interest rates.

Moreover, the importance of the expenditure switching versus income absorption effect might change over time for the reason that the trade elasticity, the exchange rate pass-though or other determining factors are subject to time variation. Betts and Devereux (2000) for example demonstrate that lower exchange rate pass-through reduces the expenditure switching role of exchange rate changes, and there is evidence that this pass-through is subject to time variation.[4] Hjortsoe *et al.* (2016) show that the impact of monetary policy shocks on the current account depends on the degree of economic regulation in different markets which changes over time. Time variation in the importance of the expenditure switching versus the income absorption effect will be reflected in time variation in the international spillovers and spillbacks of monetary policy shocks.

In this paper, we first document some stylized facts on the empirical effects of a US monetary policy tightening on the trade balance, allowing these to change over time. After that, based on the empirical estimates, we determine the key parameters that drive international trade spillovers and as such, get informed about the

[4] On time-variation in the exchange rate pass-through to import prices, see for example Campa and Goldberg (2005), Marazzi *et al.* (2005) and Forbes (2015) and the references herein.

direction and magnitude of the spillovers and spillbacks of US monetary policy. In all of this - due to the methodological set up - we will mainly focus on spillovers and spillbacks via the trade channel.

2.2. Time-variation in the international transmission of monetary policy: stylized facts

In order to evaluate how US monetary policy shocks are transmitted globally and whether this transmission changes over time, we estimate the time-varying effects of a US monetary policy shock on the US trade balance and the US real effective exchange rate as key indicators of international transmission.

2.2.1. Structural TVP-BVAR model with stochastic volatility

More specifically, we estimate a five-variable TVP-BVAR with stochastic volatility in the spirit of Primiceri (2005). Similar to Corsetti *et al.* (2008b), all data is constructed as US data relative to a foreign economy, with the latter constructed as a weighted average of five countries: Australia, Canada, Germany, Japan and the United Kingdom. The endogenous variables are relative GDP, relative CPI, relative interest rate, the US trade balance (as percentage of GDP), and the US dollar real effective exchange rate. All data is at quarterly frequency covering the sample period from 1960Q1 to 2013Q3, of which the first ten years are used as a training sample. GDP has been detrended and all variables enter the model in log levels. Further details on the data sources and construction of the relative variables can be found in the appendix. The reduced form representation of the model is as follows:

$$y_t = c_t + B_{1,t}y_{t-1} + \cdots + B_{p,t}y_{t-p} + u_t \equiv X_t'\theta_t + u_t$$

where y_t is a vector of observed endogenous variables. The time-varying intercepts c_t, the time-varying coefficients $B_{p,t}y_{t-p}$ are stored in θ_t, and the lags of y_t are collected in X_t. Given that we have five endogenous variables, the TVP-BVAR model is estimated using one lag $(p = 1)$. The term u_t is the heteroskedastic reduced-form innovation that is postulated to be normally distributed with zero mean and a time-varying variance-covariance matrix Ω_t, which can be decomposed according to the following equation:

$$\Omega_t = A_t^{-1}H_t(A_t^{-1})'$$

The lower triangular matrix A_t models the contemporaneous interactions between the endogenous variables, while the diagonal matrix H_t contains the stochastic volatilities that capture variations in the size of structural shocks. These are defined as follows:

$$A_t \equiv \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \alpha_{21,t} & 1 & 0 & 0 & 0 \\ \alpha_{31,t} & \alpha_{32,t} & 1 & 0 & 0 \\ \alpha_{41,t} & \alpha_{42,t} & \alpha_{43,t} & 1 & 0 \\ \alpha_{51,t} & \alpha_{52,t} & \alpha_{53,t} & \alpha_{54,t} & 1 \end{bmatrix} \qquad H_t \equiv \begin{bmatrix} h_{1,t} & 0 & 0 & 0 & 0 \\ 0 & h_{2,t} & 0 & 0 & 0 \\ 0 & 0 & h_{3,t} & 0 & 0 \\ 0 & 0 & 0 & h_{4,t} & 0 \\ 0 & 0 & 0 & 0 & h_{5,t} \end{bmatrix}$$

As in Primiceri (2005), we assume $\alpha_t \equiv [\alpha_{21,t}, \dots, \alpha_{54,t}]'$ to be the elements of the matrix A_t, and it is modelled as a driftless random walk according to:

$$\alpha_t = \alpha_{t-1} + \zeta_t \qquad \zeta_t \sim N(0, S)$$

The vector of volatilities $h_t = [h_1, h_2, h_3, h_4, h_5]'$ contains the diagonal elements of H_t, which are postulated to evolve as geometric random walks independent of each other:

$$\ln h_{i,t} = \ln h_{i,t-1} + \sigma_i \eta_{i,t} \qquad \eta_{i,t} \sim N(0,1)$$

As in Cogley and Sargent (2005) and Primiceri (2005), the time-varying parameters θ_t are assumed to change according to:

$$p(\theta_t | \theta_{t-1}, Q_t) = I(\theta_t) f(\theta_t | \theta_{t-1}, Q_t)$$

with $I(\theta_t)$ being an indicator function that rejects unstable draws, thus imposing stationarity to the model. More specifically, if the roots are inside the unit circle, then $I(\theta_t) = 0$ and the draw is accepted. Otherwise, the draw is discarded. The term $f(\theta_t | \theta_{t-1}, Q_t)$ is given by:

$$\theta_t = \theta_{t-1} + v_t \qquad v_t \sim N(0, Q_t)$$

which evolves as a driftless random walk. As in Primiceri (2005), the block-diagonal structure for S is defined to have the following form:

$$S \equiv Var(\tau_t) = \begin{bmatrix} S_1 & 0_{1\times2} & 0_{1\times3} & 0_{1\times4} \\ 0_{2\times1} & S_2 & 0_{2\times3} & 0_{2\times4} \\ 0_{3\times1} & 0_{3\times2} & S_3 & 0_{3\times4} \\ 0_{4\times1} & 0_{4\times2} & 0_{4\times3} & S_4 \end{bmatrix}$$

with $S_1 \equiv Var(\zeta_{21,t})$, $S_2 \equiv Var([\zeta_{31,t}, \zeta_{32,t}]')$, $S_3 \equiv Var([\zeta_{41,t}, \zeta_{42,t}, \zeta_{43,t}]')$, and $S_4 \equiv Var([\zeta_{51,t}, \zeta_{52,t}, \zeta_{53,t}, \zeta_{54,t}]')$. This definition implies that different rows of the matrix A_t evolve independently of each other. This structure allows for correlation of endogenous variables within equations, but assumes that the variables across equations are uncorrelated. The equations above are estimated using Bayesian methods (Markov Chain Monte Carlo estimation algorithm) as outlined in Kim and Nelson (1999).

The priors for the initial states of the time-varying coefficients $(p(\theta_t))$, the covariances $(p(\alpha_t))$, and the log volatilities $(p(\ln h_0))$ are assumed to be normally distributed, independent of each other and independent of the hyperparameters, which are the elements of Q, S and σ_i^2 for $i = \{1, \dots, 5\}$. Particularly, the priors are calibrated on the point estimates of a fixed-coefficient VAR model estimated over the training sample period from 1960Q1 to 1970Q1.

The posterior distribution is simulated by sequentially drawing from the conditional posterior of four blocks of parameters: the coefficients (θ^T), the simultaneous relations (A^T), the variances (H^T), and the hyperparameters - the elements of Q, S and σ_i^2 for $i = \{1, \dots, 5\}$, which are collectively referred to as M. The superscript T refers to the entire sample. Posteriors for each block of the Gibbs sampler are conditional on the observed data (Y^T). Further details of the implementation and MCMC algorithm can be found in Primiceri (2005), Benati and Mumtaz (2007) and Baumeister and Peersman (2013). In total, we perform 10,000 iterations of the Bayesian Gibbs sampler, but keep only every 10th draw in order to mitigate the autocorrelation among the draws. After a burn-in period of 50,000 iterations, the sequence of draws from the conditional posteriors of the four blocks form a sample from the joint posterior distribution $p(\theta^T, A^T, H^T, M|Y^T)$. In total, we collect 2,000 simulated values from the Gibbs chain on which the structural analysis is based.

2.2.2. Identification of the US Monetary Policy Shock

Since the objective of this paper is to uncover the international transmission of a US-specific monetary policy shock, the empirical model is specified in relative variables (US minus a foreign aggregate) which should help in better identifying a US-specific shock. This choice also leads to a more parsimonious setup which is desirable in TVP-BVAR models.

The US monetary policy shock is identified using sign restrictions, which has a number of advantages compared to other identification schemes since it is consistent with the findings of micro-founded structural models, and the sign restriction method is relatively agnostic and less restrictive compared to other identification approaches, see for example Peersman and Straub (2009). In line with Mumtaz and Sunder-Plassmann (2013) among others, we assume that a contractionary monetary policy shock increases the interest rate difference, decreases relative output and relative prices and causes an appreciation of the US dollar real effective exchange rate. The sign restrictions are implemented as weak inequality signs and are only imposed on impact. As this is our main spillover variable of interest, the US trade balance is left unrestricted. The sign restrictions are summarized in Table 1.

