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Financial frictions and global spillovers

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Non-technical summary

Research Question

Considering the pivotal role of the United States in international financial markets, a key question is how financial shocks that originate from the US propagate across the globe. In particular, we ask whether US financial shocks give rise to global spillovers that depend nonlinearly on the severity of financial frictions in the US economy. A consensus seems to emerge from theoretical models that financial frictions are central to understanding the nonlinearities observed during financial crisis episodes. Moreover, theoretical studies have shown that financial frictions lead to an amplification of cross-border shocks, and structural models featuring such frictions provide a more realistic picture of international macroeconomic fluctuations. However, most empirical studies on macro-financial linkages resort to linear models that fail to account for the nonlinear amplification mechanisms implied by the theoretical literature. There is an equally limited empirical literature that investigates the relation between financial frictions and global spillovers. This paper aims to fill these gaps.

Contribution

The novelty of this paper is to incorporate nonlinear features into an empirical model of international financial spillovers. In particular, we investigate whether frictions in US financial markets amplify the international propagation of US financial shocks. To that end, the dynamics of the US economy is modeled jointly with global macroeconomic and financial variables using a threshold vector autoregression that allows us to capture regime-dependent dynamics conditional on the tightness of US credit market conditions, measured by the excess bond premium on US corporate bonds. The US economy switches from a regime of unconstrained access to credit to one characterized by tight credit whenever the bond risk premium exceeds a critical threshold. The effects of US financial shocks may vary across these two regimes, which enables us to study regime-specific financial spillovers.

Results

We identify three periods of distress in US banking and credit markets. The first tight credit episode coincides with the savings and loan crisis of the 1980s and early 1990s. The second episode occurs in the early 2000s, around the Enron, Y2K, and 9/11 debacles and following the burst of the dotcom bubble. Finally, the 2007-09 financial crisis is identified as the most recent credit crunch. We study the nonlinear effects of an US financial shock on the global economy in the TVAR model using regime-specific impulse response functions. US financial shocks have an insignificant effect on the global economy when borrowers have unconstrained access to credit. On the contrary, US financial shocks give rise to a worldwide economic contraction in the tight credit regime. Moreover, US financial shocks are a relatively more important driver of US and global business cycles in times of tight credit. The findings are robust to the way US financial shocks are identified and to the aggregation method used to obtain global variables from country-specific data.

Nicht-technische Zusammenfassung

Forschungsfrage

Angesichts der Schlüsselrolle, die den Vereinigten Staaten an den internationalen Finanzmärkten zukommt, stellt sich die Frage, wie sich von den USA ausgehende Finanzmarktschocks auf internationaler Ebene ausbreiten. Ganz konkret interessiert uns, ob in den USA entstandene Finanzmarktschocks globale Auswirkungen haben, die eine nichtlineare Abhängigkeit von der Tragweite finanzieller Friktionen in der US-Wirtschaft aufweisen. Ausgehend von theoretischen Modellen herrscht offenbar ein Konsens darüber, dass finanzielle Friktionen für das Verständnis der nichtlinearen Strukturen im Verlauf von Finanzmarktkrisen von zentraler Bedeutung sind. Ferner haben theoretische Studien gezeigt, dass am Finanzmarkt herrschende Spannungen grenzüberschreitende Schocks verstärken und Strukturmodelle, in denen solche Friktionen mit einbezogen werden, ein realistischeres Bild internationaler makroökonomischer Schwankungen zeichnen. Die meisten empirischen Studien zu makrofinanziellen Verflechtungen greifen jedoch auf lineare Modelle zurück, in denen die von der theoretischen Literatur implizierten nichtlinearen Verstärkungsmechanismen nicht berücksichtigt werden. Auch der Zusammenhang zwischen finanziellen Friktionen und globalen Ansteckungseffekten wird in der empirischen Literatur nur in begrenztem Maße untersucht. Das vorliegende Papier soll diese Lücken schließen.

Forschungsbeitrag

Das Novum an diesem Papier besteht darin, dass bei einem empirischen Modell für Ansteckungseffekte auf das internationale Finanzsystem nichtlineare Merkmale zum Tragen kommen. Im Einzelnen wird untersucht, ob an den US-Finanzmärkten herrschende Ungleichgewichte ein Übergreifen von Schocks auf das internationale Umfeld begünstigen. Hierzu werden die Entwicklung der US-amerikanischen Wirtschaft sowie globale makroökonomische und finanzielle Variablen in einem Modell zueinander in Relation gesetzt. Verwendet wird ein schwellenwertbasiertes Vektorautoregressionsmodell (TVAR-Modell), das es uns ermöglicht, regimeabhängige, durch die Kreditvergabebedingungen in den USA bedingte Entwicklungen, gemessen an den Überschussprämien für US-Unternehmensanleihen, zu erfassen. Sobald die Anleiherisikoprämie einen bestimmten Schwellenwert übersteigt, geht die US-Wirtschaft von einem Regime mit uneingeschränktem Zugang zu Krediten zu einer restriktiven Kreditvergabepolitik über. Da die Auswirkungen von Finanzmarktschocks in den Vereinigten Staaten entsprechend dieser beiden Regime variieren können, sind wir in der Lage, regimespezifische finanzielle Ansteckungseffekte zu untersuchen.

Forschungsergebnisse

Es lassen sich drei Krisenphasen an den Banken- und Kreditmärkten der Vereinigten Staaten feststellen. Bei der ersten Phase handelt es sich um die sog. Savings-and-Loan-Krise in den Achtzigerjahren und Anfang der Neunzigerjahre. Die zweite Phase folgte zu Beginn des neuen Jahrtausends vor dem Hintergrund des Enron-Unternehmensskandals, des Jahr-2000-Problems, der Terroranschläge vom 11. September 2001 und nach dem Platzen der Technologieblase. Im Zuge der Finanzkrise von 2007 bis 2009 kam es schließlich zur jüngsten Kreditklemme. Wir untersuchen die nichtlinearen weltwirtschaftlichen Auswirkungen von in den USA entstandenen Finanzmarktschocks mithilfe des TVAR-Modells und anhand regimespezifischer Impuls-Antwort-Funktionen. Wenn die Kreditnehmer unbeschränkten Zugang zu Krediten haben, wirken sich US-Finanzschocks kaum auf die globale Wirtschaft aus. Bei restriktiven Kreditbedingungen hingegen lösen sie weltweit eine wirtschaftliche Kontraktion aus. Darüber hinaus haben Finanzschocks in den USA in Zeiten strikter Kreditvergabebedingungen einen stärkeren Einfluss auf die heimischen und ausländischen Konjunkturzyklen. Die Ergebnisse sind robust im Hinblick auf die Feststellung von US-Finanzmarktschocks und die Aggregationsmethode zur Berechnung globaler Variablen auf der Grundlage länderspezifischer Daten.

Financial frictions and global spillovers*

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Abstract

We investigate whether frictions in US financial markets amplify the international propagation of US financial shocks. The dynamics of the US economy is modeled jointly with global macroeconomic and financial variables using a threshold vector autoregression that allows us to capture regime-dependent dynamics conditional on the tightness of US credit market conditions, measured by the excess bond premium on US corporate bonds. The US economy switches from a regime of unconstrained access to credit to one characterized by tight credit whenever the bond risk premium exceeds a critical threshold. US financial shocks have an insignificant effect on the global economy when borrowers have unconstrained access to credit. On the contrary, US financial shocks give rise to a worldwide economic contraction in the tight credit regime. Moreover, US financial shocks are a relatively more important driver of US and global business cycles in times of tight credit.

Keywords: Financial frictions; Financial shocks; Nonlinear dynamics; Spillover

JEL classification: C32; C34; E32; G01; F44.

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1 Introduction

The 2007-08 turmoil in US financial markets gave rise to a credit crunch with widespread effects on the global economy. Considering the pivotal role of the United States in international financial markets, a key question is how financial shocks that originate from the US propagate across the globe. In particular, we ask whether US financial shocks give rise to global spillovers that depend nonlinearly on the severity of financial frictions in the US economy. We provide new insights into the international transmission of US financial shocks by studying the amplification mechanisms that arise from credit constraints that bind in times of crisis. Our empirical results reveal that binding credit constraints amplify the international propagation of US financial shocks.

A consensus seems to emerge from structural models that "occasionally binding" financial constraints are central to understanding the nonlinearities observed during financial crisis episodes; see e.g. Mendoza (2010), Bianchi (2011), Brunnermeier and Sannikov (2014), and Perri and Quadrini (2014). Specifically, this strand of the literature predicts that economies are resilient to shocks as long as the flow of credit is unconstrained. Binding credit constraints can, however, give rise to aggregate economic contraction. Moreover, recent theoretical studies have shown that financial frictions lead to an amplification of cross-border shocks, and structural models featuring such frictions provide a more realistic picture of international macroeconomic fluctuations; see e.g. Krugman (2008), Devereux and Yetman (2010, 2011), Olivero (2010), Kollmann, Enders, and Müller (2011), and Dedola and Lombardo (2012). Empirical models that ignore nonlinear amplification mechanisms may therefore deliver biased estimates of cross-country spillovers.

