The Effects of Surprise and Anticipated Technology Changes on International Relative Prices and Trade*

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Abstract

This paper argues that it is important to distinguish surprise and anticipated components of total factor productivity (TFP) when we study the international transmission of TFP shocks. We document that surprise and anticipated shocks to US TFP induce distinct dynamics for international relative prices (the real exchange rate and the terms of trade) and international trade. These findings are robust under two fundamentally different identification methods. Our empirical findings can reconcile some conflicting empirical results in the literature and hence lead to a better understanding of the international transmission of TFP shocks. We evaluate a standard international macroeconomic model using our empirical results. The model cannot generate the documented dynamics of international relative prices, though it can replicate the dynamics of other variables relatively well. Anticipated TFP shocks are also found to contribute more than surprise TFP shocks to real exchange rate movements lending support to the studies of exchange rates as asset prices.

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1 Introduction

This paper empirically studies the international transmission of surprise and anticipated shocks to US total factor productivity (TFP) in structural vector autoregressions (SVARs). Surprise shocks, hereafter called contemporaneous TFP shocks, affect TFP immediately. Anticipated shocks have no immediate impact on TFP, but portend its future movements. Following the literature, they are called news TFP shocks. See equations (1) and (2) for an example of surprise and news TFP shocks.

In particular, we focus on the effects of these two TFP shocks on international relative prices (the real exchange rate and the terms of trade) and international trade (real exports, real imports, and the trade balance). Besides international trade, international relative prices also play important roles in the international transmission of country-specific productivity shocks. Relative price movements are a major channel for trade adjustment and induce important cross-country wealth effects.[1] We highlight these transmission channels for two distinct TFP shocks: news and contemporaneous shocks. We also investigate if the predictions of standard international business cycle models are in line with our empirical findings.

Recently, there has been a revived and growing interest in the role of news shocks in explaining business cycles.[2] In the empirical studies, news TFP shocks are found to account for a large fraction of US business cycles. Beaudry and Portier (2006) document that news TFP shocks explain more than 50% of business cycle fluctuations in US consumption, output, and hours worked. Barsky and Sims (2011) propose a novel strategy to identify news TFP shocks in SVARs and find that about 40% of the forecast error variances of US consumption and output at business cycle frequencies are attributable to their identified news shocks. Schmitt-Grohé and Uribe (2012) provide evidence that news shocks to TFP play a major role in driving US business cycles by estimating a dynamic stochastic general equilibrium model.[3]

In light of the importance of news TFP shocks in driving US business cycles, it is of interest to study the international transmission of US news TFP shocks by distinguishing them from US contemporaneous TFP shocks. There are several recent empirical studies on the international transmission of US-specific productivity shocks, for instance, Corsetti, Dedola, and Leduc (2006 and forthcoming), Enders and Muller (2009), Enders, Muller, and Scholl (2011), and Juvenal (2011). However, none of these studies make a distinction between news and contemporaneous productivity shocks. Our paper complements theirs and the

[1] For instance, see Cole and Obstfeld (1991) and Corsetti, Dedola, and Leduc (2008), among others.

[2] For instance, see Barsky and Sims (2011), Beaudry and Portier (2004, 2006, and 2007), Cochrane (1994), Fujiwara, Hirose, and Shintani (2011), Jaimovich and Rebelo (2009), and Schmitt-Grohé and Uribe (2012), among others.

[3] Schmitt-Grohé and Uribe (2012) estimate a dynamic stochastic general equilibrium model by applying Bayesian and classical likelihood-based methods. They find that anticipated components of various structural shocks all together explain almost 50% of the variances of US consumption, investment, output, and hours. In their baseline shock specification, news TFP shocks are found to play a minor role. However, in a parsimonious shock specification, news TFP shocks are a major source of US aggregate fluctuations.

findings in this paper also shed light on some puzzling results in these previous studies.

Furthermore, we examine the relative importance of US news and contemporaneous TFP shocks in accounting for US real exchange rate movements. This is motivated by previous studies suggesting that exchange rates behave like asset prices and exchange rate movements are more linked to changes in future fundamentals rather than current ones, for instance, Engel and West (2005) and Chen, Rogoff, and Rossi (2010), among others. Although some empirical work studies the link between future productivity and asset prices (e.g., stock prices and interest rates), no study has been done to examine whether and to what extent exchange rates are influenced by news about future productivity.[4] Our work also fills this gap in the literature.

We achieve the above goals in three dimensions. First, we identify news and contemporaneous shocks to US TFP in the SVAR framework by employing a method proposed by Barsky and Sims (2011), and then study the international transmissions of these two TFP shocks. We also investigate the relative importance of these two shocks in explaining US real exchange rate movements. Second, using our estimated VAR impulse responses, we estimate and evaluate a standard international macroeconomic model that is augmented with news TFP shocks and also shares many features with existing models used in the literature. Last but not least, we check the robustness of our empirical findings from Barksy and Sims' method, using an alternative identification scheme – the sign restrictions method. This exercise also facilitates a comparison between our results and other related empirical studies that employ the sign restrictions method.

Our study uses quarterly data for the US and an aggregate of the rest of G7, which is referred to as the rest of the world (ROW). Our VAR models include US TFP, US trade variables, and the US-ROW differences of the other aggregate variables including the real exchange rate and the terms of trade. News and contemporaneous US-specific TFP shocks in such VAR models are identified by employing Barsky and Sims' (2011) identification scheme. Then, we investigate the international transmission of these two identified shocks by examining their estimated impulse response functions (IRFs).

One of our main findings is that the US real exchange rate exhibits substantially different dynamics in response to the identified news and contemporaneous shocks to US TFP. Following a favorable news TFP shock, the real exchange rate appreciates strongly on impact and continues to appreciate for a few quarters before starting to converge back to its initial level. The real appreciation following the positive news TFP shock is very persistent, lasting for more than 16 quarters. We define the exchange rate such that a decrease

[4] Fama (1990) and Schwert (1990) find that stock returns are highly correlated with future production growth rates. More recently, Beaudry and Portier (2006) find that stock price movements capture well news about future productivity. Kurmann and Otrok (forthcoming) document that movements in the slope of the term structure of interest rates mainly reflect the asset market's response to news about future productivity.

indicates an appreciation. Under this definition, the IRF of the real exchange rate to a favorable news TFP shock resembles a horizontal J-curve. In contrast, the real exchange rate exhibits a hump-shaped impulse response to a favorable contemporaneous TFP shock: it slightly drops below zero (appreciates) or barely moves on impact of the shock, but quickly increases above zero (depreciates) and remains significantly depreciated for more than 12 quarters before converging back to its initial level. We will take the above dynamics of the real exchange rate as a key criterion when evaluating standard international business cycle models, which will be discussed shortly.