Table 1: Sign restriction identification of the TVP-BVAR

	Relative Output	Relative prices	Difference interest rates	Trade balance	Real effective exchange rate
Restrictive monetary policy shock	≤ 0	≤ 0	≥ 0	unrestricted	≥ 0

Notes: an increase in the exchange rate is an appreciation. Relative variables are defined as US minus a foreign aggregate.

2.2.3. Empirical results

Figure 1 shows the estimated time-varying impact responses on impact following a restrictive US monetary policy shock that is normalized to increase the annualized interest rate difference with 10 basis points on impact. The non-normalized impulse responses following a one-standard deviation shock over the full horizon are shown in Figure A1 in the appendix. As imposed by the sign restrictions, a restrictive US monetary policy shock increases the interest rate difference, lowers relative CPI and GDP and leads to an appreciation of the US dollar. The impact effect of a US monetary policy tightening on the domestic trade balance tends to be negative - on average - although there are noticeable exceptions. This average negative impact implies that most of the time a US monetary policy tightening generates positive trade spillovers to the foreign economy as the US trade balance deteriorates due to the US dollar appreciation, making imports cheaper and exports more expensive. That is, the expenditure switching effect dominates. These results are in line with Lee and Chinn (2006) for example.

However, it is clear that this is only true on average; there is substantial time-variation in the effects of US monetary policy. First, looking at broader trends[5], the impact of a monetary policy shock on the US dollar exchange rate has considerably grown over time indicating that the exchange rate channel of monetary policy has substantially gained in importance over the years. Similar time-varying exchange rate dynamics are found in Mumtaz and Sunder-Plassmann (2013) following a monetary policy shock in Canada, the euro area and the UK. At the same time, the effect on the US trade balance has become slightly more negative– amid substantial short-run variation – indicating that the expenditure switching effect might have gradually increased in importance over time.

Second, there is substantial shorter-run time-variation in the effects of a US monetary policy tightening, particularly for the trade balance. The response of the US trade balance switched from being negative to insignificant or even positive in some periods. At those instances, the income absorption effect has likely dominated the expenditure switching effect as the US trade balance increases despite a stronger US dollar. In turn, this should cause the trade spillovers to the foreign economy to become negative as the foreign trade balance worsens. Liu *et al.* (2011) have documented similar dynamics for the UK economy by showing that the spillovers of a global monetary contraction to UK real activity (being the foreign economy) switched over time from being positive and significant (consistent with expenditure switching effect) to negative and insignificant (consistent with the income absorption effect).

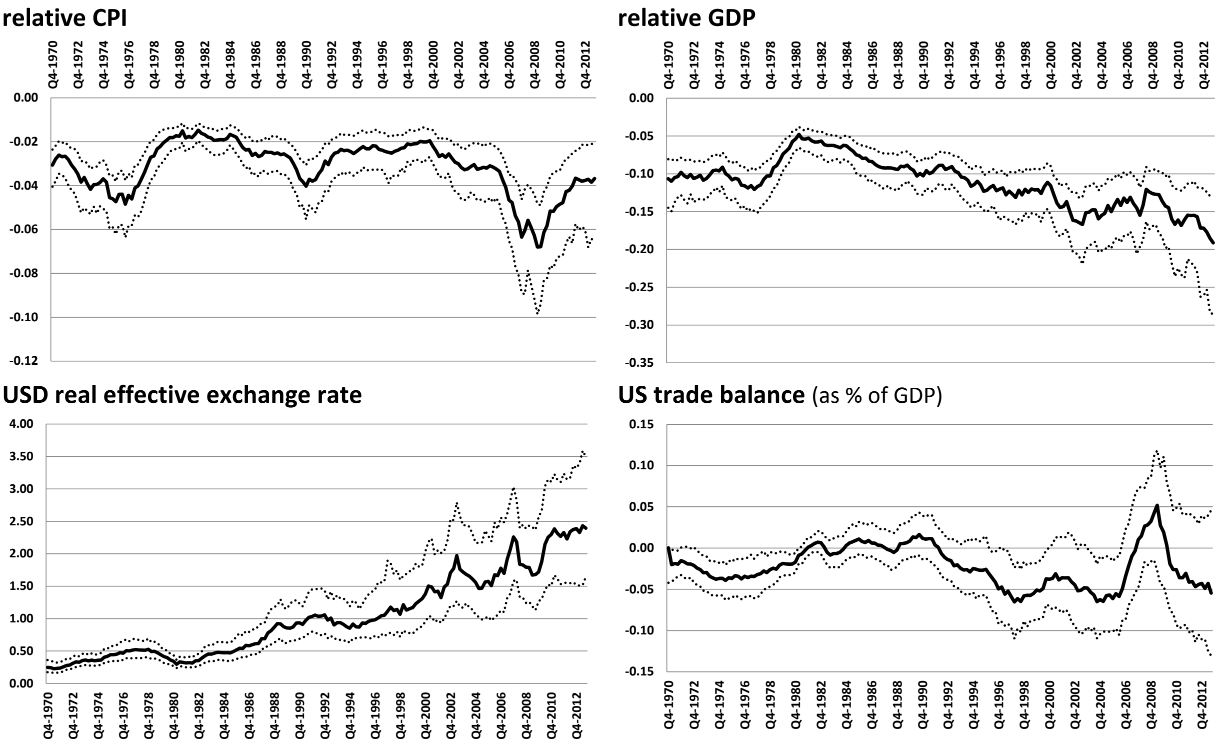
So far, most of the literature estimating the effects of US monetary policy on the trade balance and/or foreign GDP has been using structural VAR models with constant parameters (Kim 2001; Canova 2005; Mackowiak 2007; Bleudorn and Bowdler 2011; Georgiadis 2015). Their findings might average out important changes in spillovers dynamics. Kim (2001), for example, shows that a tightening of US monetary policy causes the US trade balance to first improve (dominance income absorption effect) before it worsens after about one year (dominance expenditure switching effect) using data over the period 1974 - 1996.[6] Although similar results might be found *on average*, our time-varying estimates indicate that the findings of Kim (2001) might be

[5] As GDP and CPI are expressed in relative terms (US relative to a foreign aggregate), the time variation found in these responses is difficult to interpret as it could come from variation in the US response, foreign response or in both.

[6] Kim (2001) estimates the effects following a monetary policy expansion but as the VAR framework used is linear, the results also apply to a monetary policy tightening which is looked at in this paper.

biased by the trade balance reaction in the middle part of the sample used (1981-1992). In the years before and after that, the impact reaction of the trade balance actually had the opposite sign.

Figure 1: Time-varying impact effects of a normalized annualized 10bp US monetary policy shock tightening



Notes: The responses are the impact responses following a normalized 10bp impact increase in the annualized interest rate difference. The units are in percentage points. The relative variables are defined as the US minus the foreign economy. An increase in the real effective exchange rate is an appreciation of the US dollar.

3. Explaining time-variation in US monetary policy trade spillovers and spillbacks

A limitation of the time-varying VAR framework is that it is silent about the causes of time-variation in the effects. For that reason, we use the time-varying impulse response functions to estimate a two-country open economy DSGE model using minimum distance estimation techniques over the full sample period, following the approach of Hofmann, Peersman and Straub (2012). This will generate time-varying estimates of the key structural model spillover parameters that will inform us on why the international transmission of US monetary policy has changed over time.

3.1. Estimating a two-country open economy New Keynesian DSGE model

3.1.1. Two-country DSGE model with incomplete exchange rate pass-through

In this section, we briefly outline the quantitative business cycle model which is used to estimate the structural parameters and generate the counterfactuals. The model is a two-country New Keynesian DSGE model with capital and sticky prices, frequently used in previous studies including Chari, Kehoe, and McGrattan (2002) and

Enders *et al.* (2011), to which we add incomplete exchange rate pass-through to import prices. The world economy consists of two symmetric economies and we index the intermediate good firms in both home and foreign countries by $j \in [0,1]$.

Households. In the home country, a representative household allocates consumption expenditures on final goods, C_t, and supplies labour, N_t, to monopolistic firms given the following preferences:

$$E_0 \sum_{t=0}^{\infty} \beta_t \frac{[C_t^{\mu}(1-N_t)^{1-\mu}]^{1-\gamma}}{1-\gamma}, \qquad \mu < 1, \qquad \beta_0 = 1,$$

$$\beta_{t+1} = \left(1 + \psi[C_t^{\mu}(1-N_t)^{1-\mu}]\right)^{-1} \beta_t, \qquad t \geq 0.$$

where $\beta_{i,t}$ is an endogenous discount factor such that discounting is higher if average consumption and leisure are above their steady state values[7]. The parameter ψ determines the elasticity of the discount factor to the level of consumption and leisure, and it also pins down the discount factor value in the steady-state. We assume that the representative household does not internalize the effect of consumption and labor on the discount factor. The parameter γ measures the degree of risk aversion, and the parameter μ measures the weight of consumption in the utility function relative to leisure.