The novelty of this paper is to incorporate nonlinear features into an empirical model of international financial spillovers. To that end, we model the dynamics of the US economy jointly with global macroeconomic and financial variables in a threshold vector autoregression (TVAR) that distinguishes between normal and tight US credit regimes. In contrast to models in which regime switching is governed by a latent Markov-process, transition across regimes in the TVAR is determined directly by the severity of credit constraints in the US economy. Specifically, whenever the tightness of credit exceeds an endogenously estimated threshold level, the economy shifts from a state characterized by unconstrained access to credit to a regime in which borrowers face stringent credit constraints. The VAR dynamics as well as the volatility of shocks varies across these two regimes, which enables us to study regime-specific financial spillovers.

The excess bond premium (EBP) proposed by Gilchrist and Zakrajsek (2012) enters the TVAR model as the threshold variable. The EBP reflects a risk premium demanded by investors for bearing exposure to credit risk across the entire maturity spectrum (from 1- to 30-years) and the range of credit quality (from D to AAA) in the US corporate bond market, beyond the compensation for the usual counter-cyclical movements in expected corporate default.[1] The EBP thus provides a useful measure of credit supply

[1] Gilchrist and Zakrajsek (2012) construct a composite credit spread index as an arithmetic average of credit spreads on senior unsecured corporate bonds issued by 1,112 nonfinancial firms. For each firm, the credit spread for a corporate bond of a given maturity is obtained as the difference between the corporate bond yield and the yield of a corresponding synthetic risk-free security from the Treasury yield curve. Gilchrist and Zakrajsek (2012) decompose the credit spread index using a Black-Scholes-Merton option-pricing model estimated under a risk-neutrality assumption. This model removes (i.) the systematic counter-cyclical movements in firm-specific distance-to-default, (ii.) the level, slope and curvature of

conditions in the US economy. In particular, Gilchrist and Zakrajsek (2011, 2012) argue that fluctuations in the EBP give an adequate description of the disruptions in the financial intermediation process. Using a DSGE model, they show that an increase in the EBP reflects a reduction in the risk-bearing capacity of the financial sector, which raises the cost of external finance for non-financial borrowers, leading to a decline in aggregate spending and production.

Our objective is to investigate the regime-specific effects of an unexpected rise in the EBP. Following Helbling, Huidrom, Kose, and Otrok (2011), we study the international propagation of US financial shocks by augmenting a baseline TVAR model for the US economy with a weighted average that captures aggregate global output. The US model specification comprises output, prices, credit, the federal funds rate, and the EBP. Subsequently we include other global variables one-at-a-time into our model in order to assess potential shock transmission channels. Following Gilchrist and Zakrajsek (2011, 2012), EBP shocks are identified via a recursive identification scheme which postulates that the EBP reacts without delay to all shocks hitting the economy. Remarkably, our main empirical findings continue to hold when EBP shocks are identified via sign restrictions on the estimated impulse responses in line with Peersman (2012), Rubio-Ramirez, Waggoner, and Zha (2010), and Fry and Pagan (2011).

Our results reveal a strong asymmetry in the macroeconomic responses to EBP shocks upon distinguishing between normal and tight credit regimes. There is no significant response of the real economy to EBP shocks when borrowers have unconstrained access to credit. On the contrary, EBP shocks are detrimental for the economy when credit is scarce. Under binding credit constraints, an unexpected rise in the EBP acts as an adverse shock to the supply of credit. Specifically, a 10 basis point increase in the EBP is accompanied by a decline in real credit volume of about 0.5 percentage points and by a 10 basis point fall in the federal funds rate. The EBP shock is also followed by a 0.1 percentage point decrease in consumer prices and an 0.4 percentage point contraction of industrial output. Remarkably, global output contracts by about 0.3 percentage points following an EBP shock in the tight credit regime, while it reacts insignificantly to the US financial shock in the normal credit regime.

US financial shocks are a relatively more important driver of US and global business cycles in times of tight credit. Under normal credit supply conditions, EBP shocks account for only around one half of a percent of the variation in US and global output. However, there is an eightfold increase in this figure for US output and a threefold increase for global output when the economy resides in a tight credit regime. Moreover, while EBP shocks account for only around 1.5 percent of the variation in the volume of real credit in normal times, they contribute to around 10 percent of the forecast error variance of credit in the tight credit regime.

The US economy is interconnected with the rest of the world via trade and financial linkages, which constitute potential transmission channels of the US financial shock. A range of global variables is added one-at-a-time to the baseline model specification to study these international transmission channels. Again, we find a strong asymmetry across US credit regimes. Global consumer prices and interest rates fall, financial volatility

the Treasury yield curve, and (iii.) the realized volatility of ten-year Treasury bonds. The EBP is the residual component unexplained by these factors, it thus reflects systematic deviations in the pricing of US corporate bonds relative to the expected default risk of the underlying issuers.

rises, and corporate credit spreads widen significantly after an EBP shock in the tight regime. Furthermore, US trade with the rest of the world shrinks for about 1.5 years after the shock, and the real oil price drops significantly in the tight regime. Thus, deteriorating global financial conditions serve as a conduit for the US financial shock in the spirit of an "international finance multiplier" described by Krugman (2008), Devereux and Yetman (2010, 2011), Olivero (2010), Kollmann et al. (2011), and Dedola and Lombardo (2012), while US financial shocks have little impact during normal times.

Our paper contributes to three strands of the literature. First, our econometric approach provides an empirical counterpart to the recently developed macroeconomic models that feature occasionally binding financial constraints; see e.g. Mendoza (2010), Bianchi and Mendoza (2010), Bianchi (2011), Brunnermeier and Sannikov (2014), and Perri and Quadrini (2014). Our results complement this theoretical literature with empirical evidence on regime-specific spillover effects that arise from financial frictions. Second, our paper contributes to a growing literature on macro-financial linkages; see e.g. Gilchrist and Zakrajsek (2012) and Meeks (2012). Macro-financial models often fail to capture nonlinear amplification effects and feedback loops. Balke (2000) constitutes an important exception, but focuses on a closed economy setup. Our paper adds to existing studies by accounting for nonlinearities in an empirical model of international spillovers. Finally, our work is also related to papers on the international transmission of financial shocks; see e.g. Bagliano and Morana (2012), Cettorelli and Goldberg (2012), and Fry-McKibbin, Martin, and Tang (2014). Thus far, the empirical literature on the link between credit markets and global spillovers is scarce. The paper by Helbling et al. (2011) on the global transmission of US credit shocks is closest to ours, but uses a constant-parameter VAR model. As a result, they obtain statistically insignificant spillovers from the US to the global economy.

The remainder of the paper is organized as follows. We present our econometric approach in section 2. Section 3 offers a brief description of the data, and it outlines our empirical results. Finally, section 4 summarizes our findings, and it concludes the paper.

2 Methodology

2.1 The threshold vector autoregressive model

Our point of departure is a baseline monetary system for the US economy that comprises the growth rate of industrial production (q_t), consumer price inflation (π_t), the growth rate of real credit (c_t), the federal funds rate (i_t), and the excess bond premium (ebp_t). This system is augmented with a factor that captures aggregate global output growth (q_t^*), and a range of global variables is subsequently added to the baseline model specification in order to study international spillovers. $Y_t = (q_t^*, q_t, \pi_t, c_t, i_t, ebp_t)$ is assumed to follow a threshold vector autoregressive process given in structural form by:

$$Y_t = \begin{cases} \mathrm{A}^1 Y_t + \Theta^1(L)Y_t + \varepsilon_t^1 & \text{if} \quad ebp_{t-d} < \gamma, \\ \mathrm{A}^2 Y_t + \Theta^2(L)Y_t + \varepsilon_t^2 & \text{if} \quad ebp_{t-d} \geq \gamma, \end{cases} \tag{1}$$

for $t \in \{1, ..., T\}$, where ebp_{t-d} acts as a threshold variable with delay d. The parameter matrices A^1 and A^2 reflect the contemporaneous relationships between the endogenous variables contained in Y_t, while the lag polynomial matrices $\Theta^1(L) = \Theta_1^1 L^1 + ... + \Theta_{p_1}^1 L^{p_1}$

and $\Theta^2(L) = \Theta^2_1 L^1 + ... + \Theta^2_{p_2} L^{p_2}$ describe their dynamic interaction. The vectors of orthogonal, regime-specific shocks ε^1_t and ε^2_t are normally distributed with zero mean and regime-dependent positive definite covariance matrices $\Sigma^1_\varepsilon = E(\varepsilon^1_t \varepsilon^{1\prime}_t)$ and $\Sigma^2_\varepsilon = E(\varepsilon^2_t \varepsilon^{2\prime}_t)$. Whenever the EBP crosses a threshold level γ, the economy shifts from a state in which access to credit is unconstrained ("normal credit regime") into one where borrowers face stringent credit constraints ("tight credit regime"). The VAR dynamics as well as the volatility of shocks can vary across these two regimes. The model is estimated using the maximum likelihood estimator (MLE) described in Appendix A.