We find that both news and contemporaneous TFP shocks generate co-movement among US-ROW relative macroeconomic aggregates though the dynamics of the aggregates are different under these two shocks. A favorable news shock induces an expectation-driven boom as documented in Beaudry and Portier (2006) and Beaudry, Nam, and Wang (2011), while a favorable contemporaneous shock leads to an economic boom as predicted by standard international macroeconomic models. Following a positive news TFP shock, US TFP increases with a delay of more than one year. US-ROW relative consumption, investment, GDP, and hours all rise substantially and peak before US TFP starts to increase significantly, with the sharp increase in relative consumption leading the increases in relative investment, GDP, and hours. On the other hand, following a positive contemporaneous TFP shock, US TFP increases immediately and then declines gradually over time. US-ROW relative consumption, investment, and GDP all increase immediately and these increases are persistent. US-ROW relative hours exhibit a hump-shaped response following the shock.

We also study the effects of news and contemporaneous TFP shocks on US trade variables and want to highlight three findings. First, the terms of trade has similar dynamics to the real exchange rate: it exhibits a horizontally J-shaped response to a positive news TFP shock, while it displays a hump-shaped response to a positive contemporaneous TFP shock. Second, the dynamics of real exports and real imports are distinct for news and contemporaneous TFP shocks, reflecting different dynamics of domestic absorption and the terms of trade following these two shocks. Third, the trade balance (measured by the ratio of nominal net exports to nominal GDP) exhibits a well-known J-curve following both news and contemporaneous TFP shocks. However, the dynamics of the J-curve are quite distinct for these two TFP shocks.

More specifically, following a favorable news shock to US TFP, US real imports increase strongly on impact of the shock, reflecting an immediate and sharp increase in US domestic consumption relative to the ROW. Then, real imports continue to rise and peak after around 7 quarters, driven by the subsequent rise in US domestic investment. Such increases in US domestic absorption are supported by a strong appreciation of the US terms of trade following the news TFP shock. US real exports also rise on impact of the shock, but return to zero quickly. Then, real exports start to bounce back and stay significantly above zero persistently,

reflecting increases in US exports caused by two factors: the depreciation of the US terms of trade after its initial appreciation and the materialization of the expected increase in US TFP. Due to the described dynamics of real exports, real imports, and the terms of trade, the US trade balance exhibits a very persistent J-curve with a delayed response: it deteriorates significantly after several quarters following the shock, but improves over time with the increase in real exports and the decrease in real imports. This J-curve pattern of the response of the trade balance is also documented in previous studies (e.g., Enders and Muller, 2009 and Corsetti, Dedola and Leduc, forthcoming). However, we find that both real imports and real exports contribute significantly to the dynamics of the trade balance following the news TFP shock. Results are mixed in previous studies that do not make a distinction between news and contemporaneous TFP shocks.[5]

The US trade balance also exhibits a J-curve following a favorable contemporaneous TFP shock. But, the contemporaneous TFP shock leads to an immediate deterioration of the trade balance and a short-lived J-curve relative to that induced by the news TFP shock. Following a favorable contemporaneous TFP shock, US real exports increase strongly over time, reflecting the persistent depreciation of the US terms of trade in response to the contemporaneous TFP shock and an immediate increase in US TFP. US real imports also increase following the shock and peak after 10 quarters.

The different dynamics of international relative prices and trade variables following news and contemporaneous TFP shocks demonstrate the importance of separating these two shocks when studying the international transmission of TFP changes.

We also find that news TFP shocks are more important than contemporaneous TFP shocks in explaining the volatility of the US real exchange rate. The identified news TFP shocks explain about 30% of the forecast error variance of the US real exchange rate at most horizons up to 40 quarters. In contrast, the identified contemporaneous TFP shocks only account for less than 10%. This finding suggests that anticipated future changes in TFP, rather than unanticipated current changes, drive the US real exchange rate, lending support to the studies of exchange rates as asset prices.

Next, we evaluate a group of standard international business cycle models (e.g., Chari, Kehoe, and McGrattan, 2002) for their empirical success, in particular on the dynamics of the real exchange rate our VAR study documents. We consider an international macroeconomic model sharing many features with other existing models and augmented with news TFP shocks. The model is estimated by minimizing the distance between the impulse responses of our empirical VAR and theoretical model. Our estimation results indicate that the standard international business cycle models fail to replicate, both qualitatively and quantitatively,

[5]For instance, Corsetti, Dedola, and Leduc (forthcoming) find that real exports do not make any significant contribution to the dynamics of the trade balance following their identified productivity shock.

the documented real exchange rate dynamics following a news/contemporaneous TFP shock, although the models can match the dynamics of other variables (e.g., relative consumption, investment, GDP) in the data relatively well.

After a seminal theoretical study by Corsetti, Dedola, and Leduc (2008), it is now a well-known model prediction that when the trade price elasticity is sufficiently low and the international financial markets are incomplete, the real exchange rate appreciates rather than depreciates following a positive home productivity shock. Consistent with such a model prediction, our estimation results show that a low trade price elasticity is required for our theoretical model to match the real appreciation in the data following a positive news TFP shock. However, the model still fails to replicate the horizontally J-shaped response of the real exchange rate in the data. In addition, the model with a low trade price elasticity cannot generate the observed depreciation of the real exchange rate following a positive contemporaneous TFP shock. Thus, our empirical findings and theoretical investigations pose challenges to existing international business cycle models for exchange rates and also provide empirical guidance to future studies of theoretical modeling.

In the last part of the paper, we check the robustness of our empirical findings under Barsky and Sims' (2011) method, by employing an alternative identification scheme, the sign restrictions method, to identify news and contemporaneous TFP shocks. The sign restrictions are derived from our international business cycle model and also consistent with previous empirical studies. We find that our benchmark identification strategy of Barsky and Sims' (2011) method and our sign restrictions scheme yield very similar results and complement each other. In addition, the results of our robustness check now facilitate the understanding of some puzzling results in previous empirical studies on the international transmission of US productivity shocks, which also use the sign restrictions method.

The remainder of the paper is organized in four sections. In Section 2, we describe our benchmark identification strategy and our data set. Then we present our results on the international transmission of news and contemporaneous shocks to US TFP, focusing on their effects on international relative prices and trade. Section 3 presents an international business cycle model and discusses the model estimation results. Section 4 conducts robustness checks on our empirical findings presented in Section 2, using the sign restrictions method. This section also discusses other related studies. Section 5 concludes.

2 International Transmission of TFP Shocks

2.1 Identification Strategy, Data, and Benchmark VAR Model

We identify news and contemporaneous shocks to US TFP in our VAR models, following Barsky and Sims (2011). Their identification scheme assumes that news and contemporaneous shocks to TFP fully explain variation in observed TFP. Under this assumption, contemporaneous TFP shocks are identified as reduced-form innovations in TFP. News TFP shocks are restricted to have no immediate impact on TFP and also to be orthogonal to the contemporaneous shocks. Given these restrictions and the contribution of the contemporaneous shocks to variation in TFP, news TFP shocks are identified as a structural shock that can account for TFP variation as much as possible over all forecast horizons up to a truncation horizon.[6] We leave the details on this identification strategy to the appendix.