We assume that labor and capital are internationally immobile. Households in the home country own the domestic capital stock denoted by $K_t = \int_0^1 K_t(j)dj$, and rent it to intermediate good firms. We assume that it is costly to adjust the level of investment, I_t, as in Christiano, Eichenbaum, and Evans (2005). The law of motion for capital is therefore given by

$$K_{t+1} = (1-\delta)K_t + [1 - G(I_t/I_{t-1})]I_t$$

where δ measures the depreciation rate. By restricting $G(1) = G'(1) = 0$ and $G''(1) = \chi > 0$, we impose that capital stock at the steady-state is independent of investment adjustment cost, which is captured by the parameter χ. We assume incomplete financial markets which implies that only nominal non-contingent bonds, B_t, denominated in local currency, are traded across countries. The budget constraint of the representative household in nominal terms reads as follows:

$$W_t + R_t^K K_t + \Pi_t - P_t C_t - P_t I_t = \frac{B_{t+1}}{1+R_t} - B_t$$

[7] See Schmitt-Grohé and Uribe (2003) for a detailed examination of this setup.

where W_t and R_t^K denotes the nominal wage rate and the rental rate of capital, respectively. R_t is the gross nominal interest rate denominated in domestic currency. P_t is the price of final good, and Π_t are claims on nominal profits earned by firms and transferred to households.

Final good firms. In the home country, there is a continuum of firms that produce differentiated intermediate goods $Y_{H,t}(j)$. These producers of the composite good $Y_{H,t} = \int_0^1 Y_{H,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj$ are subject to perfect competition and buy intermediate goods from the continuum of monopolistic competitive firms indexed by j. The composite goods are assembled using domestic and foreign tradable goods, denoted $Y_{F,t} = \int_0^1 Y_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj$, to a final good that is used for private consumption, private investment, and government consumption. The final goods are produced using the following technology:

$$Y_t = \left[\omega\left(\int_0^1 Y_{H,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\sigma-1}{\sigma}} + (1-\omega)\left(\int_0^1 Y_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

where σ denoted the elasticity of substitution between foreign and domestic goods (also referred as trade elasticity), ε measures the elasticity between the goods produced by each firm within the same country. The parameter $\omega > 0.5$ measures the home bias in the composition of final goods for private consumption, investment, and government consumption. Let $P_{H,t}(j)$ be the price of an intermediate tradable good j produced in the home country. We denote S_t as the nominal exchange rate.

The price index of the final good P_t is given by:

$$P_t = \left[\omega P_{H,t}^{1-\sigma} + (1-\omega)P_{F,t}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

where

$$P_{H,t} = \left(\int_0^1 Y_{H,t}(j)^{1-\varepsilon}\, dj\right)^{\frac{1}{1-\varepsilon}}$$

and

$$P_{F,t} = \left(\int_0^1 Y_{F,t}(j)^{1-\varepsilon}\, dj\right)^{\frac{1}{1-\varepsilon}}$$

denote the price indices of intermediate goods $P_{H,t}(j)$ and $P_{F,t}(j)$, respectively.

The final good firms' problem in the home country is to minimize expenditures in assembling intermediate goods subject to their production function and the constraint that $Y_t = C_t + I_t$. The resulting first order condition defines the total demand for a generic intermediate good as follows:

$$Y_{H,t} = \omega \left(\frac{P_{H,t}}{P_t}\right)^{-\sigma} Y_t$$

$$Y_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t}\right)^{-\sigma} Y_t$$

The total demand for a generic good j produced in the home country is given by

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} \left[Y_{H,t} + Y_{H,t}^{*}\right]$$

The real exchange rate of the home country is defined as

$$Q_t = \left(\frac{S_t P_t^{*}}{P_t}\right)$$

such that an increase corresponds to a depreciation. The terms of trade is defined as the price of imports relative to the price of exports:

$$ToT_t = \frac{P_{H,t}}{P_{F,t}}$$

To conclude, the ratio of trade balance as share of output is defined as

$$NX_t = \frac{P_{H,t} Y_{H,t}^{*} - P_{F,t} Y_{F,t}}{P_{H,t} Y_{H,t}}$$

Intermediate good firms. Intermediate good firms specialize in the production of differentiated goods. A generic firm $j = [0,1]$ in the home country operates under monopolistic competition facing imperfectly-elastic demand from domestic and foreign final goods producers and the domestic government. The Intermediate good firms' production function is determined by the following Cobb-Douglas technology:

$$Y_{H,t}(j) = A_t K_t(j)^{\theta} N_t(j)^{1-\theta}$$

where A_t denotes the level of technology common to all firms, which follows the log-linear exogenous process below

$$A_t = \rho_A A_{t-1} + \varepsilon_{A,t}$$

where ρ_A captures the degree of autocorrelation and $\varepsilon_{A,t}$ is the total factor productivity shock at period t.

Labor and capital inputs are assumed to adjust freely in each period, but prices are assumed to be sticky. Price setting is constraint exogenously by a discrete time version of the mechanism suggested by Calvo (1983). Each firm has the opportunity to change its price with a given probability $1-\xi$. When a firm has the opportunity to update its price, it sets the new price in order to maximize the expected discounted value of net profits, otherwise prices are indexed to past inflation. In setting the new prices $P_{H,t}(j)$, the problem of a domestic generic intermediate good firm j is given by

$$\max \sum_{k=0}^{\infty} \xi^k E_t\left[F_{t,t+k} \Pi_{t+k}(j)\right]$$

where $\Pi_t(j) = P_{H,t}(j)Y_{H,t}(j) - MC_t Y_{H,t}(j)$ are period-t nominal profit and MC_t is the marginal cost given the optimal choice of factor inputs. In this setup, we assume that demand is met by actual production at all times. As firms are owned by households, we have that $F_{t,t+k} = \frac{\beta_{t+k} U_c(C_{t+k}, N_{t+k})}{\beta_t U_c(C_t, N_t)}$. Firms maximize the discounted value of profits given the production function.

Importing firms. In this section, we outline the optimization problem of the representative local importer, which buys intermediate foreign goods under the assumption that the law of one price holds "at the dock", which implies that exchange rate pass-through to import prices is complete. Following Monacelli (2003), incomplete exchange rate pass-through is implemented in our model setup using staggered pricing à la Calvo (1983) for the imported goods. This generates deviations from the law of one price in the short run, while complete pass-through is achieved on the long-run.

We consider a local importer buying good j "at the dock":

$$P_{F,t}(j) = S_t P^*_{F,t}(j); \qquad P_{H,t}(j) = S_t P^*_{H,t}(j)$$

Similar to domestic intermediate good firms, the local importer chooses a price $P^{IM}_{H,t}(j)$, expressed in units of domestic currency, to maximize:

$$E_t \sum_{k=0}^{\infty} \xi^{IM} \beta_{t+k}\left[P^{IM}_{H,t}(j) - S_t P^*_{F,t+k}(j)\right] IM_{H,t+k}(j)$$

subject to the demand faced by each single importer, defined as

$$IM_{H,t} = \left(\frac{P_{IM,t}(j)}{P_{IM,t}}\right)^{-\varepsilon_{IM}} IM_t$$

where $P^*_{F,t}(j)$ is the price of the imported intermediate goods "at the dock", the parameter ε_{IM} is the elasticity of substitution between different types of imported goods, ξ^{IM} is the Calvo parameter, and β_t is the relevant stochastic discount factor.

The resulting log-linear aggregate imports price at home country evolves according to:

$$p_{F,t} \equiv p_{IM,t} = \xi^{IM}\left(p_{IM,t-1} - \pi_1\right) + (1 - \xi^{IM})\tilde{p}_{IM,t}$$

where $\tilde{p}_{IM,t}$ is the optimal updated price of the imported goods in the home country.

The Calvo parameter for imported goods, ξ^{IM}, can be interpreted as the degree of exchange rate pass-through in the model. As $\xi^{IM} \to 0$, import prices become perfectly flexible and exchange rate pass-through becomes complete. Conversely, values of $\xi^{IM} \to 1$ suggest the case of incomplete exchange rate pass-through.

Monetary Policy, the Foreign Economy, and Exogenous Shocks. The monetary policy is characterized by a standard Taylor-type interest rate rule specified in terms of domestic consumer price inflation and output growth,

$$R_t = \emptyset_R R_{t-1} + (1 - \emptyset_R)\left[\emptyset_\pi\left(\frac{P_t}{P_{t-1}}\right) + \emptyset_{gY}\left(\frac{Y_t}{Y_{t-1}}\right)\right] + \varepsilon_{R,t}\sigma_{MP,t}$$

where $\emptyset_R$ denotes the interest rate smoothing parameter, while $\emptyset_\pi$ and $\emptyset_{gY}$ measure the long-run inflation and output growth responses, while the term $\varepsilon_{R,t}$ represents a serially independently and identically distributed exogenous monetary policy innovation, and $\sigma_{MP,t}$ denotes the shock size.