Our objective is to investigate the regime-specific effects of an unexpected rise in the US excess bond premium. Conditional on the threshold γ, the TVAR model reduces to a piecewise linear VAR. Therefore, we can obtain regime-specific structural impulse response functions (IRFs) that describe the effects of EBP shocks within each regime, in line with Ehrmann, Ellison, and Valla (2003) and Candelon and Lieb (2013). Identification of regime-specific shocks can be achieved by imposing orthogonality restrictions on the contemporaneous relationships A^1 and A^2. Specifically, the reduced form covariance matrices can be decomposed as $\Sigma^1_u = (\mathrm{A}^1)^{-1}\Sigma^1_\varepsilon(\mathrm{A}^1)^{-1\prime}$ and $\Sigma^2_u = (\mathrm{A}^2)^{-1}\Sigma^2_\varepsilon(\mathrm{A}^2)^{-1\prime}$, from which the shocks can be recovered as $\varepsilon^1_t = \mathrm{A}^1 u^1_t$ and $\varepsilon^2_t = \mathrm{A}^2 u^2_t$.

Following Gilchrist and Zakrajsek (2011, 2012), EBP shocks are identified via a recursive scheme which is implemented by performing a Cholesky decomposition of the regime-specific reduced-form covariance matrices Σ^s_u, where $s = 1, 2$, with ebp_t ordered last.[2] The identifying assumption entails that the EBP responds without delay to all macroeconomic and policy shocks hitting the economy, while the macroeconomy reacts with a slack to EBP shocks. This identification scheme delivers a lower bound on the estimated effects of EBP shocks. Moreover, it acknowledges the high-frequency nature of financial markets, which constitutes a standard approach in the VAR literature.

In order to verify the robustness of our findings to the identification scheme, we also impose a combination of zero and sign restrictions on the estimated impulse responses. This identification approach exploits the fact that the EBP captures credit supply conditions in the US economy, as argued by Gilchrist and Zakrajsek (2011, 2012). Hence, an unexpected rise in the EBP can be thought of as a tightening in the supply of credit. This shock is isolated from other macro and financial shocks and in particular from monetary policy induced changes in credit supply via zero and sign restrictions. Specifically, in line with Peersman (2012), the shock of interest is assumed to have only a lagged impact on output and prices, i.e. the contemporaneous impact on both variables is restricted to be zero. Moreover, a tightening of credit supply ($ebp_t \geq 0$) is accompanied by a decline in the volume of real credit ($c_t \leq 0$) and by a drop in the federal funds rate ($i_t \leq 0$). The responses of global output to an EBP shock are left unrestricted.

Table 1 summarizes the identifying assumptions regarding the signs of the impulse responses. All restrictions are assumed to hold for at least 6 months following the shock, and all other shocks hitting the economy are assumed to display a different pattern. The sign restrictions are implemented using the method by Rubio-Ramirez et al. (2010). It is well known that sign restrictions do not allow us to achieve unique identification of shocks. Hence, we draw rotation matrices until 500 of them yield shocks consistent with

[2] We attach an economic interpretation solely to the EBP shock, while we do not interpret the remaining orthogonal shocks from a structural perspective, i.e., these may reflect a mixture of the true underlying structural disturbances.

Table 1: Identification of EBP shocks via zero and sign restrictions

Response of	q_t^*	q_t	π_t	c_t	i_t	ebp_t
		0	0	≤ 0	≤ 0	≥ 0
Horizons		Contemp.	Contemp.	0-6 M	0-6 M	0-6 M

Note: q_t^*: global output, q_t: US output, π_t: prices, c_t: real credit volume, i_t: fed funds rate, ebp_t: excess bond premium.

our sign restrictions. We adopt the median target approach to pick among all models the one which yields impulse responses closest to the median response (Fry and Pagan, 2011).

3 Empirical results

3.1 Data

We use monthly data between January 1984 and December 2012. Thus, our sample ranges from the ascent of the Great Moderation until the recovery from the global financial crisis. The effective federal funds rate and the excess bond premium enter in levels, and the baseline model specification also contains the logarithmic difference of the industrial production index, the consumer price index (CPI), and the volume of commercial and industrial loans issued by all US commercial banks, deflated by the CPI to obtain real credit. Time series for the US are obtained from the Federal Reserve Bank of St. Louis and from Gilchrist and Zakrajsek (2012).[3] Following Helbling et al. (2011), we add a weighted average that captures aggregate global output to the baseline US VAR in order to study the international dimensions of EBP shocks. The 6-variate VAR is subsequently augmented one-at-a-time with three US and seven global macro and financial variables to shed light on different transmission channels.

We add sequentially 3 variables to the 6-variate baseline VAR that capture transmission channels of EBP shocks via US financial markets. In particular, we gauge US credit market conditions by the high-yield bond spread (the difference between Moody's Baa rated long-term corporate bonds and 10-year Treasuries) and by an index of broader credit conditions which is a subindex of the Chicago Fed's National Financial Conditions Index (NFCI). In addition we add the S&P 500 stock price index deflated by CPI.

Among global variables, we include global output, global consumer prices, the global short-term nominal interest rate, global financial uncertainty, the global corporate credit spread, the nominal effective exchange rate, global trade, and the real price of oil. Global variables are obtained as weighted averages of time series for 18 major economies, where

[3] The data of Gilchrist and Zakrajsek (2012) was retrieved from the *American Economic Association* webpage at: `http://www.aeaweb.org/articles.php?doi=10.1257/aer.102.4.1692`, and we are grateful to Simon Gilchrist and Egon Zakrajsek for kindly supplying the extended time series that span until December 2012.

Table 2: Model selection criteria

Selection criterion	q_t^*	q_t	π_t	c_t	i_t	ebp_t
BW	3.058	3.919	3.837	4.444	3.174	4.624
BLM	2.936	3.671	3.603	4.092	3.038	4.232

Note: The table shows the BW and BLM statistics for each equation of the estimated models. The nonlinear TVAR model is chosen over the linear VAR if BW > 1 and, similarly, if BLM > 1.

the weights reflect the average overall size of the economy over the estimation period, measured by average PPP-adjusted real GDP from the Penn World Tables.[4] For the sake of robustness, we also consider two alternative weighting schemes based on bilateral trade and financial linkages. The countries included are Argentina, Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, India, Italy, Japan, Korea, Mexico, the Netherlands, Spain, Sweden, and the United Kingdom. Output is measured by industrial production data obtained from the OECD, we use national CPI indices from Datastream, and we use short-term monetary policy interest rates. Financial uncertainty is captured by realized stock market volatility, obtained as the sum of squared daily stock market returns within each month using the MSCI price index of the total national stock market. Corporate credit spreads are measured by the difference between long-term corporate and government bonds from the IMF Stress Index data set. We use the nominal effective exchange rate index of the US with respect to its 15 main trading partners reported by the Bank for International Settlements. Finally, we proxy US trade by the total sum of bilateral imports and exports between the US and its 18 counterparts (deflated by US CPI), obtained from the IMF Direction of Trade statistics.

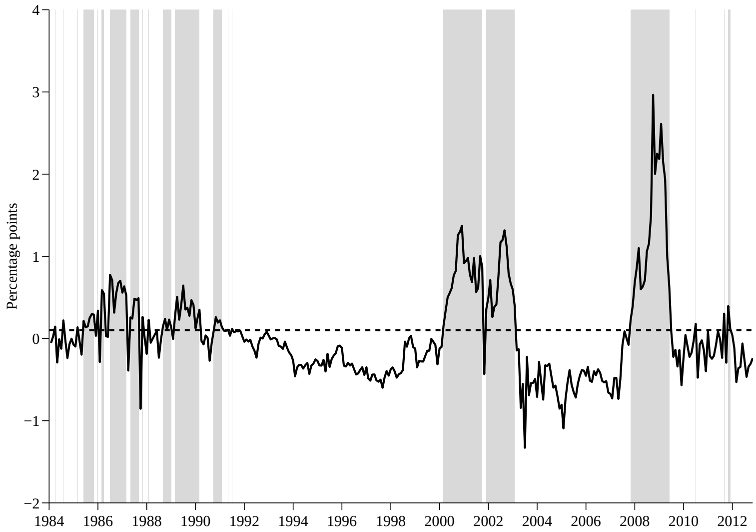
3.2 Model selection

We employ three statistics in order to choose between a linear and a threshold VAR model (the analytical details are presented in Appendix B). First, we test the null hypothesis of a constant-parameter linear VAR model against the threshold-VAR alternative using the heteroskedasticity-robust SupLM statistic proposed by Hansen and Seo (2002). The threshold γ is not identified and constitutes a nuisance parameter under the null. Hence, the asymptotic distribution of the test statistic must be approximated via a bootstrap simulation method (see Hansen, 1996). We obtain a SupLM value of 126.457 (p-value=0.042) which implies a rejection of the null hypothesis of linearity in favor of the TVAR alternative. Rejection of the null suggests that financial frictions give rise to significant nonlinearities.