We use quarterly data for the US and the rest of the G7 countries over the post-Bretton Woods period from 1973:Q1 to 2010:Q4. The other G7 countries include Canada, France, Germany, Italy, Japan, and the UK, which are used to represent the rest of the world (ROW). The ROW series are constructed by aggregating these countries' quarterly growth rates weighted by each country's GDP share in the group's total GDP. Then the ROW series are used to obtain the US-ROW relative series. Most data are taken from the OECD, IMF, US Bureau of Labor Statistics (BLS), and US Bureau of Economic Analysis (BEA), among others. Details about the data sources can be found in the appendix.

As in Barsky and Sims (2011), our measure of US TFP is the US quarterly factor-utilization-adjusted TFP series provided in Fernald (2009).[7] This TFP series is adjusted for capital utilization and labor effort, which is crucial for Barsky and Sims' identification scheme. Barsky and Sims (2011) impose the restriction that news TFP shocks have no immediate impact on TFP. If measured TFP is not adjusted for factor utilization, this restriction is no longer valid. For instance, Jaimovich and Rebelo (2009) and Nam and Wang (2010a) show in their theoretical models that capital utilization changes immediately in response to news TFP shocks. As a result, TFP measures that are not adjusted for capital utilization change immediately following news TFP shocks. In addition, Barsky and Sims (2011) assume that all variation in observed TFP is only driven by news and contemporaneous TFP shocks. This assumption is unlikely to hold for the non-adjusted TFP series, since other structural shocks can also affect variation in non-adjusted TFP through their effects on

[6] As in Barsky and Sims (2011), the truncation horizon H is set equal to 40 quarters. Our results are robust to other choices of H.

[7] The factor-utilization-adjusted TFP series is obtained from John Fernald's website. The original series is provided in terms of annualized percentage changes (i.e., 400 times changes in its logarithm). The quarterly TFP series in levels is recovered by dividing the original series by 400 and then cumulating the resulting series. See Fernald (2009) for more details on this TFP series.

factor utilization.

Factor-utilization-adjusted TFP is not available for the ROW, so we only use US TFP in our VAR models rather than US-ROW relative TFP.[8] This practice is not uncommon in the literature. Besides US TFP, our VAR models include US-ROW relative variables of GDP, consumption, investment, and hours worked. US real GDP, real personal consumption expenditures of nondurable goods and services, and real gross private domestic investment serve as our measures of US GDP, consumption, and investment, respectively. They are obtained from the BEA and the corresponding data for the ROW are taken from OECD Main Economic Indicators and Economic Outlook as well as national statistics agencies in some countries. Our measure of US hours worked is total hours worked in the business sector taken from the BLS. The ROW hours worked series is constructed from hours worked in the total economy that are obtained from OECD Economic Outlook. Our study also considers the US-ROW relative nominal interest rate and annualized CPI inflation. The US nominal interest rate is measured by the effective federal funds rate in the Federal Reserve database. Nominal interest rates of the other G7 countries are measured by the short-term interest rates obtained from the IMF. The US CPI is from the BLS and the ROW CPI is constructed from the other G7 countries' CPI series obtained from the OECD and national statistics agencies in some countries.

We use two measures of international relative prices between the US and the ROW: the US real exchange rate and the US terms of trade. The real exchange rate is measured by the ROW CPI in the US dollar divided by the US CPI. As a result, an increase in the real exchange rate indicates a real US-dollar depreciation. To obtain our real exchange rate series, we first calculate the bilateral real exchange rates between the US and the other G7 countries using the CPIs and bilateral nominal exchange rates. Then the bilateral real exchange rates are aggregated to obtain the US real exchange rate. Similarly, the US terms of trade is calculated using bilateral nominal exchange rates and export deflators for the US and the other G7 countries obtained from the OECD, so our measure of the terms of trade is a proxy for the international relative prices of traded goods. The bilateral nominal exchange rates between the US and the rest of the G7 countries, which are used to calculate the US real exchange rate and terms of trade, are taken from the International Financial Statistics (IFS) of the IMF. The exchange rates of euro-zone countries after 1999 are replaced with the dollar-euro exchange rate.

Finally, three US trade variables are also used. US real exports and real imports are obtained from the BEA, and the US trade balance is measured by the ratio of nominal net exports to nominal GDP. In sum, our data include four US-specific variables (US TFP, real exports, real imports, and the trade balance), six

[8] In using US TFP rather than US-ROW relative TFP, a specific concern is that the shocks we identify could contain both US-specific and global components. This issue will be discussed in more detail in the next subsection.

US-ROW relative variables (US-ROW relative GDP, consumption, investment, hours, nominal interest rate, and CPI inflation), and two relative price variables between the US and the ROW (the US real exchange rate and terms of trade).

In our benchmark VAR model, we include the following six variables: US TFP, US-ROW relative consumption, investment, GDP, hours worked, and the US real exchange rate.[9] When we study the effects of two TFP shocks on three US trade variables and the US terms of trade, we consider seven-variable VAR systems. In these systems, the real exchange rate in the benchmark system is replaced with the terms of trade and one of the three trade variables is added to the VAR system. Larger VAR models are also considered in the section of robustness checks.

2.2 Effects of Surprise and Anticipated TFP Shocks on International Prices

In this subsection, we present the impulse response functions (IRFs) to identified news and contemporaneous US TFP shocks in our benchmark VAR model. We analyze them to study the international transmission of these two TFP shocks, focusing on the dynamics of the real exchange rate. The results show that the US real exchange rate exhibits substantially different dynamics following news and contemporaneous TFP shocks.

In Figure 1, the left and right panels display the estimated IRFs to favorable news and contemporaneous TFP shocks, respectively.[10] We rely on the Bayesian approach with 1,000 draws for our statistical inference. The line with circles is the median response and the gray area between the two starred lines represents the confidence interval with the 16th and 84th quantiles.

Following a favorable news shock, US TFP increases, but with a delay. Indeed, its IRF remains statistically insignificant in the first 6 quarters. US consumption relative to the ROW increases sharply on impact of the shock. Relative investment, GDP, and hours do not respond as strongly as relative consumption on impact of the shock, but all of them rise quickly in subsequent periods and peak before US TFP starts to increase significantly. These response patterns are consistent with the idea of news-driven economic booms: a favorable news shock to US TFP induces a generalized economic boom in the US relative to the ROW, with consumption leading investment, GDP, and hours. Jaimovich and Rebelo (2009) show that a positive news TFP shock can generate such a generalized boom across the economy in a model with investment adjustment costs, variable capital utilization, and preferences minimizing the wealth effect on labor supply.

[9] All variables enter the benchmark VAR system in log levels, and a constant and four lags are also included. This specification is also applied to other VAR systems we consider. Our results are robust to different numbers of lags.

[10] It is worthwhile to note that the sum of the forecast error variances of TFP attributable to our identified news and contemporaneous TFP shocks at all horizons up to 40 quarters is almost 90%, which validates the identification assumption that observed TFP is only driven by these two TFP shocks. See Table 1.