The foreign economy has an analogous representation. Thus, foreign country consumers choose consumption, capital, and hours worked in similar fashion as in home economy. The foreign final good firms utilize the same production function and adjust prices in the same way as described previously. The equilibrium dynamics of the model are solved following log-linearization around the non-stochastic zero inflation steady state.

Calibration. We parameterize the DSGE model using quarterly U.S. data for the period 1970Q1 to 2013Q3 and the baseline calibrated parameters are reported in Table A1 in the appendix. We use parameters at values that are commonly found in the business cycle literature. The annual real interest rate is set at 6%, which gives a quarterly subjective discount factor (β) of 0.985. The home bias (ω) is calculated at 0.9 to match the historical import to output shares of 10% in the US relative to the foreign economy. The domestic price stickiness (ξ) is set to 0.8. The parameters $\mu = 0.34$ and $\gamma = 2$ are the weight of leisure in the utility function and degree of risk aversion, respectively. These parameters jointly determine the Frisch elasticity and the intertemporal elasticity of substitution. On the supply side, the elasticity of substitution between different types of intermediate goods (ε) is set at 6 so that there is a 20% price markup over marginal costs for intermediate goods firms in the steady state. We set the capital share in the economy (θ) at 0.36 in the steady state. It is assumed that the annual capital depreciation rate is 10%, so the quarterly depreciation rate (δ) is set at 0.025. The investment adjustment cost parameter (χ) is calibrated at 3. We calibrate both the domestic and foreign economies using the same values and it is assumed that the size of the home and foreign economy is the same.

3.1.2. Minimum distance estimation of a two-country New Keynesian DSGE model

We estimate the main structural spillover parameters of the two-country New Keynesian DSGE model using Bayesian minimum distance techniques, following the approach of Hofmann, Peersman and Straub (2012). Their approach consists in minimizing the distance between the impulse response functions as generated by the TVP-BVAR and the DSGE model following a US monetary policy shock, and it differs from Christiano *et al.* (2011) mainly in relation to the way the empirical model is estimated and identified. In this study, the empirical impulse response functions are generated using Bayesian methods and identification is achieved using sign restrictions. Consequently, there is no point estimate in which the minimum distance estimation method can be examined. Following Hofmann, Peersman and Straub (2012), we estimate the posterior mode of the structural parameters for each of the 500 impulse response functions that meet the imposed sign restrictions in the TVP-BVAR, as summarized in Table 1, and then calculate the corresponding distribution of the posterior modes for each of the structural parameters.

We choose to focus on estimating six key structural spillover parameters of the DSGE model; the elasticity of substitution between domestic and foreign goods, i.e. the trade elasticity (σ), the exchange rate pass-through parameter to import prices (ξ^{IM}) and the parameters of the Taylor rule, i.e. the interest rate smoothing coefficient ($\emptyset_R$), the output ($\emptyset_{gY}$) and inflation ($\emptyset_\pi$) stabilization coefficient, and the size of the monetary policy shock (σ_{MP}). As we identify the monetary policy shock in the TVP-BVAR model using relative variables, we impose symmetry on the estimated parameters across the two economies in the model. The imposed priors are given in Table 2. The prior mean and density distribution for the Taylor rule and exchange rate pass-through parameters mainly follow Smets and Wouters (2007), Adolfson *et al.* (2007) and Justiniano and Primiceri (2008), but generally with looser priors to allow for sufficient dynamics in the parameters over time. For the trade elasticity, we follow Christoffel *et al*. (2008), again with a very loose prior. We estimate the structural parameters for the first quarter of each year over our sample period 1970Q1-2013Q3.

Table 2: Priors imposed on the DSGE model parameters

Parameter	Density	Mean	Standard deviation
Trade elasticity	gamma	2.00	0.75
Exchange rate pass-through	beta	0.50	0.10
Taylor rule: interest rate smoothing	beta	0.75	0.25
Taylor rule: inflation	normal	1.50	0.25
Taylor rule: output	normal	0.40	0.05
Size monetary policy shock	Inverted gamma	1.00	2.00

Concerning the DSGE estimation, the Bayesian minimum distance estimator consists of two steps; a TVP-BVAR step and an impulse response matching step that go as follows:

TVP-BVAR step. For each time period, the estimated impulse response functions are stacked into a vector $\hat{\psi}$, which corresponds to the number of estimated impulse responses; 20 impulse response horizons times 5 variables for each of the draws so that the vector $\hat{\psi}$ has 100 elements. According to the standard asymptotic theory, when the number of observations, T, is large, we then have

$$\sqrt{T}\left(\hat{\psi} - \psi(\theta_0)\right) \sim N\big(0, W(\theta_0, \zeta_0)\big)$$

where θ_0 represents the true values of the parameters which are estimated, while ζ_0 denotes the true values of the parameters of the shocks that are in the model.

As a result, the asymptotic distribution of can be written in the following form:

$$\hat{\psi} \sim N\big(\psi(\theta_0), V(\theta_0, \zeta_0, T)\big)$$

where

$$V(\theta_0, \zeta_0, T) \equiv \frac{W(\theta_0, \zeta_0)}{T}$$

Impulse response matching step. In the second step, $\hat{\psi}$ is treated as data and the value of θ is chosen so to minimize the distance between $\psi(\theta_0)$ and $\hat{\psi}$. Thus, we define the approximate likelihood of the data, $\hat{\psi}$, is defined as function of θ:

$$f\left(\hat{\psi}|\theta, V(\theta_0, \zeta_0, T)\right) = \left(\frac{1}{2\pi}\right)^{N/2} |V(\theta_0, \zeta_0, T)|^{-1/2} \times \exp\left[-\frac{1}{2}\left(\hat{\psi} - \psi(\theta)\right)' V(\theta_0, \zeta_0, T)^{-1}\left(\hat{\psi} - \psi(\theta)\right)\right]$$

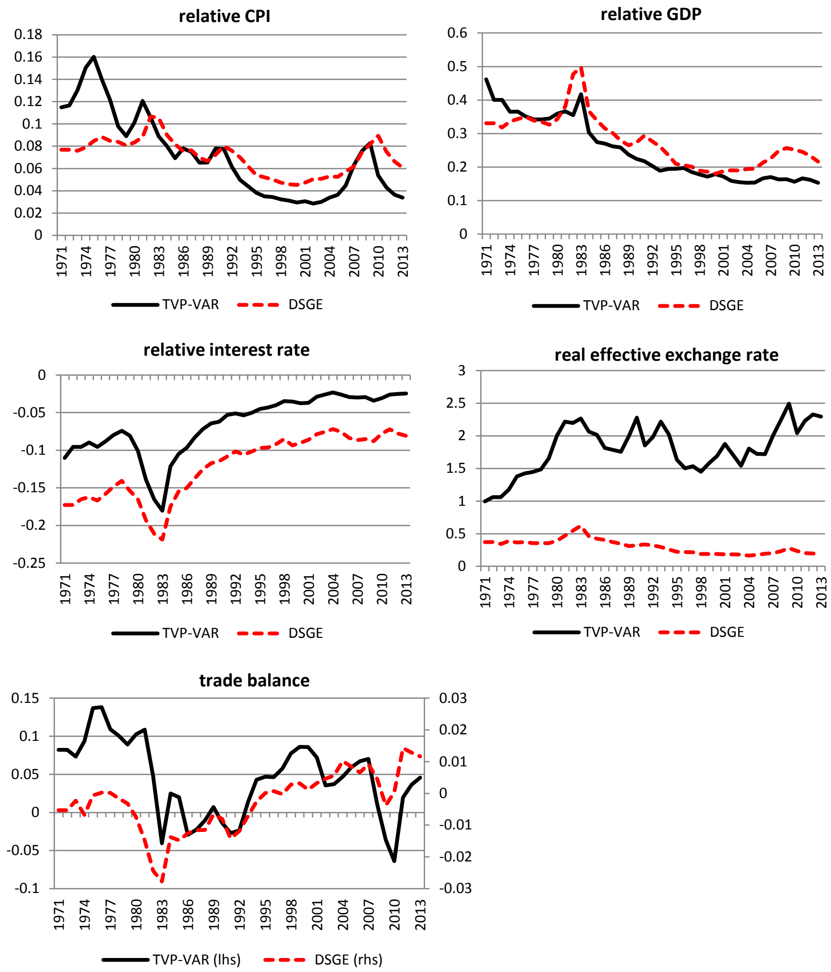
where $V(\theta_0, \zeta_0, T)$ is treated as a known object and N is the number of elements in ψ. Thus, the value of θ that maximises the equation above represents an approximate maximum likelihood estimator of θ.