In addition, following Altissimo and Corradi (2002), Galvao (2006), and Artis, Galvao, and Marcellino (2007), we use the bounded supWald (BW) and bounded supLM (BLM) statistics, which constitute consistent model selection criteria when a nuisance parameter

[4] We treat the data as an unbalanced panel and aggregate accordingly, as some time series do not stretch back to 1984.

Figure 1: Excess bond premium and financial regimes



Note: The solid line depicts the lagged excess bond premium and the dashed line corresponds to the estimated threshold value ($\hat{\gamma}_{US} = 0.1004$). Tight credit regimes are shaded in grey. Sample: January 1984 - December 2012.

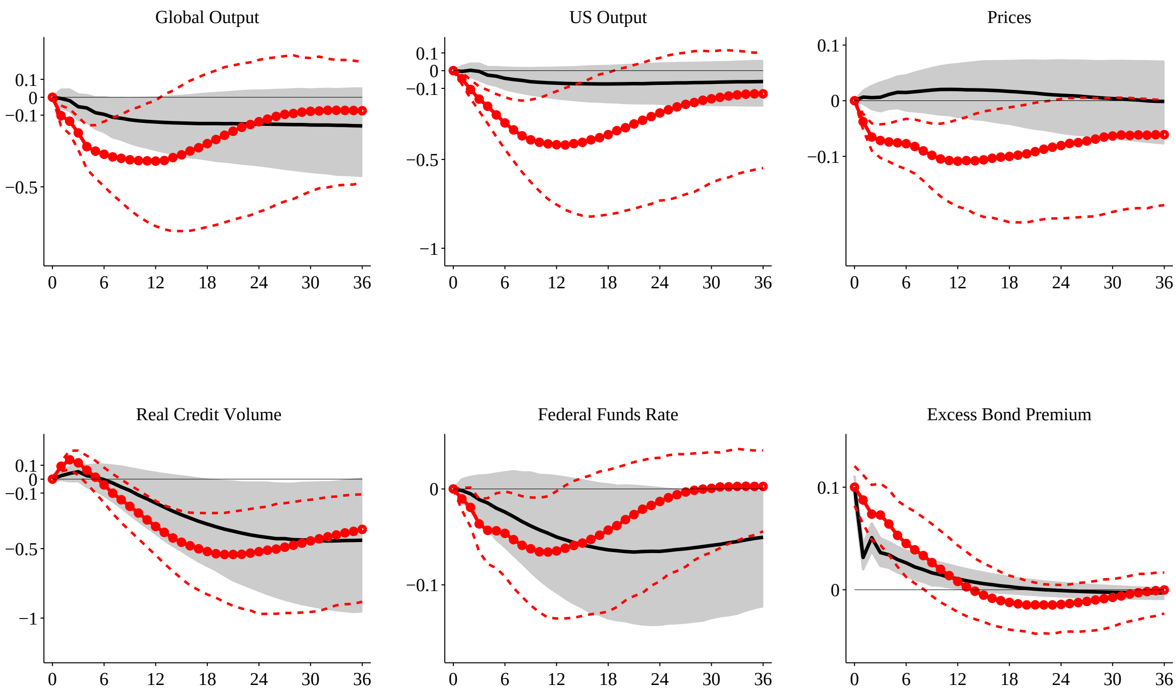
is present only under the nonlinear alternative. The TVAR model is preferred over the linear VAR if the statistics exceed unity (BW > 1 and, similarly, BLM > 1). This model selection rule ensures that type I and type II errors are asymptotically zero. Table 2 shows the BW and BLM statistics that guide our model selection between a constant-parameter linear VAR against the threshold-VAR alternative. The table shows the test statistics for each individual equation in the baseline model. Again, the equation-wise supremum statistics speak unequivocally in favor of the nonlinear model.

3.3 Credit regimes

We estimate the TVAR with $p_1 = 4$ lags in the normal credit regime and $p_2 = 3$ lags in the tight credit regime, selected using the Akaike information criterion (AIC) proposed by Tsay (1998) and the bias-corrected AIC proposed by Wong and Li (1998). The threshold $\hat{\gamma}_{US}$ is estimated endogenously from the 5-variate baseline model specification for the US economy. The estimated threshold value equals $\hat{\gamma}_{US} = 0.1004$ percentage points with a delay of $\hat{d} = 1$ month. Subsequently, global variables are added to Y_t, and the TVAR is re-estimated with $\hat{\gamma}_{US}$. In order to facilitate comparability across different model specifications, $\hat{\gamma}_{US}$ is exogenously held constant across all estimated TVARs. This approach ensures that the identified regimes reflect distressed credit conditions in the US economy, and it amounts to studying the international transmission of US financial shocks in times when constraints are binding in US credit markets.

Figure 1 illustrates the lagged EBP (solid line) together with the estimated threshold (dashed line). The shaded areas correspond to periods when the EBP resides above the threshold. At a first glance, three major episodes of distress in US banking and credit

Figure 2: Effects of an EBP shock identified via Cholesky decomposition



Note: Impulse responses to a 10 basis point rise in the EBP from the 6-variate TVAR identified via Cholesky decomposition. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

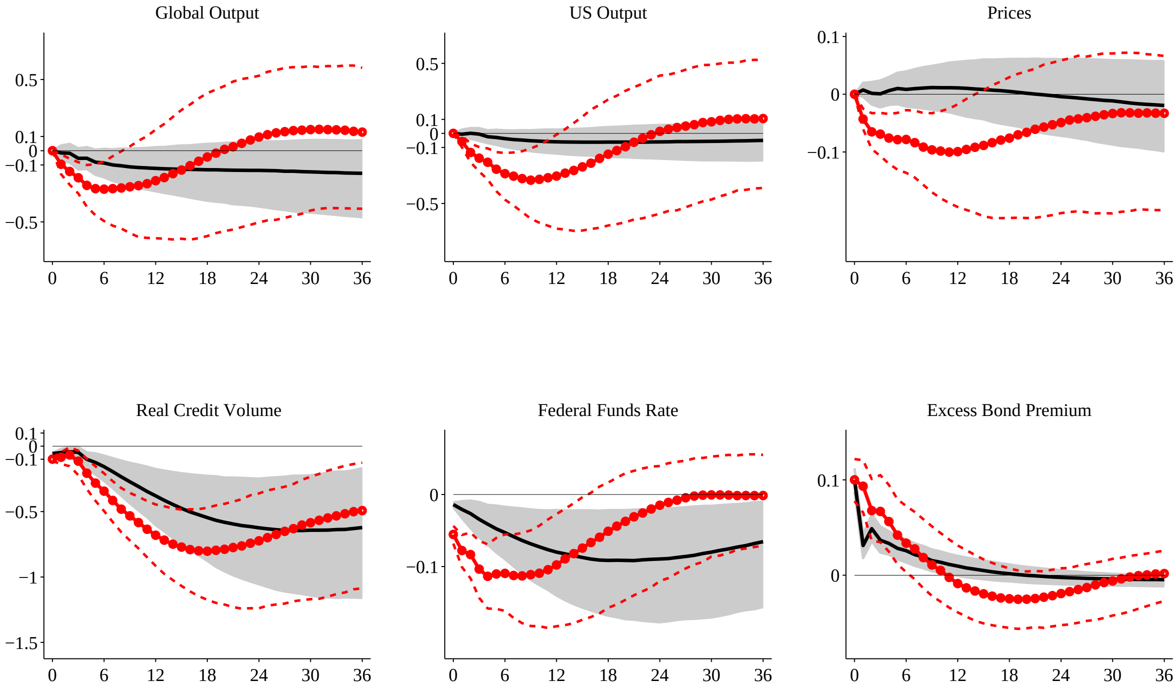
markets stand out. The first wave of tight credit coincides with the savings and loan crisis of the 1980s and early 1990s. An exhaustive historical account of the banking crises of that era is provided by Federal Deposit Insurance Corporation (1997). Following a period of relative financial stability during the 1990s, the US economy was again characterized by stringent credit supply conditions at the wake of the new millennium, around the Enron, Y2K, and 9/11 debacles, and the burst of the dotcom bubble. Finally, credit constraints were binding throughout the recent global financial crisis.