On impact of a favorable contemporaneous shock, US TFP increases immediately by construction and the data suggest that this increase is very persistent. Relative consumption, investment, and GDP also increase instantly. But the impact increase in relative consumption is not as strong as that following the favorable news shock. The increases in relative consumption, investment, and GDP are also quite persistent, lasting until the 16th quarter or so. Relative hours barely move for the first few quarters, but increase gradually in the following periods and eventually converge back to their initial level. Overall, a favorable contemporaneous TFP shock in the US induces an immediate, persistent economic boom in the US relative to the ROW, as predicted by standard international macroeconomic models. However, the dynamics of relative macro aggregates in such an economic boom are quite distinct from those in the economic boom driven by a favorable news shock as we have described previously.[11]

The most striking observation is that news and contemporaneous TFP shocks induce substantially different dynamics for the US real exchange rate. The IRF of the US real exchange rate is presented in the last chart of each panel. The real exchange rate decreases (appreciates) strongly on impact of a positive news TFP shock and continues to decrease for a few quarters before starting to converge back to its initial level. The real appreciation following a positive news TFP shock is very persistent, lasting for about 16 quarters. In contrast, the real exchange rate only falls (appreciates) slightly on impact of a positive contemporaneous TFP shock. It then rises above zero significantly and peaks at around the 9th quarter before gradually reverting back to its initial level. The real depreciation following a positive contemporaneous TFP shock is also persistent, lasting for around 12 quarters. In a nutshell, while the real exchange rate displays a persistent J-curve shaped impulse response to a favorable news shock, it exhibits a hump-shaped impulse response following a favorable contemporaneous shock.

The persistent real appreciation following a favorable news TFP shock could be caused by an increase in nontraded goods prices relative to traded goods prices, that is, the Balassa-Samuelson effect. However, when we replace the real exchange rate with the terms of trade in our benchmark model (and in other exercises), the estimated impulse responses of the terms of trade to both news and contemporaneous TFP shocks are very similar to those of the real exchange rate (see Figure 2). This finding suggests that our results for the real exchange rate are not mainly driven by the Balassa-Samuelson effect.

The US real exchange rate also exhibits delayed overshooting in response to both news and contemporaneous TFP shocks: the real exchange rate continues to appreciate following a favorable news shock or

[11] We use US TFP instead of US-ROW relative TFP in our VAR models. Therefore, the identified shock to US TFP could contain both US-specific and global components. However, US-ROW relative variables in our VAR models respond strongly to the identified (news or contemporaneous) TFP shock, indicating we are likely to pick up a US-specific component. We will revisit this issue in Section 4 when employing an alternative identification scheme (i.e., the sign restrictions method) for the robustness check.

to depreciate following a favorable contemporaneous shock for several quarters before starting to converge back to its initial state. Note that the maximum real appreciation occurs 4 quarters after a positive news TFP shock, and the maximum real depreciation occurs 9 quarters after a positive contemporaneous TFP shock. Delayed overshooting of the real exchange rate following productivity shocks is also found in previous empirical studies. For instance, see Corsetti, Dedola, and Leduc (2006 and forthcoming), Enders and Muller (2009), and Enders, Muller, and Scholl (2011). We will compare our results with theirs in Section 4.

Exchange rate movements will affect trade adjustment and also induce important cross-country wealth effects. Therefore, an important question is whether existing open economy macroeconomic models can replicate the dynamics of the real exchange rate in the data. In Section 3, we will assess if a standard international macroeconomic model can replicate the estimated IRFs of the real exchange rate following news and contemporaneous TFP shocks.

2.3 Effects of Surprise and Anticipated TFP Shocks on Trade

This subsection studies the dynamics of real exports, real imports, the trade balance, and the terms of trade following news and contemporaneous TFP shocks. Such dynamics help us understand the international transmission of these two TFP shocks through the trade and cross-country wealth effects. In particular, we find that the trade balance exhibits a well-known J-curve following both news and contemporaneous TFP shocks. However, the dynamics of the J-curve are quite distinct for these two TFP shocks. News TFP shocks induce a delayed deterioration of the trade balance and a very persistent J-curve, while contemporaneous TFP shocks lead to an immediate deterioration of the trade balance and a short-lived J-curve. Such a difference reflects different responses of the terms of trade, real exports, and real imports following news and contemporaneous TFP shocks. In addition, we link our findings to another well-documented feature in the data: the S-shaped cross-correlation function for the terms of trade and the trade balance.

2.3.1 Dynamics of Trade Variables and the Terms of Trade

We replace the US real exchange rate in our benchmark six-variable VAR model with the US terms of trade. In addition, we add one of the following three trade variables to the system: the US trade balance (nominal net exports divided by nominal GDP), real exports, and real imports. Then news and contemporaneous TFP shocks are identified in these seven-variable VAR models.

Figure 2 displays the IRFs of the terms of trade (TOT), the trade balance, real exports, and real imports to the identified news and contemporaneous TFP shocks in the seven-variable VAR models.[12] The IRFs of

[12]The reported IRF of the terms of trade is estimated in the seven-variable system with the terms of trade and the trade

the other five variables in these VAR models remain qualitatively and quantitatively similar to those in the benchmark VAR model and are not reported to save space.

We first highlight two results in Figure 2. First, the dynamics of the US TOT in response to news and contemporaneous shocks are similar to those of the US real exchange rate (see Figure 1). Following a favorable news TFP shock, the TOT appreciates strongly on impact, and continues to appreciate for a few quarters before it converges gradually back to its initial level. Following a favorable contemporaneous TFP shock, the TOT appreciates slightly on impact, but quickly rises above zero and remains significantly depreciated for almost 4 years before it converges back to its initial level. This finding suggests that our results for the real exchange rate are unlikely to be mainly driven by the Balassa-Samuelson effect.

Second, the US trade balance, which is measured by nominal net exports to nominal GDP, displays a more delayed and persistent J-curve following a positive news TFP shock than following a positive contemporaneous TFP shock. Both the terms of trade and trade quantities (real exports and real imports) contribute to this difference. On impact of a positive news TFP shock, real imports increase immediately and strongly. They continue to rise in the following periods while real exports decline, indicating a substantial fall in real net exports. However, the trade balance does not deteriorate until the 5th quarter because the TOT appreciates substantially following the news shock. The valuation effect from the TOT helps to stabilize the trade balance.

In contrast, the trade balance deteriorates immediately following a positive contemporaneous TFP shock. Note that real net exports do not change much in the first 10 quarters following the shock since the responses of real exports and real imports almost offset each other. The immediate deterioration of the trade balance is mainly due to the deterioration of the TOT. Therefore, TOT movements contribute greatly to the short-run dynamics of the trade balance in this way: they stabilize the trade balance following news TFP shocks, but destabilize it following contemporaneous TFP shocks. This result illustrates the importance of distinguishing news and contemporaneous TFP shocks in understanding trade dynamics.