Defining the function f as the likelihood of $\hat{\psi}$, it follows that the Bayesian posterior of θ conditional on $\hat{\psi}$ and $V(\theta_0, \zeta_0, T)$ can be written as:

$$f\left(\theta|\hat{\psi}, V(\theta_0, \zeta_0, T)\right) = \frac{f\left(\hat{\psi}|\theta, V(\theta_0, \zeta_0, T)\right) p(\theta)}{f\left(\hat{\psi}|V(\theta_0, \zeta_0, T)\right)}$$

where $p(\theta)$ denotes the priors on θ and $f\left(\hat{\psi}|V(\theta_0, \zeta_0, T)\right)$ denotes the marginal density of $\hat{\psi}$. As standard practice, the mode of the posterior distribution of θ can be computed by simply maximizing the value of the numerator, since the denominator is not a function of θ. A vital component of the adopted methodology is the weight matrix $V(\theta_0, \zeta_0, T)$ which depends on the second moments of the conditional impulse response function in each period. In other words, the wider the posterior distribution of the empirical impulse responses at a point in time, the less weight is given to the corresponding observation.

Figure 2: Match between estimated TVP-BVAR and simulated DSGE impact responses



Notes: the charts compare the estimated TVP-BVAR responses with the simulated DSGE responses that are based on the estimated structural parameters for the first quarter of all years in the period 1971 - 2013. The responses are the impact values following a one standard deviation increase in the relative interest rate (US minus foreign). Units are in percentages and all variables, including the interest rate, are in quarterly terms.

There is a fairly good match between the impulse response functions of the DSGE model and the structural TVP-BVAR model. Figure 2 shows the correspondence between the estimated impact responses of the TVP-BVAR and DSGE model. The match between the complete impulse response functions for selected years is given in Figure A2 in the appendix. The DSGE model closely traces the estimated magnitude and time-variation in the responses of relative CPI, relative GDP and relative interest rates. In addition, even though the DGSE simulates the trade balance effect to be smaller than the TVP-BVAR, it captures well the time dynamics which is of core importance. One aspect the DSGE model does not succeed in capturing is the strengthening of the real effective exchange rate response found in the empirical set-up, which is consistent with the well-known challenge of matching empirically observed exchange rate dynamics in DSGE models and the fact that exchange rates are increasingly driven by capital flows which are not accounted for in our DSGE model.[8] For that reason, we avoid making inferences concerning the real exchange rate behavior over longer time periods within the DSGE framework in this paper.

3.1.4. Estimation of the key structural DSGE spillover parameters

Estimating the two-country DSGE model provides time-varying estimates of the key spillover parameters that will help us understanding why the international transmission of US monetary policy has changed over time. The results are shown in Figure 3 and summarized in order to focus on the broader trends in Table 3. The posterior means of the estimated structural parameters are in line with the estimates found in the literature, see Justiniano and Primiceri (2008), Adolfson *et al.* (2007), and Lama and Rabanal (2014).[9]

First, as is well known in the literature, monetary policy has become more active in stabilizing the economy with a higher estimated inflation stabilization coefficient (Clarida, Galí and Gertler 2000; Cogley and Sargent 2002; Primiceri 2005; Boivin and Giannoni 2006). At the same time, the size of the monetary policy shock has substantially declined. Second, despite shorter-term variation, the trade elasticity parameter has generally increased over time in line with increased global trade. A higher substitution between domestic and foreign goods – as captured by this parameter - might explain why the effect of a US monetary policy tightening on the trade balance has become slightly more negative over time, see Figure 1. More trade stimulates the expenditure switching effect and leads to more favorable foreign output spillovers of a US monetary policy tightening. Interestingly, over shorter time periods, the trade elasticity is found to vary considerably, dropping from about 2 to below 1.5 in specific periods such as the global financial crisis. Finally, the exchange rate pass-through parameter is estimated to have declined over time, meaning that the pass-through of exchange rate changes to import prices has increased. This might also support the strengthening of the expenditure switching effect over time, although the broader change in the estimated parameter seems not to be very significant in line with Campa and Goldberg (2005).

[8] On this, see Corsetti, Dedola and Leduc (2008a) for example.

[9] The output growth response in the Taylor rule mean prior estimate is relatively high compared to values normally found in the literature. For example, Lubik and Schorfheide (2004) estimated this parameter at 0.17 and 0.30 in the pre and post-Volcker periods, respectively, while Bilbiie and Straub (2013) found this parameter to range from 0.40 in the pre-Volcker period to 0.33 after 1984.

Figure 3: Estimates of the structural parameters of the two-country DSGE model

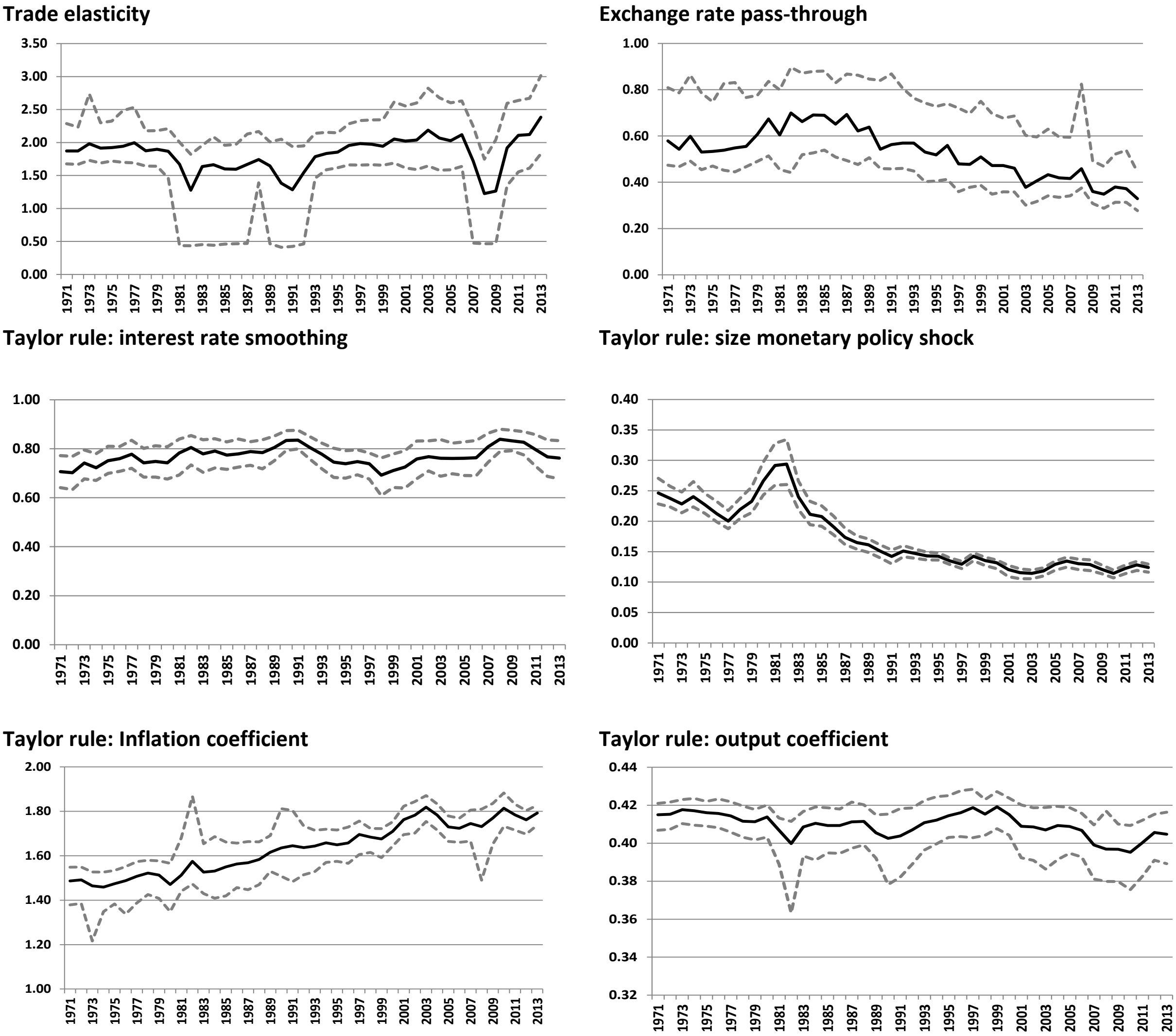


Table 3: average median estimated structural parameters

	trade elasticity	exchange rate pass-through	Taylor rule: interest rate smoothing	Taylor rule: inflation	Taylor rule: output gap	Taylor rule: shock size
1980s	1.64	0.66	0.78	1.55	0.41	0.21
1990s	1.75	0.53	0.76	1.66	0.41	0.14
2000s	1.95	0.41	0.78	1.76	0.40	0.12