3.4 Structural analysis

In this section we estimate the regime-specific effects of an EBP shock on the US and the global economy, conditional on whether the US economy resides in a normal or tight credit regime.[5] Figure 2 shows regime-specific impulse response functions (IRFs) to a 10 basis point rise in the EBP from the baseline 6-variate TVAR identified via Cholesky decomposition. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% bootstrapped con-

[5]For the sake of robustness, we report results from a closed economy TVAR model in Appendix C.

Figure 3: Effects of an EBP shock identified via sign restrictions



Note: Impulse responses to a 10 basis point rise in the EBP from the 6-variate TVAR identified via sign restrictions. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

fidence bands obtained from 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

The EBP levels out in both regimes after about one year following a US financial shock. However, the IRFs display a clear asymmetry across the two regimes. There is no significant response of the macro-economy to the US financial shock when borrowers have unconstrained access to credit. Thus, when the US financial system is in good health and credit is abundant, the economy is resilient in the face of a financial shock. In contrast, the EBP shock is detrimental for the economy under binding credit constraints. A rise in the EBP is followed by a significant decline in real credit volume of about 0.5 percentage points within two years after the shock in the tight credit regime. Besides, the EBP shock is accompanied by an 0.1 percentage point decline in consumer prices and an 0.4 percentage point contraction of industrial output. Moreover, the federal funds rate falls significantly by about 5 basis points, which suggests that monetary policy takes an accommodative stance in the face of tightening financial conditions. Most remarkably, the EBP shock facilitates a significant contraction in global industrial production of about 0.3 percentage points in times when credit is scarce in US credit markets, while global

Table 3: Contribution of EBP shock to forecast error variances

Contribution of EBP shock in normal credit regime (%)						
Horizon (months)	q_t^*	q_t	π_t	c_t	i_t	ebp_t
1	0.00	0.00	0.00	0.00	0.00	96.27
12	0.25	0.27	0.38	0.18	0.80	90.89
24	0.43	0.59	0.78	0.93	2.51	89.85
36	0.52	0.70	0.97	1.54	3.65	88.98
48	0.60	0.71	1.07	1.75	4.16	88.46
60	0.67	0.71	1.14	1.76	4.30	88.24
Contribution of EBP shock in tight credit regime (%)						
Horizon (months)	q_t^*	q_t	π_t	c_t	i_t	ebp_t
1	0.00	0.00	0.00	0.00	0.00	86.78
12	2.36	4.83	5.23	3.52	3.37	39.88
24	1.88	4.39	4.51	10.30	3.68	36.27
36	1.67	3.91	4.11	10.51	3.71	34.07
48	1.55	3.79	3.94	10.61	3.78	33.41
60	1.44	3.77	3.85	10.72	3.79	33.34

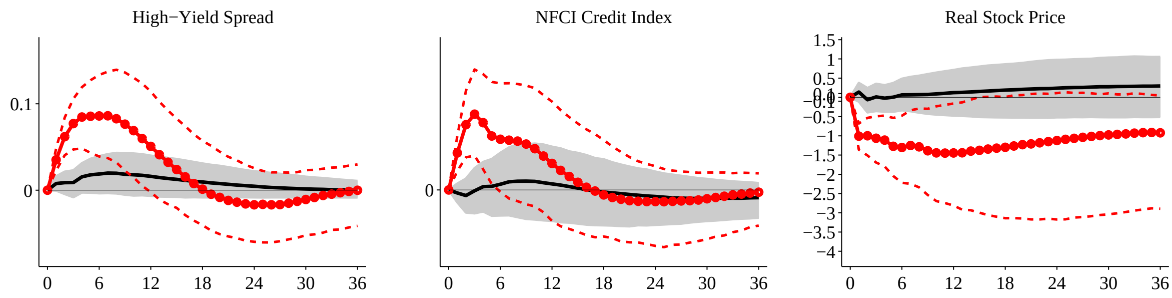
Note: The table shows the regime-specific contribution of recursively identified EBP shocks to the forecast error variance of each variable obtained from the TVAR model.

output does not respond significantly in the normal credit regime. Hence, US financial shocks propagate across the globe when US credit constraints are binding.

The asymmetric transmission of EBP shocks does not hinge upon the structural identification scheme. Our empirical results remain qualitatively unchanged and also quantitatively similar when the EBP shock is identified via a combination of zero and sign restrictions, as illustrated in Figure 3. Nevertheless, both credit and the fed funds rate decline upon impact and their drop is more accentuated when the contemporaneous zero restrictions imposed by the recursive Cholesky scheme are removed.

Table 3 shows the regime-specific contribution of recursively identified EBP shocks to the forecast error variance of each variable obtained from the TVAR model. US financial shocks seem to be a relatively more important driver of US and global business cycles during periods of tight credit in which the non-financial sector faces difficulties in raising external finance. Under normal credit supply conditions, EBP shocks account for only around one half of a percent of the variation in US and global output. However, there

Figure 4: Effects of an EBP shock on US financial markets



Note: Impulse responses to a 10 basis point rise in the EBP identified via Cholesky decomposition. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

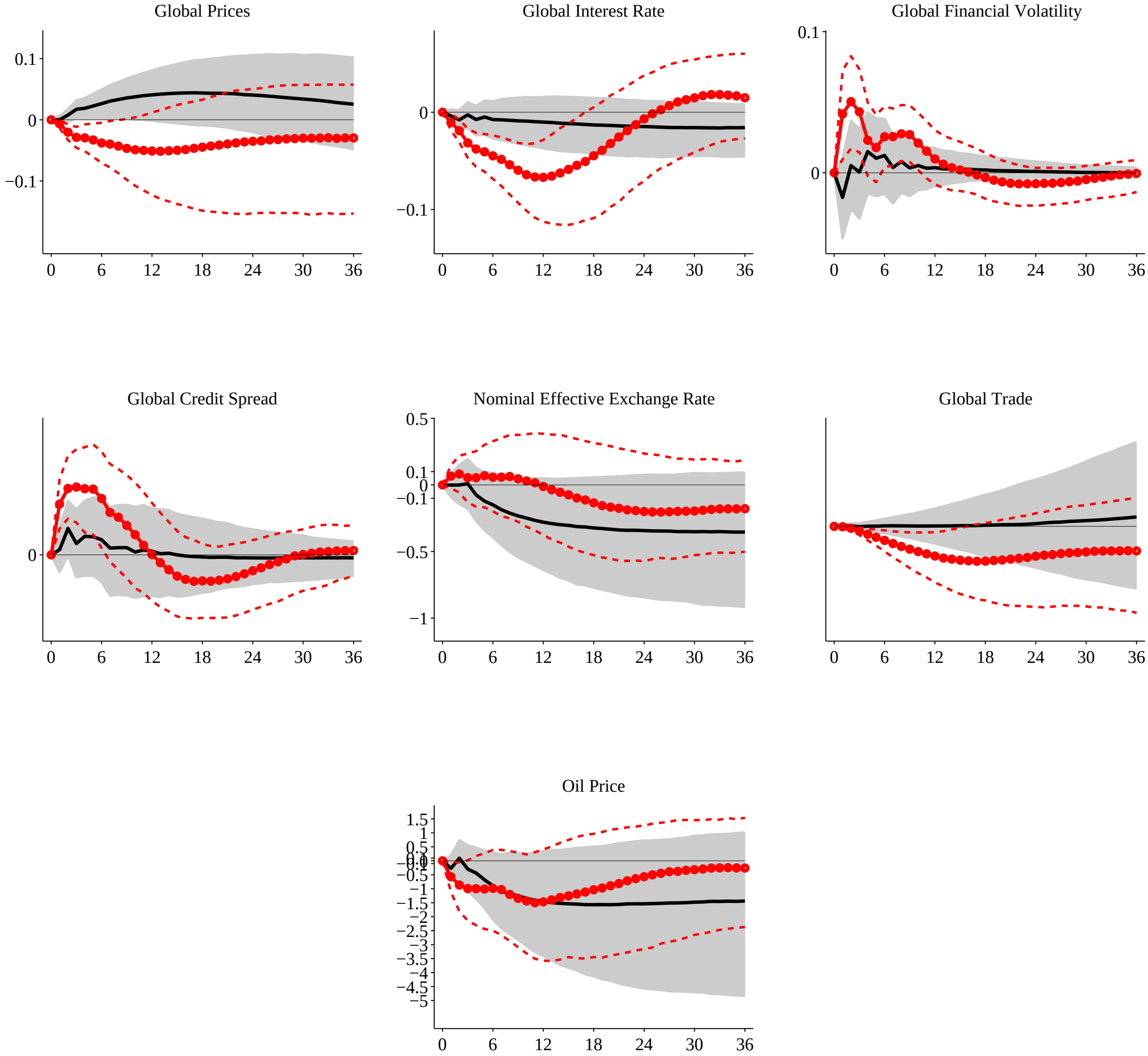
is an eightfold increase in this figure for US output and a threefold increase for global output when the economy resides in a tight credit regime. Moreover, while EBP shocks account for only around 1.5 percent of the variation in the volume of real credit in normal times, they contribute to around 10 percent of the forecast error variance of credit in the tight credit regime. In addition, there is an almost fourfold increase in the consumer price variability explained by EBP shocks moving from the normal to the tight credit regime, while US financial shocks account for around 4 percent of the variation in the federal funds rate in both regimes.