In the medium and long run, the difference in the persistence of the J-curve is also attributable to the distinct dynamics of real exports and real imports following these shocks. For both news and contemporaneous TFP shocks, the trade balance eventually converges back to its initial level with an increase in real exports and a decrease in real imports. But the trade balance returns to zero more slowly following a news TFP shock than following a contemporaneous TFP shock. Note that the trade balance remains under zero even 40 quarters after the news shock, while it has already converged back to zero in the 20th quarter following the contemporaneous shock. The slow convergence of the trade balance following a news shock

balance. Other seven-variable systems have similar results for the IRF of the terms of trade.

is associated with a very persistent increase in real imports, which keeps the trade balance in deficit for a prolonged period. The trade balance converges to zero more quickly following a contemporaneous shock due to a quick and substantial increase in real exports, which helps to close the trade deficit. Note that following the news shock, real imports are significantly above zero even after 40 quarters and following the contemporaneous shock, real exports peak at a level significantly above zero after around 20 quarters. These timings are consistent with the timing of the trade balance as we have just mentioned above.

Now, we connect the results of trade variables and the TOT in Figure 2 to the dynamics of the other aggregate variables shown in Figure 1. We focus our discussion on the median response of each variable. On impact of a favorable news shock, US real imports increase sharply by 1%. They continue to increase and peak at 2.5% at around the 7th quarter, before starting to decline gradually. Even after 40 quarters, real imports still remain above 1%, a level similar to their initial increase on impact of the shock. Such dynamics of US real imports are due to the movements of US domestic absorption relative to the ROW (see Figure 1). The initial jump in US real imports reflects an immediate, strong increase in US consumption relative to the ROW following a positive news shock. The gradual increase in US consumption and investment relative to the ROW in the following 6 quarters results in a continuous increase in US real imports until the 7th quarter. The increase in US consumption and investment relative to the ROW is likely caused by the wealth effect of good news about future US TFP. Moreover, the strong appreciation of the US TOT following a positive news shock amplifies the wealth effect in favor of the US as the appreciation increases the relative value of US output.

Following a favorable news shock, US real exports increase for the first 2 quarters, but quickly fall back to their initial level in the next 10 quarters. Then they start to bounce back and remain at 1% even after 40 quarters. The increase in US real exports after the 12th quarter is linked to two factors. First, the US TOT starts to rise (deteriorate) in the 4th quarter following its initial strong appreciation and the deterioration of the TOT helps boost US exports. Second, US TFP increases after 6 quarters following a positive news shock and peaks around the 12th quarter (see Figure 1). The increase in US TFP reflects the materialization of the positive news shock and promotes US exports.

The above dynamics of trade aggregates and the TOT suggest the following mechanism for the international transmission of news TFP shocks. In response to good news about future TFP in the US, the US first increases its domestic consumption immediately and sharply, followed by a gradual increase in its domestic investment relative to the ROW, which results in a substantial and persistent increase in US real imports. The US TOT also helps this process by inducing a positive wealth effect for the US. After the anticipated technology improvement in the US materializes and the US builds up its capital stock, the US significantly

exports more to the ROW, and the TOT now induces a wealth effect in favor of the ROW relative to the US.

Finally, we examine the effects of contemporaneous TFP shocks on US trade and link them to the dynamics of the other macro aggregates. Following a favorable contemporaneous shock, US real exports stay around their impact response level of 0.4% in the first 6 quarters. Then they rise substantially and peak at 1.7% after about 20 quarters. The increase in US real exports is very persistent: it remains at almost 1.2% even after 40 quarters. Such a substantial and persistent increase in US real exports is associated with the persistent depreciation of the US TOT following the contemporaneous TFP shock. In contrast, US real imports peak much earlier: they increase quickly and peak at 1% only after 10 quarters. The dynamics of US real imports reflect the response of US domestic absorption relative to the ROW: following a favorable contemporaneous TFP shock, US consumption and investment both peak after around 10 quarters (see Figure 1).

These dynamics are consistent with the international transmission of country-specific contemporaneous productivity shocks in standard international macroeconomic models. With an immediate increase in US TFP, the US produces more goods relative to the ROW. As a result, the relative price of US goods falls (i.e., the US TOT deteriorates), which causes an increase in US real exports. At the same time, the US consumes more and also increases its domestic investment to build up the capital stock, leading to an increase in US real imports. The US trade balance deteriorates initially since the deterioration of the US TOT makes US imports more expensive than exports. However, once the buildup of capital stock is completed, the US can export more than before to the ROW and the US trade balance improves.

2.3.2 The S-shaped Cross-correlation for Terms of Trade and Trade Balance

The cross-correlation function (CCF) for the TOT and the trade balance displays a horizontally S-shaped pattern in the data and also in standard international business cycle models. For instance, Backus, Kehoe, and Kydland (1994) document the S-curve in the OECD data and replicate this empirical finding in a two-country international business cycle model. Senhadji (1998) documents the S-curve in the data of less developed countries and finds that a small-open-economy model can replicate the pattern. More recently, Enders and Muller (2009) emphasize that a model with incomplete international financial markets and low trade elasticity can also replicate the S-curve well and such a model matches the international transmission mechanism of technology shocks documented in their SVAR study better than standard international macro models.

All of the above studies only consider contemporaneous technology shocks. In Section 2.3.1, we doc-

umented that (1) the TOT displays substantially different dynamics following news and contemporaneous TFP shocks and (2) the dynamics of the trade balance in response to these two TFP shocks are also quite distinct even if the overall pattern resembles the J-curve for both TFP shocks. It is likely in this case that news and contemporaneous TFP shocks can induce substantially different patterns of the CCFs for the TOT and the trade balance. In this section, we compare the CCFs of the TOT and the trade balance conditional on our identified news and contemporaneous TFP shocks. We find that both TFP shocks indeed induce similar S-shaped CCFs, which suggests that distinct international transmission mechanisms under two TFP shocks square with the S-shaped CCF in previous studies. However, the news shocks may contribute more to the S-curve in the data since the unconditional CCF in the data traces more closely with the CCF conditional on news shocks than on contemporaneous shocks.

We calculate the conditional CCFs of the terms of trade (TOT_t) and the trade balance (TB_{t+k}) for k ranging from -16 to $+16$ quarters, using the counterfactual series. The counterfactual series are fitted values of our estimated VAR model conditional on the identified news or contemporaneous TFP shocks, or both.[13] We also compute the CCF in the actual data, which is called the unconditional CCF. Before we calculate these conditional and unconditional CCFs, all (counterfactual and actual) series are filtered with the band pass filter, whose frequencies are set between 6 and 32 quarters. In a similar way, we also calculate the conditional and unconditional CCFs of the terms of trade (TOT_t) with real exports (EX_{t+k}) and real imports (IM_{t+k}).