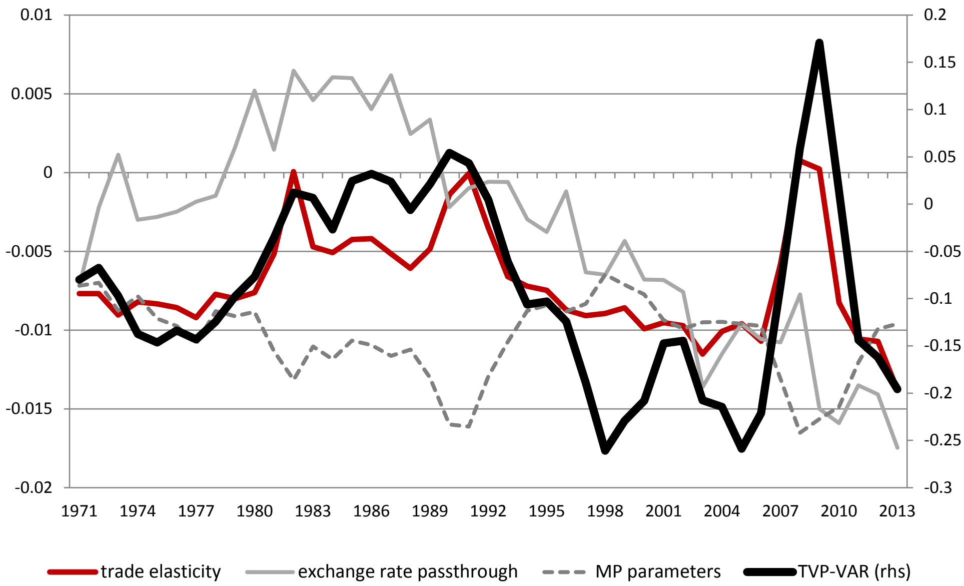
Notes: A higher value of the exchange rate pass-through parameter indicates a lower pass-through of exchange rate movements to import prices. These structural parameters are estimated through minimum distance estimation using the structural TVP-VAR impulse response functions discussed in Section 3.1.2.

3.2. Explaining time-variation in the trade balance effect of US monetary policy

3.2.1. Variation in the trade elasticity as the most important explanatory factor

The DSGE framework allows us to find the main drivers behind the time-varying effects of US monetary policy using the estimated values of the main structural parameters. Specifically, using counterfactual analysis, we can simulate the implied dynamics of the trade balance following a monetary policy shock when varying only one specific structural parameter of the DSGE model, keeping the others constant. The estimated posterior means of 2005 are chosen as the benchmark year from which we start the counterfactual simulations.[10] Figure 4 shows the correspondence between the estimated empirical US trade balance effect from the TVP-BVAR and the dynamics of the trade balance implied by changing respectively only (i) the trade elasticity, (ii) the exchange rate pass-through parameter and (iii) the monetary policy parameters, keeping all other parameters constant.[11]

Figure 4: Explaining the variation in the trade balance effect using counterfactual analysis



Notes: the chart shows the correspondence between (i) the empirically estimated impact response of the US trade balance to a normalized 10 basis points restrictive US monetary policy shock resulting from the TVP-BVAR and (ii) the implied impact response of the trade balance when using the DSGE model to simulate the effect of the same US monetary policy shock on the trade balance using the estimated posterior values of the structural parameters resulting from the minimum distance estimation procedure, starting from the parameterization of 2005. Restrictive US monetary policy shock is a 10 basis points increase in the quarterly interest rate.

It is clear that time-variation in the trade elasticity parameter is primarily responsible for variation in the trade balance effect following US monetary policy shocks found in the data. Figure 4 shows a close correspondence between the estimated trade balance impact response coming from the TVP-VAR and the implied variation of the trade balance effect when only changing the trade elasticity parameter coming from the counterfactual exercise. The correlation is 0.86 and becomes even slightly higher when excluding the period after the global financial crisis. A lower trade elasticity (i.e. less substitution between domestic and foreign goods) causes the expenditure switching effect to decline following a restrictive monetary policy shock, resulting in a less

[10] Although the choice of the benchmark year is arbitrary, 2005 is chosen given that it is recent and therefore arguably more representative, there was no recession and because of the good fit between the impulse response functions of the TVP-BVAR and DSGE model. Conclusions remain the same when choosing a different benchmark year.

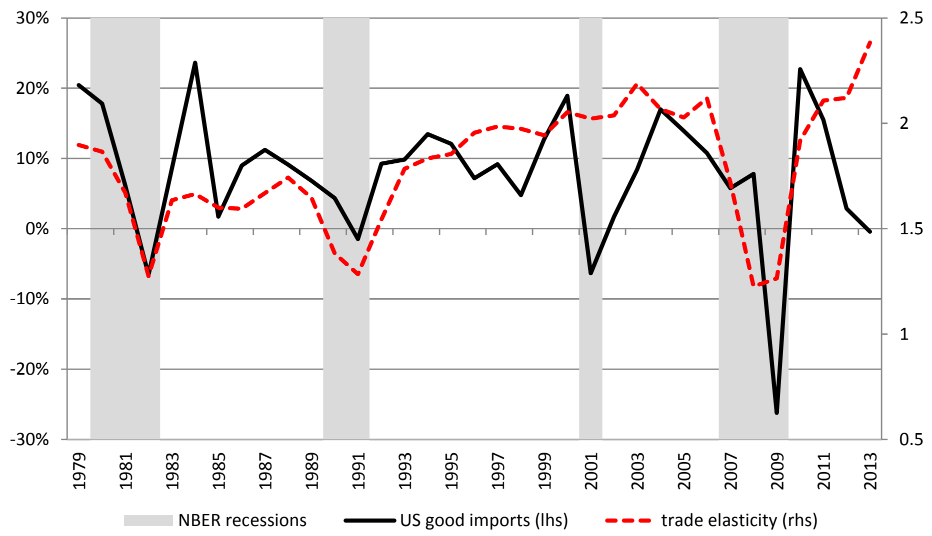
[11] For ease of presentation, the estimated monetary policy parameters are grouped together under "MP parameters. Results for the monetary policy parameters separately are available from the authors upon request.

negative effect on the US trade balance and changed trade spillovers to the foreign economy. We demonstrate this in more detail in the next section. In contrast, variation in the estimated monetary policy and exchange rate parameter have less explanatory power.

3.2.2. Why does the trade elasticity vary over time? Recessions versus normal times

Knowing that the trade elasticity parameter explains most of the time dynamics in the trade balance effect of US monetary policy; why does the trade elasticity change over time in the first place? We argue that the trade elasticity declines considerably in recessions, thereby altering the way US monetary policy shocks spill over to the foreign economy via trade. This is in line with the observed substantial declines in global trade during economic downturns.

Figure 5: Trade elasticity parameter and US trade during recessions



Notes: growth rate of US good imports is in yearly percentage changes, trade elasticity parameter is estimated through minimum distance estimation of the DSGE model using the structural TVP-VAR impulse response functions as discussed in Section 3.1.2, shaded areas indicate the NBER recession periods.

Figure 5 shows that, during past NBER recessions, US trade dropped significantly and also the trade elasticity parameter is estimated to be considerably lower. The close correspondence between US recessions, growth in US good imports and the estimated trade elasticity is intuitive, and in line with a large literature investigating the drop in global trade that occurs in economic downturns (e.g. Baldwin 2009, Levchenko *et al*. 2010; Chor and Manova 2012).

To show this differently, Table 4 lists the average estimated impact of a 10 basis point monetary policy tightening on the trade balance and the estimated structural trade elasticity parameter during NBER recessions and compares these with their values three years before. When entering a recession, the average trade balance effect switches from negative to being insignificant or positive following a US monetary policy tightening (from -0.009 to 0.012 on average over the NBER recessions since the 1980s). In line with these TVP-

BVAR results, also the estimated trade elasticity parameter is found to have declined during all NBER recessions (from 1.6 to 1.9 on average). For spillovers, this implies that a US monetary policy shock transmits very differently globally in recessions because of collapsed trade. Indeed, recessions are exactly also the periods in the which the estimated trade balance effect of a US monetary policy tightening are found to be insignificant, or even positive, see Figure 1. [12]

Table 4: Comparison of empirical trade balance effects and trade elasticity parameter in NBER recessions and three years prior

	US trade balance effect (as % of GDP)	**Trade elasticity parameter**
NBER recession: 1981Q1 - 1982Q4	-0.010	1.844
3 years prior	*-0.013*	*1.924*
NBER recession: 1990Q3-1991Q1	0.013	1.321
3 years prior	*0.004*	*1.635*
NBER recession: 2001Q1-2001Q4	0.004	2.000
3 years prior	*-0.018*	*2.021*
NBER recession: 2007Q4 - 2009Q2	0.039	1.292
3 years prior	*-0.008*	*1.971*
Average NBER recessions	**0.012**	**1.614**
Average 3 years prior	***-0.009***	***1.874***

Notes: First column: the trade balance impact is calculated as the maximum estimated median impact over a horizon of 29 quarters following a normalized 10bp impact increase in the annualized relative interest rate (US minus foreign) using the TVP-BVAR. Second column; the trade elasticity is estimated through minimum distance estimation using the structural TVP-BVAR impulse response functions discussed in Section 3.1.2 for each quarter over the period 1980Q1 – 2013Q3. The elasticity is calculated as the average over the indicated period, with 3 years taken as the 12 quarters before the onset of the recession. The NBER recessions over the period 1981Q1 - 1980Q3 and 1981Q3 - 1982Q4 are grouped together given the little time in between.