The macroeconomic downturn triggered by the US financial shock in the tight credit regime suggests that a rise in the EBP induces banks to ration lending, which forces firms and households to postpone investment and consumption plans under binding credit constraints, leading to a decline in aggregate spending and production. In support of these arguments, Figure 4 shows the recursively identified IRFs from TVAR models augmented one-at-a-time with variables that capture financial market conditions in the US economy.[6] In the tight credit regime, an adverse EBP shock is followed by a significant rise in the Baa-Treasury spread and in the NFCI Credit Index, which signal a tightening of financial conditions in high-yield and broader US credit markets. As this credit crunch unfolds, real stock prices decline significantly by almost 1.5 percentage points.

Figure 5 depicts the recursively identified impulse responses to an EBP shock of seven global variables added to the 6-variate TVAR one-at-a-time. Again, we find a clear asymmetry across US credit regimes. US financial shocks generate worldwide repercussions in the tight credit regime due to trade and financial links with the rest of the world, while US financial shocks have little impact during normal times. Specifically, a rise in the EBP is accompanied by a significant rise in credit spreads and in financial market volatility worldwide in the tight credit regime, signalling an increase in global financial uncertainty

[6]We only show the responses of the additional global variables, as the remaining IRFs from the TVAR are largely robust to variations of the model.

Figure 5: Effects of an EBP shock on global variables



Note: Impulse responses to a 10 basis point rise in the EBP identified via Cholesky decomposition. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

as a result of deteriorating financial conditions in the US. Global financial markets thus serve as a conduit for the US financial shock in the spirit of an "international finance multiplier" described by Krugman (2008), Devereux and Yetman (2010, 2011), Olivero (2010), Kollmann et al. (2011), and Dedola and Lombardo (2012). The global economic downturn associated with the EBP shock in the tight credit regime is accompanied by a worldwide monetary expansion that amounts to a 5 basis point decrease in the global interest rate. Moreover, following an EBP shock, US trade with the rest of the world shrinks for about 1.5 years, and global consumer prices and the real oil price drop significantly. In contrast, exchange rates do not seem to serve as an important transmission channel.

3.5 Robustness checks

We verify the robustness of our findings against two alternative weighting schemes of global variables, based on bilateral trade and financial positions. Trade weights are constructed as $w_i^{Tra} = (EX^{\text{US to } i} + IM^{\text{US from } i})/(\sum_i EX^{\text{US to } i} + \sum_i IM^{\text{US from } i})$ following Frankel and Rose (1998), where $EX^{\text{US to } i}$ denotes US exports to country i and $IM^{\text{US from } i}$ denotes US imports from country i. Following Imbs (2004), financial weights are constructed as $w_i^{Fin} = |(NFA_i/GDP_i) - (NFA_{US}/GDP_{US})|$, using the data from Lane and Milesi-Ferretti (2007). NFA_i denotes the net foreign asset position in country i. The weight w_i^{Fin} will take high values for countries that have diverging external positions with respect to the US, as such countries are more likely to lend and borrow from the US according to Imbs (2004). Trade as well as financial weights are normalized and sum to 1.

Figure 6 depicts the IRFs identified recursively from the TVAR with global output weighted according to the two alternative weighting schemes. The upper panel shows the results from the model with trade weights, while the lower panel shows the IRFs from the model with financial weights. A comparison of Figure 6 and Figure 2 reveals that our main findings remain unchanged irrespective of the aggregation method employed.

4 Conclusion

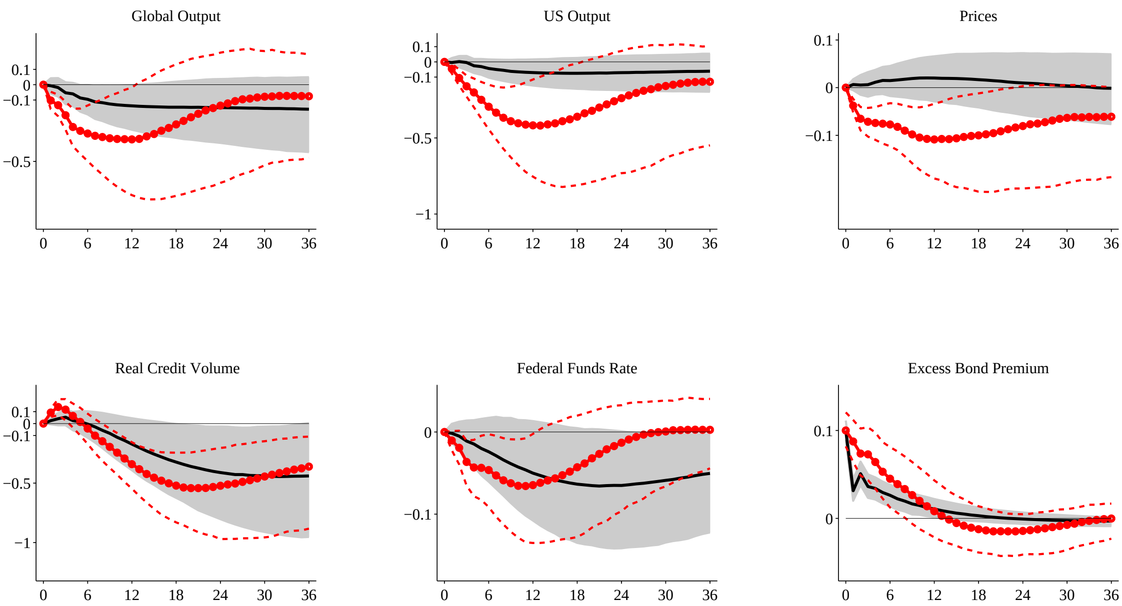
Occasionally binding financial constraints are often embedded in macroeconomic models, however, most empirical studies on macro-financial linkages resort to linear models that fail to account for the amplification mechanisms implied by the theoretical literature. There is an equally limited empirical literature that investigates the relation between financial frictions and global spillovers. This paper aims to fill these gaps.

We model the dynamics of the US economy jointly with global macroeconomic and financial variables using a threshold vector autoregressive model. This model captures regime-dependent dynamics conditional on the tightness of credit supply conditions in the US economy, measured by the excess bond premium proposed by Gilchrist and Zakrajsek (2012). Transition from a state of unconstrained access to credit to a regime characterized by binding financial constraints arises endogenously in this framework whenever the excess bond premium crosses an estimated threshold value.

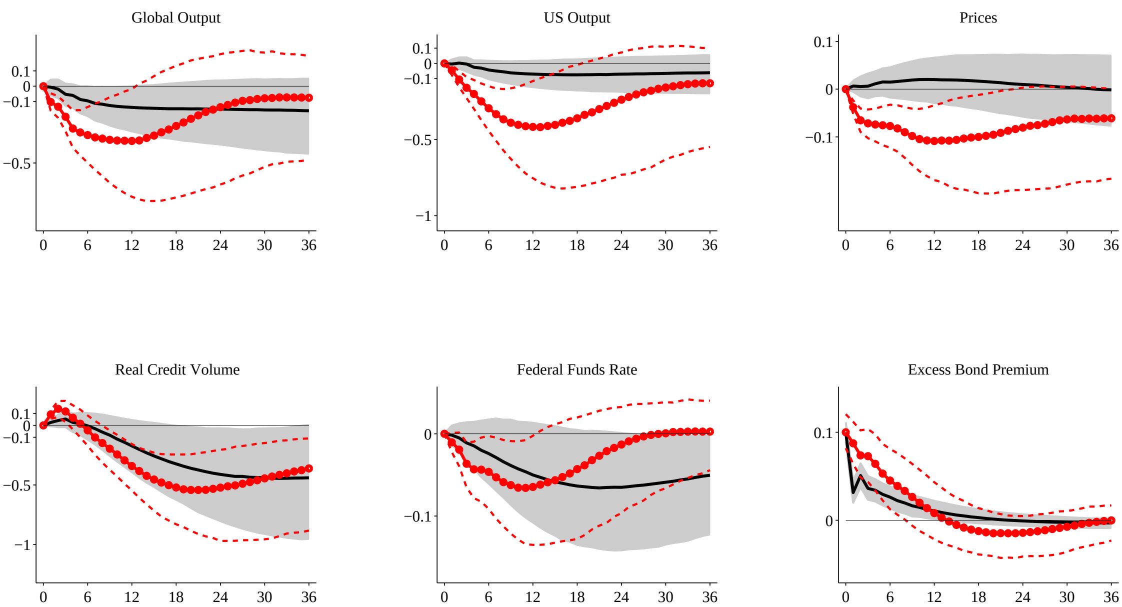
Using the excess bond premium as a threshold variable, we identify three periods of distress in US banking and credit markets. The first tight credit episode coincides with

Figure 6: Robustness checks

Trade Weights



Financial Weights



Note: Impulse responses to a 10 basis point rise in the EBP identified via Cholesky decomposition from the TVAR model augmented with global output aggregated using trade weights and financial weights, respectively. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

the savings and loan crisis of the 1980s and early 1990s. The second episode occurs in the early 2000s, around the Enron, Y2K, and 9/11 debacles and following the burst of the dotcom bubble. Finally, the 2007-09 financial crisis is identified as the most recent credit crunch.