Figure 3 presents our CCF results. The left, middle, and right panels show the CCFs of the TOT with the trade balance, real exports, and real imports, respectively. In each panel, the top, middle, and bottom charts are conditional on news shocks, contemporaneous shocks, and both shocks, respectively. In each chart, the line with circles is the median CCF and the gray area between the two starred lines represents the confidence interval with the 16th and 84th quantiles. For the purpose of comparison, the unconditional CCF calculated from the actual data is also plotted in these charts (the red line with diamonds). In the left panel of Figure 3, the unconditional CCF for the TOT and the trade balance in our data displays a horizontally S-shaped pattern as documented in other studies (e.g., Backus, Kehoe, and Kydland, 1994), indicating that the current TOT is positively correlated with the future trade balance, but negatively correlated with the past trade balance. The CCFs conditional on the identified news and contemporaneous TFP shocks also have a similar S-curve.

Although the conditional CCF is S-shaped for both news and contemporaneous TFP shocks, the under-

[13] To obtain the counterfactual series, we first identify news and contemporaneous TFP shocks in our seven-variable VAR model with the terms of trade and the trade balance (i.e., the case for their IRFs shown in Figure 2). Then, we simulate the estimated VAR model with the series of the identified news or contemporaneous shocks, or both.

lying mechanism for such a pattern is quite different, as documented in Section 2.3.1. Following a positive news TFP shock, the TOT falls strongly on impact, but the trade balance decreases only gradually with a delay. In other words, a decline in today's TOT is followed by a decrease in the future trade balance, which indicates a positive correlation between the current TOT and the future trade balance. In contrast, it is an increase in the TOT and the following increase in the trade balance that contribute to the positive correlation between the current TOT and the future trade balance conditional on contemporaneous TFP shocks. Note that following a positive contemporaneous TFP shock, the TOT depreciates (increases) quickly after its slight appreciation on impact of the shock and peaks in the 5th quarter. Such a depreciation is followed by an improvement of the trade balance that starts in the 8th quarter after its initial deterioration.

Comparing between news and contemporaneous TFP shocks, the CCF conditional on news TFP shocks traces the unconditional CCF in the actual data better. In addition, the CCF conditional on both TFP shocks in the bottom chart suggests that other structural shocks, besides two TFP shocks, also affect business cycle fluctuations in the TOT and the trade balance since the median CCF conditional on both TFP shocks deviates from the unconditional CCF by a large margin.

The middle and right panels of Figure 3 show the CCFs of the TOT with real exports and real imports, respectively. For real exports, the CCF resembles an S-curve conditional on news or contemporaneous TFP shocks, which is consistent with the data. As for the trade balance, the underlying mechanism of this S-curve, however, is different for news and contemporaneous TFP shocks. As shown in Figure 2, the positive conditional correlation between the current TOT and future real exports is due to the fact that: (1) following a positive news shock, the TOT falls sharply on impact, which is followed by a gradual decline in real exports in the first 12 quarters; (2) following a positive contemporaneous shock, the TOT continues to increase until the 5th quarter, which is followed by a gradual increase in real exports between quarter 5 and 20.

For real imports, the CCFs display a reversed S-shaped pattern, indicating that the current TOT is negatively correlated with future real imports, but positively correlated with past real imports.[14] Again, the mechanism for such a reversed S-shaped pattern is different for news and contemporaneous TFP shocks. Following a positive news shock, the impact decrease (appreciation) in the TOT is followed by a continuous increase in real imports in the first 8 quarters, indicating that the current TOT and future real imports are negatively correlated. Following a positive contemporaneous shock, the TOT remains around its peak between quarter 5 and quarter 10. The real imports start to decline in the 10th quarter after their initial

[14] In the data, the contemporaneous correlation between the TOT (TOT_t) and real imports (IM_t) is slightly negative, but almost zero. The corresponding correlation conditional on news TFP shocks is strongly negative while the correlation conditional on contemporaneous TFP shocks is strongly positive. In particular, the CCF conditional on both TFP shocks in the bottom chart traces the unconditional CCF much better than the CCF conditional on either news or contemporaneous TFP shocks.

increase, which suggests a negative correlation between the current TOT and future real imports.

2.4 Importance of Anticipated TFP Shocks on Exchange Rate Movements

This subsection examines the relative importance of our identified news and contemporaneous TFP shocks in accounting for US real exchange rate movements. Along with the forecast error variance (FEV) decomposition, a series of exercises using our counterfactual data suggest that news TFP shocks play a more important role than contemporaneous TFP shocks in explaining US real exchange rate movements.

Table 1 reports the FEVs of the six variables in our benchmark VAR model at various horizons. The left and middle panels of the table are the shares of the FEV attributable to the identified news and contemporaneous TFP shocks, respectively, and the right panel shows the sum of these two shares. The FEV decomposition results indicate that news TFP shocks are much more important than contemporaneous TFP shocks in explaining the FEV of the US real exchange rate at all horizons. The identified news TFP shocks explain about 30% of the FEV of the US real exchange rate at most horizons up to our truncation horizon (40 quarters). In contrast, the identified contemporaneous TFP shocks account for less than 10% of the FEV. This finding provides some empirical support to the argument that exchange rate volatility is mainly attributed to changes in expectations about future economic fundamentals rather than changes in current fundamentals (e.g., Engel and West, 2005).

In total, the identified news and contemporaneous TFP shocks together account for a large portion (about 40%) of the FEV of the US real exchange rate at horizons greater than 8 quarters. At horizons less than 4 quarters, however, TFP shocks explain only a small share (about 10% of the FEV) of US real exchange rate movements. This finding suggests that other structural shocks, such as demand, monetary policy, or financial market shocks, can make significant contributions to short-run fluctuations of the US real exchange rate. For instance, Clarida and Gali (1994) and Juvenal (2011) find that demand shocks explain a large portion of the variation in the US real exchange rate. Farrant and Peersman (2006) document that nominal shocks, such as monetary policy shocks, play an important role in explaining exchange rate fluctuations, although Faust and Rogers (2003) find a minor role of monetary policy shocks in exchange rate volatility. Engel and West (2010) find that most of the strength of the US dollar in 2008 and 2009 is mainly driven by changes in the risk premium.

In the right panel of Table 1, news and contemporaneous TFP shocks jointly account for almost 90% of the FEV of US TFP at all horizons, which validates the identification assumption that all variation in TFP is explained by these two structural shocks. In addition, two TFP shocks together contribute to over 80%

of the FEV of relative consumption, 30-40% of the FEVs of relative investment and hours, and 40-70% of the FEV of relative GDP at business cycle frequencies. Comparing the left and middle panels, however, we find that news TFP shocks make main contributions to the FEVs of these relative aggregate variables. In particular, news TFP shocks alone account for about 70% of the FEV of relative consumption at all horizons.

We further assess the relative importance of news and contemporaneous TFP shocks in driving business cycle fluctuations of the US real exchange rate in two additional exercises. Following Altig et al. (2011), we compute the ratio of the variance of the counterfactual series conditional on each identified TFP shock to the variance of the actual series after applying the band pass filter to the series.[15] Panel A of Table 2 reports the results for this business cycle variance decomposition. The contribution of the identified news TFP shocks to the variance of the US real exchange rate (30%) is much larger than that of the identified contemporaneous TFP shocks (11%), indicating that news shocks are more important than contemporaneous shocks for the business cycle volatility of the US real exchange rate. News TFP shocks also contribute more to business cycle fluctuations in US-ROW relative aggregates than contemporaneous TFP shocks. In particular, identified news TFP shocks explain 71% of the variance of relative consumption at business cycle frequencies, which is consistent with the FEV decomposition result in Table 1.