3.2.3. What happens to trade spillovers of US monetary policy when trade collapses?

How does a US monetary policy shock transmit internationally via trade and how does this change in a when trade collapses? Using the posterior estimates of the structural parameters in different years, we simulate the effects of a restrictive US monetary policy shock and analyze its global transmission in (i) 'normal' times taking 2005 as the benchmark year and (ii) in a recession when the trade elasticity drops, taking the estimated value of the trade elasticity parameter of 2009 and keeping all other parameters at their 2005 value.[13] Figure 6 shows the results.

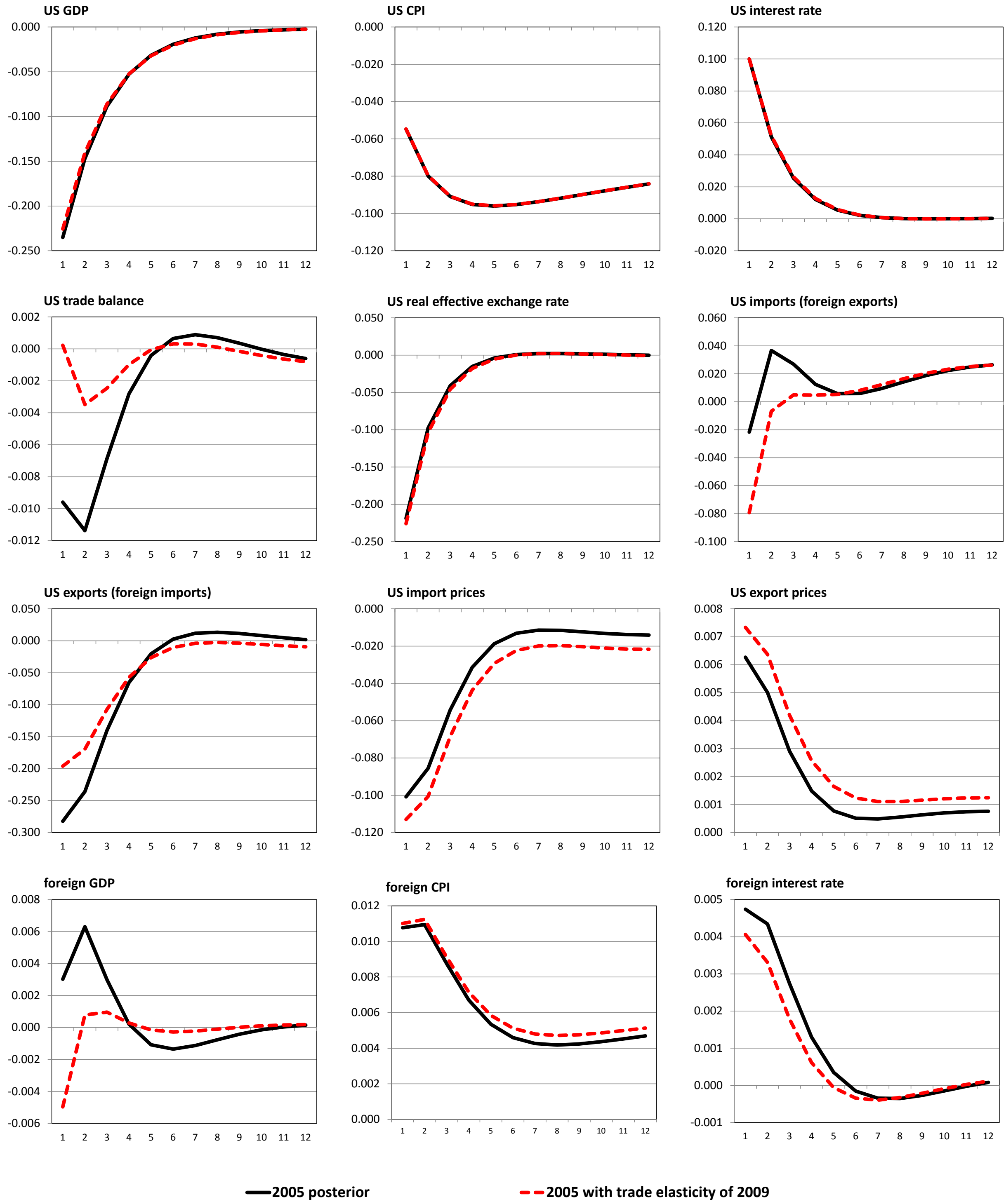
[12] An exception is the 1973-1975 recession which was associated with the collapse of Bretton Woods. We overlook this period in our analysis due to the specific international monetary conditions of the time.

[13] Depending on the specific years chosen, the exact transmission of the monetary policy shock can differ as the values of the estimated parameters change over time. However, the qualitative change in dynamics when entering a recession – which is the main focus of this section – remains the same when analysing different recession periods.

First, focusing on the year 2005 ('normal' times), a US monetary policy tightening leads to a decline in domestic GDP and CPI and an appreciation of the US dollar effective exchange rate. This appreciation causes import prices to decline and export prices to be higher. Despite the US dollar appreciation, US imports drop on impact after the monetary policy tightening due to a negative demand effect (income absorption effect), but then increase as imports become cheaper (expenditure switching effect). At the same time, US exports fall as these become more expensive. As a result, the US trade balance deteriorates, which is in line with the empirical estimates (see Figure 1). For the foreign economy, a stronger US dollar implies higher import prices and upward pressures on inflation. The foreign central bank reacts by tightening interest rates, creating negative demand effects that put downward pressure on GDP. However, positive trade spillovers – as foreign exports increase due to the expenditure switching effect – offset these negative demand effects and cause foreign GDP to rise following a US monetary policy tightening.

However, when the trade elasticity declines (from a value of 2.03 in 2005 to 1.26 in 2009), global trade spillovers of a US monetary policy shock change considerably. Despite a similar appreciation of real effective exchange rate, a lower trade elasticity causes US imports to decline much more as the income absorption effect dominates the expenditure switching effect that weakens due to a lower trade elasticity. This causes the decline in the US trade balance to be substantially smaller, and close to zero on impact. Because of a lower trade elasticity, there are only limited (if any) favorable trade spillovers to the foreign economy following a US monetary policy shock. The negative demand effects in the foreign economy, which result from higher interest rates in order to curb the inflationary effects of a depreciating exchange rate, are offset to a lesser extent. As a result, in this counterfactual exercise, the drop in the trade elasticity causes foreign GDP to decline following a monetary policy tightening in the US. This implies that in recessions, or more generally when trade falls, monetary policy becomes more of a beggar-thy-neighbor policy as its transmits similar output dynamics to the foreign economy as created by its own policies. This implies that risk-sharing via trade weakens in economic downturns.

Figure 6: Spillovers of US monetary policy: change in transmission when trade collapses



Notes: The units are in percentage points following a normalized 10 basis points restrictive monetary policy shock for (i) 2005 (representative for 'normal' times, full line) using the posterior estimates of the structural parameters versus (ii) 2005 with the trade elasticity set to its estimated value in 2009 (global financial crisis) . An increase in the real effective exchange rate is an appreciation. All variables, including the interest rate, are in quarterly terms and the horizon is quarterly.

3.2.4. Robustness of the results

To be added.

4. Conclusions

This paper documents time-variation in the international transmission of US monetary policy shocks and analyses the reasons behind it. US monetary policy spillovers have substantially changed over time, with a considerable strengthening in the exchange rate response and cyclical variation in the trade balance effect – which switches sign over time. This variation is key for the international transmission of US monetary policy. The crucial question is however why this variation occurs, and how it affects the global impact of US monetary policy shocks. We show that the cyclical variation in the trade balance response is most importantly explained by variation in the trade elasticity, i.e. the substitution elasticity between home and foreign tradable goods. The trade elasticity declines in US recessions, in line with observed declines in US trade. This has important implications for international spillovers of monetary policy shocks. Due to lower trade, US monetary policy becomes more of a beggar-thy-neighbor policy in economic downturns, as it transmits similar output dynamics of its domestic policies. Favorable trade spillovers that the foreign economy normally receives (through the expenditure switching effect) weaken when trade collapses, leaving negative demand effects resulting from higher interest rates (to fight the inflationary pressures caused by the depreciation of the foreign currency) to dominate the response of foreign output. That is, risk-sharing via trade weakens when one could argue that it is needed the most.

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Appendix

Appendix 1: Data Source

This appendix describes the quarterly data used in this paper for the period of 1960Q1-2013Q3.