We study the nonlinear effects of an US financial shock on the global economy in the TVAR model using regime-specific impulse response functions. We find that financial frictions amplify business cycle fluctuations within as well as across economies. Upon distinguishing between normal and tight credit regimes, we uncover a strong asymmetry in the impulse responses to an US financial shock. The US financial sector absorbs the shock when borrowers have unconstrained access to credit, and there are no aggregate economic consequences. In contrast, the US financial shock is followed by a significant contraction in the global economy when the US resides in a tight credit regime. Our empirical results thus reveal an international dimension of the US financial accelerator mechanism, which draws attention to the negative externalities imposed on the global economy via frictions in the process of financial intermediation in the United States.

Appendix A: MLE estimation of the TVAR

The reduced form of the TVAR model is given by:

$$Y_t = \begin{cases} \Phi^1(L)Y_t + u_t^1 & \text{if} \quad rp_{t-d} < \gamma, \\ \Phi^2(L)Y_t + u_t^2 & \text{if} \quad rp_{t-d} \geq \gamma, \end{cases} \tag{2}$$

where $\Phi^1(L) = (I - A^1)^{-1}\Theta^1(L)$ and $\Phi^2(L) = (I - A^2)^{-1}\Theta^2(L)$ are p_1-order (resp. p_2-order) lag-polynomial matrices of the reduced form coefficients (where $p_1; p_2 \in \mathbb{N}$), and where $u_t^1 \sim (0, \Sigma_u^1)$ and $u_t^2 \sim (0, \Sigma_u^2)$ are vectors of reduced form Gaussian white noise forecast errors, with $\Sigma_u^1 = E(u_t^1 u_t^{1'})$ and $\Sigma_u^2 = E(u_t^2 u_t^{2'})$ positive definite. The reduced form parameters are estimated using the maximum likelihood estimator (MLE) described in Galvao (2006). This entails computing the constrained MLE for $\Phi^1(L)$, $\Phi^2(L)$, Σ_u^1, and Σ_u^2, holding d and γ fixed. For a given delay d and threshold value γ, the MLE are the OLS estimators given by:

$$\begin{bmatrix} \Phi_1^1 \\ \Phi_2^1 \\ \vdots \\ \Phi_{p_1}^1 \end{bmatrix}' = \left(\left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_1} \end{bmatrix}' D_t^1 \right)' \left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_1} \end{bmatrix}' D_t^1 \right) \right)^{-1} \left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_1} \end{bmatrix}' D_t^1 \right)' Y_t$$

and

$$\begin{bmatrix} \Phi_1^2 \\ \Phi_2^2 \\ \vdots \\ \Phi_{p_2}^2 \end{bmatrix}' = \left(\left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_2} \end{bmatrix}' D_t^2 \right)' \left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_2} \end{bmatrix}' D_t^2 \right) \right)^{-1} \left(\begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ \vdots \\ Y_{t-p_2} \end{bmatrix}' D_t^2 \right)' Y_t,$$

where $D_t^1 = I(rp_{t-d} < \gamma)$ and $D_t^2 = I(rp_{t-d} \geq \gamma)$ are indicator functions. The estimated residuals are obtained as: $\hat{u}_t^1 = Y_t D_t^1 - ([Y_{t-1}', Y_{t-2}', ..., Y_{t-p_1}'] D_t^1)[\hat{\Phi^1}_1, \hat{\Phi^1}_2, ..., \hat{\Phi^1}_{p_1}]$ and $\hat{u}_t^2 = Y_t D_t^2 - ([Y_{t-1}', Y_{t-2}', ..., Y_{t-p_2}'] D_t^2)[\hat{\Phi^2}_1, \hat{\Phi^2}_2, ..., \hat{\Phi^2}_{p_2}]$. Finally, the MLEs for the covariance matrices are $\hat{\Sigma}_u^1 = 1/T^1 \sum_{t=1}^{T^1} \hat{u}_t^1 \hat{u}_t^{1'}$ and $\hat{\Sigma}_u^2 = 1/T^2 \sum_{t=1}^{T^2} \hat{u}_t^2 \hat{u}_t^{2'}$, where $T^1 + T^2 = T$.

The model is estimated for all possible values of d and γ on an equally spaced grid of rp_{t-d}. The MLE for $\hat{d}$ and $\hat{\gamma}$ are then obtained by solving the following optimization problem:

$$(\hat{\gamma}, \hat{d}) = \min_{\substack{\gamma_L \leq \gamma \leq \gamma_U \\ 1 \leq d \leq d_{max}}} \left(\frac{T^1}{2} \log(|\Sigma_u^1|) + \frac{T^2}{2} \log(|\Sigma_u^2|), \right).$$

where γ_L is the 15%th percentile and γ_U is the 85%th percentile of the empirical distribution of rp_{t-d}. Hence, following Balke (2000), we restrict the search region such that at least 15% of the observations (plus the number of parameters) are in each regime.

Appendix B: Model selection criteria

The heteroskedasticity-robust SupLM statistic for the null hypothesis of a linear VAR against the TVAR alternative can be obtained as follows (see Hansen and Seo, 2002). Let Y^1 and Y^2 be the matrices of the stacked rows $(Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p_1})D_t^1$ and $(Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p_2})D_t^2$, respectively, let ξ^1 and ξ^2 be the matrices of the stacked rows $\tilde{u}_t \otimes (Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p_1})D_t^1$ and $\tilde{u}_t \otimes (Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p_2})D_t^2$, respectively, with $\tilde{u}_t$ the reduced form residual vector from the restricted (linear) VAR model. Furthermore, define the outer product matrices $M^1 = I_m \otimes Y^{1\prime}Y^1$, $M^2 = I_m \otimes Y^{2\prime}Y^2$, $\Omega^1 = \xi^{1\prime}\xi^1$, and $\Omega^2 = \xi^{2\prime}\xi^2$. The Eicker-White covariance matrix estimators for $\text{vec}(\hat{\Phi}^1)$ and $\text{vec}(\hat{\Phi}^1)$ can be defined as $\hat{V}^1 = (M^1)^{-1}\Omega^1(M^1)^{-1}$ and $\hat{V}^2 = (M^2)^{-1}\Omega^2(M^2)^{-1}$, respectively, from which the heteroskedasticity-robust LM statistic is given by:

$$\text{LM} = \text{vec}(\hat{\Phi}^1 - \hat{\Phi}^2)'(\hat{V}^1 + \hat{V}^2)^{-1}\text{vec}(\hat{\Phi}^1 - \hat{\Phi}^2), \tag{3}$$

which is the test statistic for a given value of γ. The model is estimated by OLS for each possible γ as described above, and the SupLM statistic is given by the supremum of the LM statistics over the search region $\gamma_L \leq \gamma \leq \gamma_U$:

$$\text{SupLM} = \sup_{\gamma_L \leq \gamma \leq \gamma_U} \text{LM}. \tag{4}$$

Following Altissimo and Corradi (2002), Galvao (2006), and Artis et al. (2007), we use the bounded supWald (BW) and bounded supLM (BLM) statistics as additional model selection criteria. The BW statistic is given by:

$$\text{BW} = \frac{1}{2\log(\log(T))}\left(\sup_{\gamma_L \leq \gamma \leq \gamma_U} T\left(\frac{SSR^{lin} - SSR^{nlin}(\gamma)}{SSR^{nlin}(\gamma)}\right)\right)^{\frac{1}{2}},$$