We also examine if the identified TFP shocks can replicate the observed relative volatilities in the data in terms of each variable's standard deviation relative to that of US-ROW relative GDP. Using the filtered actual and counterfactual data (conditional on each identified TFP shock), we compute relative standard deviations of variables in our benchmark VAR model. Panel B of Table 2 reports the results. Note that the numbers for relative GDP in the table are the standard deviations in levels, while entries for other variables are relative standard deviations. Interestingly, both news and contemporaneous TFP shocks replicate well the observed relative volatility in the data. Conditioning on either news or contemporaneous TFP shocks, the median relative standard deviation of each variable is close to that in the data.[16] Most relative standard deviations conditional on contemporaneous TFP shocks are larger than those conditional on news TFP shocks. This is because the standard deviation of US-ROW relative GDP is much smaller conditioning on contemporaneous TFP shocks (0.31%) than conditioning on news TFP shocks (0.58%), consistent with the business cycle variance decomposition result in Panel A.

Finally, we calculate the correlation between the US real exchange rate and US-ROW relative consumption in the data as well as conditional on identified news or contemporaneous TFP shocks, respectively. Panel C

[15] When applying the band pass filter, the frequencies are set between 6 and 32 quarters.

[16] The relative standard deviations in the data are in the confidence intervals of the counterfactual data with one exception. Conditioning on identified news TFP shocks, the relative standard deviation of US-ROW consumption is significantly larger than that in the data.

of Table 2 presents this correlation result. The real exchange rate and cross-country relative consumption are negatively correlated in our sample (-0.27), although standard international macroeconomic models predict a positive correlation. This finding confirms the well-known Backus-Smith puzzle in the literature. Recent studies on this puzzle include Corsetti, Dedola, and Leduc (2008), Raffo (2009), and Opazo (2006), among others. Conditional on identified news TFP shocks, the median correlation between the US real exchange rate and US-ROW relative consumption is -0.9 with the 16th and 84th quantiles of -0.97 and -0.64. Conditional on identified contemporaneous TFP shocks, the 16th and 84th quantiles are -0.52 and 0.62, respectively, with the median correlation of 0.12. Therefore, this finding suggests that news TFP shocks make a major contribution to the Backus-Smith puzzle in the data.

3 Evaluation of Standard International Macroeconomic Models

In this section, we introduce an international macroeconomic model that shares many features with existing models used for quantitative international business cycle studies and is augmented with news TFP shocks. To evaluate the ability of the model to replicate the international transmission of news and contemporaneous TFP shocks that we documented in the previous section, we estimate the model using our empirical impulse response functions in the benchmark VAR model. In what follows, we first describe the model and explain the estimation method, and then present our estimation results.

3.1 International Business Cycle Model and Estimation Strategy

We consider a standard two-country sticky-price dynamic stochastic general equilibrium (DSGE) model that is similar to models widely used in the international business cycle literature. For instance, see Chari, Kehoe, and McGrattan (2002), Kollmann (2002), and Enders, Muller, and Scholl (2011), among others. We briefly describe the model since it is standard.

There are two symmetric countries, home and foreign, and we focus on the home country side to describe the model. In the home country, households consume final goods C_t and supply labor L_t to domestic intermediate goods firms. Preferences of households are described by the lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \theta_t U\left(C_t, L_t\right),$$

where the functional form of the period utility function is:

$$U\left(C_t, L_t\right) = \frac{\left[\left(C_t\right)^{\gamma}\left(1-L_t\right)^{1-\gamma}\right]^{1-\sigma}}{1-\sigma},\ 0<\gamma<1;\ \sigma>0.$$

Following Schmitt-Grohé and Uribe (2003), we introduce an external endogenous discount factor in the lifetime utility, θ_t, which is defined as:

$$\theta_{t+1} = \beta\left(\widetilde{C}_t, \widetilde{L}_t\right)\theta_t \text{ for } t \geq 0 \text{ with } \theta_0 = 1;\ \beta\left(\widetilde{C}_t, \widetilde{L}_t\right) = \left(1+\psi\left[\left(\widetilde{C}_t\right)^{\gamma}\left(1-\widetilde{L}_t\right)^{1-\gamma}\right]\right)^{-1},$$

where $\widetilde{C}_t$ and $\widetilde{L}_t$ are the economy-wide average per capita consumption and labor supply, respectively, and the parameter $\psi > 0$ pins down the value of the discount factor in the steady state.[17] Households also own the capital stock K_t and rent it to domestic intermediate goods firms. We assume that it is costly to adjust the level of investment I_t, following Christiano et al. (2005). Furthermore, capital owners can adjust the rate of capital utilization denoted by u_t and a higher rate of capital utilization entails a faster rate of capital depreciation, following Schmitt-Grohé and Uribe (2012). Thus, the law of motion of capital is:

$$K_{t+1} = \left(1-\delta\left(u_t\right)\right)K_t + S\left(\frac{I_t}{I_{t-1}}\right)I_t,$$

where the functional forms of investment adjustment costs and the depreciation rate of capital are, respectively:

$$S\left(x\right) = \left(1-\frac{\kappa}{2}\left(x-1\right)^2\right) \text{ with } \kappa>0;\ \delta\left(u_t\right) = \delta_0 + \delta_1\left(u_t-1\right) + \frac{\delta_2}{2}\left(u_t-1\right)^2 \text{ with } \delta_0,\ \delta_1,\ \delta_2>0.$$

Regarding the international asset markets, home and foreign households can only trade nominal bonds that are denominated in the issuing country's currency and are zero in net supply.

There is a continuum of home intermediate goods firms indexed by $i \in [0,1]$. Each firm produces a variety of differentiated goods using capital and labor, according to:

$$y_t\left(i\right) = A_t\left(u_t K_t\left(i\right)\right)^{\varphi}\left(L_t\left(i\right)\right)^{1-\varphi},$$

where A_t is total factor productivity (TFP). Differentiated intermediate goods can be traded across countries

[17] We introduce the endogenous discount factor to induce stationarity, since we assume that the international asset markets are incomplete.

and are aggregated into a CES composite:

$$Y_{Ht} = \left(\int_0^1 y_t(i)^{\frac{\phi-1}{\phi}} di \right)^{\frac{\phi}{\phi-1}}.$$

We introduce price stickiness for intermediate goods *a lá* Calvo (1983). In each period, an individual firm re-optimizes its price with probability $1-\alpha$ by maximizing the expected discounted profits. Moreover, we consider two types of pricing currency in international trade: firms can set prices either in their own currency (producer currency pricing, or PCP) or in the importing country's currency (local currency pricing, or LCP).