Data sources

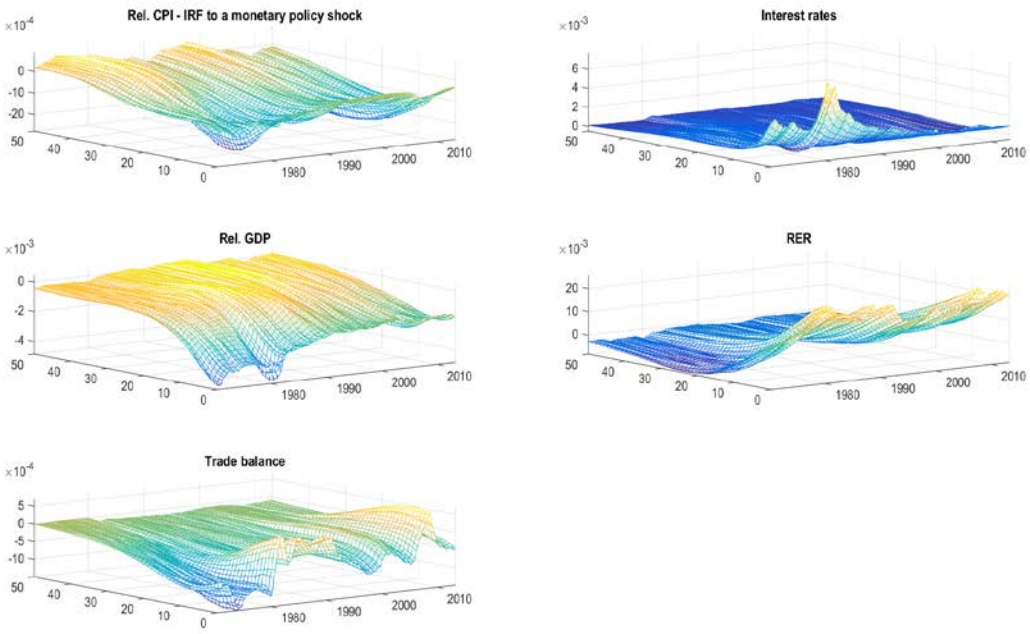
The quarterly seasonally adjusted series of real GDP (VPVOBARSA) in millions of U.S. dollars were taken from the OECD's Quarterly National Accounts (QNA). The headline quarterly consumer prices indices are sourced from the OECD Statistics database. The quarterly short-term interest rates were taken from the OECD's Monthly Monetary and Financial Statistics (MEI). The nominal exchange rates (U.S. dollar monthly average) were sourced from the OECD's Monthly Monetary and Financial Statistics (MEI). The CPI-based real exchange rate is computed by multiplying the nomiinenal exchange rate by the ratio of the U.S. CPI and the foreign country CPI.

Construction of the relative variables

Similar to Corsetti *et al*. (2008b), all data is constructed as U.S. data relative to a foreign country, with the latter constructed as a weighted average of five countries: Australia, Canada, Germany, Japan and the United Kingdom. The empirical model includes relative CPI, relative GDP, difference interest rate, US trade balance and US real exchange rate. The first step was to construct the output-weighted aggregates for foreign country comprised of Australia, Canada, Germany, Japan, and the United Kingdom. The quarterly output-weights were constructed by summing the real GDP in U.S. dollars (fixed PPPs) of the five foreign countries and then taking their respective shares. The second step was to cancel out any national base effects by taking the log difference of all series, except for the nominal interest rate which is kept in levels, and multiply them by their respective output-weights. The next step was to construct the foreign country equivalent growth rate by aggregating each country's output-weighted series described above. Finally, we constructed the relative variables by taking the log of the ratio of the indexed U.S. series (in levels) by the foreign country series. The difference interest rate series is constructed by taking the plain difference of the U.S. and foreign interest rate.

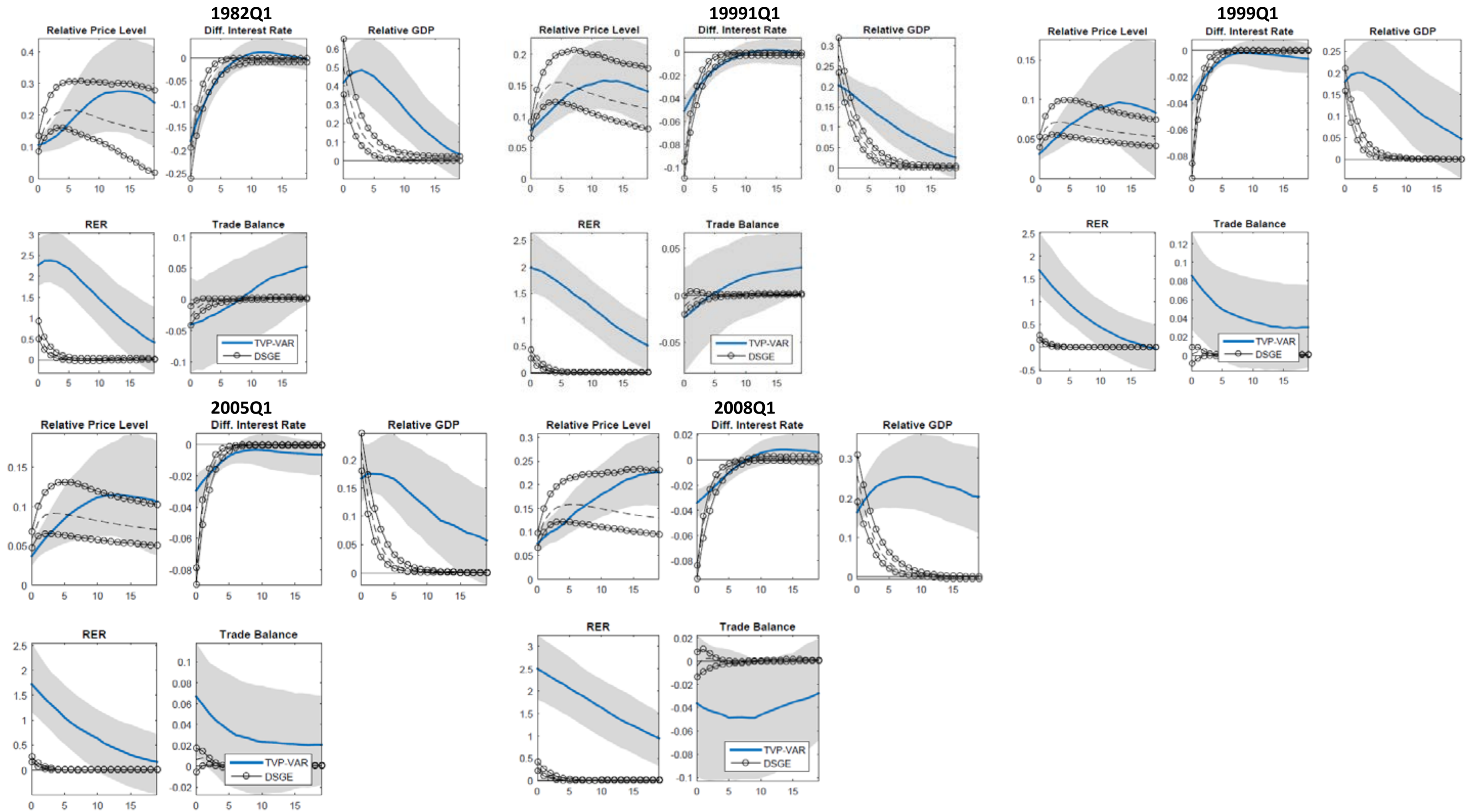
Appendix – Figures and Tables

Figure A1: Time-varying effects of one standard-deviation US monetary policy tightening



Notes: the charts show the estimated impulse responses following a one-standard deviation increase in the relative interest rate for every quarter over the period 1970Q1-2013Q3. The relative variables are defined as the US minus the foreign economy. An increase in the real effective exchange rate is an appreciation of the US dollar. Units are in percentage points, the horizon is in quarters and all variables are in quarterly terms except for the interest rate which is annualized.

Figure A2: Matching of the DSGE and TVP-BVAR impulse responses for selected years



Notes: the charts show the matching between the empirical impulse response functions of the TVP-BVAR and those of the DSGE model for selected years 1982Q1, 1991Q1, 1999Q1, 2005Q1 and 2008Q1. Horizon is quarterly, the 16th and the 84th percentiles of the posterior distributions are shown. Units are in percentages, the horizon is in quarters and all variables, including the interest rate, are in quarterly terms.

Table A1: Calibration of non-estimated parameters

	Calibrated structural parameters	Value
β	Discount factor (steady state)	0.985
ω	Home bias in final goods	0.9
μ	Leisure weight in utility function	0.34
γ	Degree of risk aversion	2
ε	Elasticity of substitution between different types of intermediate goods	6
χ	Investment adjustment costs	3
δ	Quarterly depreciation rate	0.025
θ	Capital share (steady state)	0.36