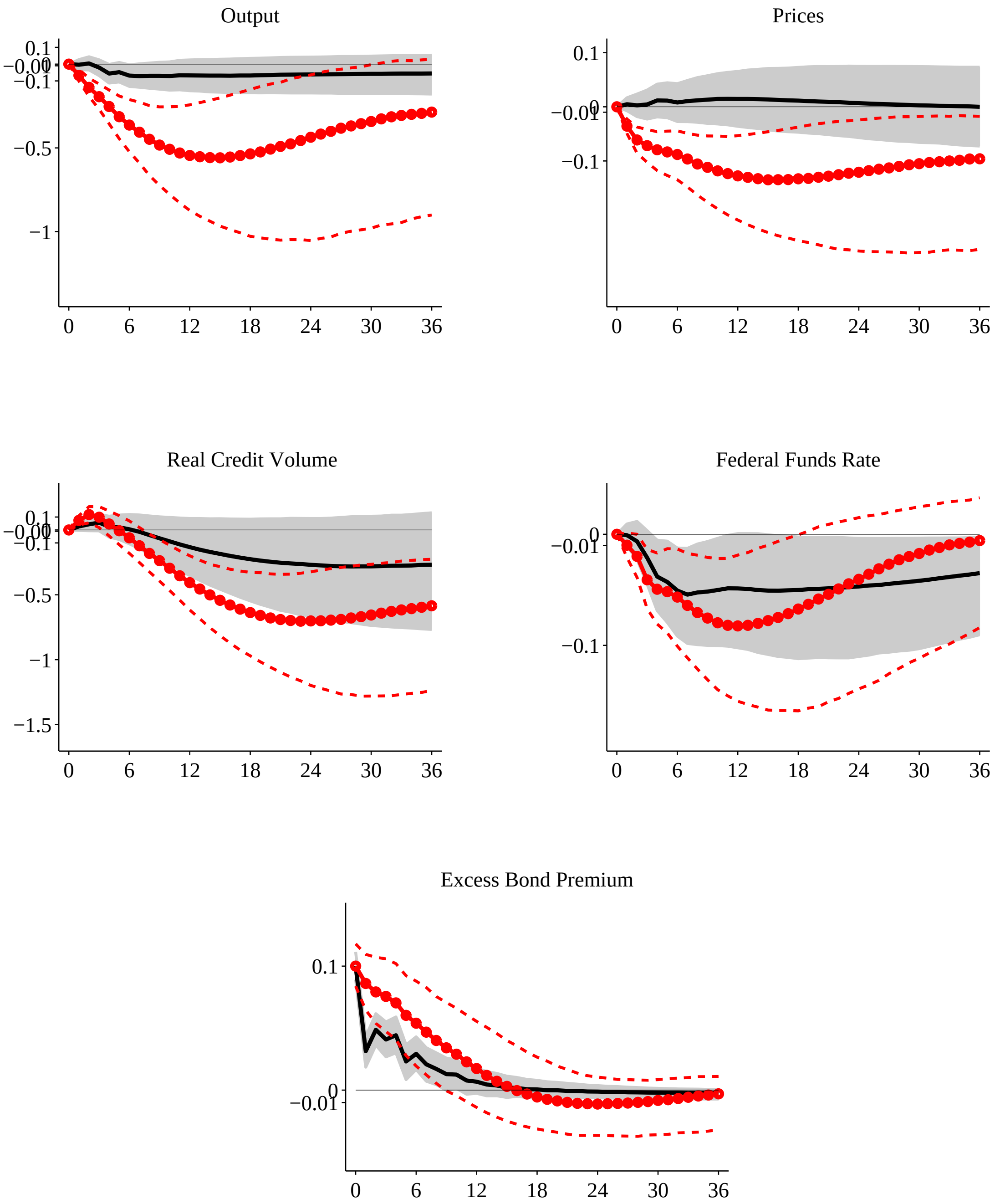
and the BLM is given by:

$$\text{BLM} = \frac{1}{2\log(\log(T))}\left(\sup_{\gamma_L \leq \gamma \leq \gamma_U} T\left(\frac{SSR^{lin} - SSR^{nlin}(\gamma)}{SSR^{lin}}\right)\right)^{\frac{1}{2}}.$$

SSR^{lin} is the the sum of squared residuals under the linear VAR null, and $SSR^{nlin}(.)$ is the sum of squared residuals under the TVAR alternative hypothesis. The statistics BW and BLM provide the asymptotic bounds on the supremum of the Wald and LM statistics computed over a grid $\gamma_L \leq \gamma \leq \gamma_U$ of possible values for the threshold γ. The TVAR model is chosen over the linear VAR if BW > 1 and, similarly, if BLM > 1. This model selection rule ensures that type I and type II errors are asymptotically zero.

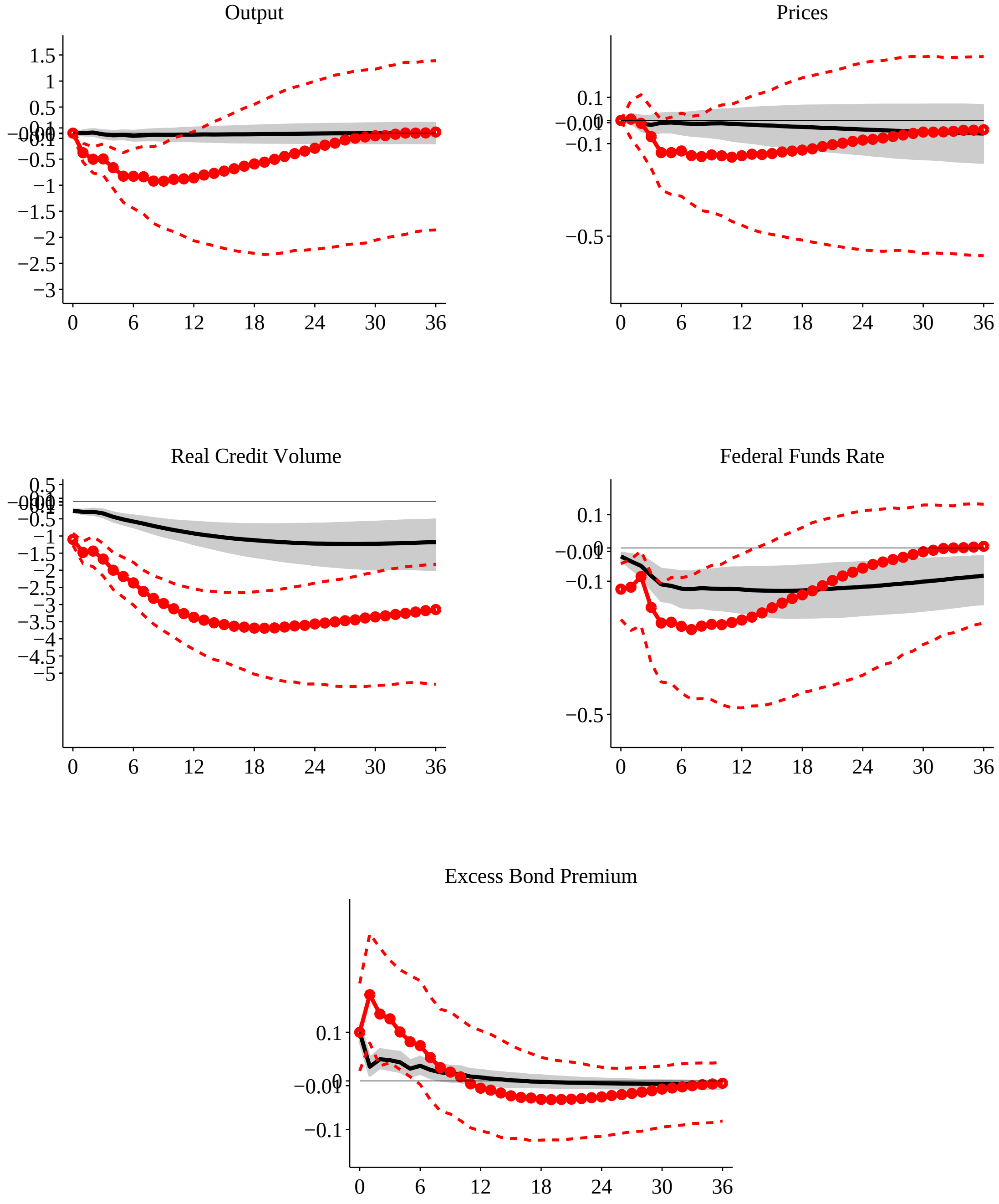
Appendix C: Closed economy IRFs

Figure 7: Effects of an EBP shock identified via Cholesky decomposition



Note: Impulse responses to a 10 basis point rise in the EBP from the baseline TVAR identified via Cholesky decomposition. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

Figure 8: Effects of an EBP shock identified via sign restrictions



Note: Impulse responses to a 10 basis point rise in the EBP from the baseline TVAR identified via sign restrictions. The black solid lines are the median impulse responses from the TVAR model in the unconstrained credit regime with shaded areas representing 90% confidence bands based on 1000 draws. The red dotted lines are the median impulse responses from the TVAR model in the tight credit regime with dashed lines representing 90% confidence bands.

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