Final goods are produced using the composites of home and foreign intermediate goods, according to:

$$Y_t = \left[\omega^{\frac{1}{\theta}} (Y_{Ht})^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} (Y_{Ft})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}},$$

where Y_{Ft} denotes the home demand for the composite of foreign intermediate goods. Final goods are only used for domestic consumption and investment. We assume that the final goods market is perfectly competitive with flexible prices.

The central bank follows a Taylor-rule type monetary policy rule:

$$\log\left(\frac{R_t}{\overline{R}}\right) = \Theta_i \log\left(\frac{R_{t-1}}{\overline{R}}\right) + (1-\Theta_i)\left(\Theta_\pi E_t\left[\log\left(\frac{\Pi_{t+1}}{\overline{\Pi}}\right)\right] + \Theta_y \log\left(\frac{GDP_t}{GDP_t^f}\right)\right),$$

where R_t is the gross nominal interest rate, $\Pi_t = \frac{P_t}{P_{t-1}}$ is the CPI inflation rate, $GDP_t = Y_{Ht} + Y_{Ht}^*$ is our measure of GDP, and GDP_t^f is the level of GDP under flexible prices. Note that P_t is the price of final goods and Y_{Ht}^* is the foreign demand for the composite of home intermediate goods. Variables with a bar denote the steady state values of the corresponding variables. Θ_i, Θ_π, and Θ_y denote the interest rate smoothing, inflation targeting, and output gap coefficients, respectively.

Following Ferrero, Gertler, and Svensson (2010), we assume that the logarithm of TFP (i.e., $a_t = \log(A_t)$) is a combination of two processes:

$$a_t = a_t^u - a_t^s, \tag{1}$$

with

$$a_t^u = \xi^u a_{t-1}^u + \varepsilon_t^c + \varepsilon_{t-p}^n \text{ and } a_t^s = \xi^s a_{t-1}^s + \varepsilon_{t-p}^n, \tag{2}$$

where $\xi^u > \xi^s$, and ε_{t-p}^n and ε_t^c are i.i.d. with zero means. First, ε_t^c only appears in the process of a_t^u and represents contemporaneous shocks to TFP, since it affects the current level of TFP (i.e., a_t) immediately

through a_t^u. Second, ε_{t-p}^n appears in the processes of both a_t^u and a_t^s and represents news shocks to TFP with an anticipation horizon of $p \geq 0$, since ε_{t-p}^n does not have any immediate impact on the current level of TFP. This is true even when $p = 0$. However, ε_{t-p}^n affects the future TFP level.

Under this setup, TFP follows an AR(1) process with its coefficient of ξ^u with respect to a contemporaneous shock, while TFP changes gradually in response to a news shock, depending on the sizes of ξ^u and ξ^s.[18] In particular, our modeling of news shocks is guided by our empirical VAR impulse response of US TFP to the identified news shock (see Figure 1) and other empirical studies on news TFP shocks (e.g., Beaudry and Portier, 2006 and Beaudry, Nam, and Wang, 2011).

Finally, we define the real exchange rate as:

$$Q_t = \frac{S_t P_t^*}{P_t},$$

where S_t is the nominal exchange rate as the home currency price of a unit of foreign currency and P_t^* is the price of final goods in the foreign country.

To estimate our model described above, we first partition the model parameters into two groups. The parameters in the first group are calibrated based on previous studies since their values are quite standard. All parameters in the second group are estimated using the empirical impulse responses from our benchmark six-variable VAR system (i.e., ones shown in Figure 1). Table 3 reports the calibrated parameter values. The risk aversion parameter (σ) is set equal to 2. The parameter for consumption weight in the period utility (γ) is calibrated such that the steady state value of hours worked is one-third and the parameter that determines the steady state discount factor (ψ) is chosen to have the discount factor of 0.99 in the steady state. The steady state value of the capital depreciation rate (δ_0) is set equal to 0.025, implying an annual depreciation rate of 10%. The parameter in capital utilization costs that governs the steady state level of the capital utilization rate (δ_1) is calibrated to ensure that it equals one in the steady state. The home bias parameter (ω) is set equal to 0.88, implying the import share in GDP is 12% in the steady state, and the capital share in the production function (φ) is 0.36. The elasticity of substitution between differentiated intermediate goods (ϕ) is set equal to 6, implying a profit margin of 20%.

We estimate all other model parameters in the second group by minimizing the distance between empirical VAR and theoretical model impulse responses, that is, the impulse response function matching estimation (IRFME). This estimation method has been increasingly used in the literature (e.g., Christiano et al., 2005, Iacoviello, 2005, Boivin and Giannoni, 2005, and Altig et al., 2011, among others). Let ζ denote a vector of

[18] The parameter ξ^u defines the persistence of contemporaneous TFP shocks. The parameter ξ^s governs the degree of diffusion of news TFP shocks, given the size of ξ^u.

the parameters to estimate. Then the IRFME estimate of ζ solves the following problem:

$$\min_{\zeta} \left(\widehat{M} - M(\zeta)\right)' W \left(\widehat{M} - M(\zeta)\right),$$

where $\widehat{M}$ is the vector of stacked empirical estimates of the VAR impulse responses, $M(\zeta)$ is the vector of stacked corresponding theoretical model impulse responses, and W is a weighting matrix. We include the first 21 elements of each impulse response function, excluding those that are zero by assumption, and set the weighting matrix equal to a diagonal matrix whose elements are equal to the inverse of the sample variances of the VAR impulse responses.

3.2 Estimation Results

We consider three cases when implementing the IRFME. As our benchmark case, the impulse responses to both news and contemporaneous TFP shocks are included in $\widehat{M}$. In this case, we try to match the impulse responses to both TFP shocks. In the other two cases, $\widehat{M}$ contains the impulse responses to either news or contemporaneous TFP shocks. Thus, Table 4 reports three sets of our estimation results for the model under the PCP case.[19] The estimation results for the LCP model are similar and thus not reported to save space.[20]

The parameter estimates in Table 4 are generally in line with previous studies. A very interesting finding is on the estimate of the trade price elasticity (θ). In our benchmark case where we try to match the IRFs to both news and contemporaneous TFP shocks, the estimate of the trade price elasticity is 1.19, which is close to the values commonly used in standard international business cycle models. For instance, Backus, Kehoe, and Kydland (1994) calibrate the trade price elasticity parameter to 1.5. Bergin (2006) estimates a two-country open economy macroeconomic model using the US and G7 data and the estimated trade elasticity is 1.13. Heathcote and Perri's (2002) estimate of this parameter is 0.9 when they try to match the real exchange rate and the trade balance in the data. In addition, if we only match the IRFs to contemporaneous TFP shocks in implementing the IRFME, the estimate of the trade price elasticity is 1.23, which is close to the one we get if we match the IRFs to both TFP shocks.

However, if we only match the IRFs to news TFP shocks, the estimate of θ is much lower: 0.28. This is very similar to the case of low trade price elasticity discussed in Corsetti, Dedola, and Leduc (2008) and

[19] The results in Table 4 are obtained by setting the anticipation horizon of news shocks to home TFP in the model (i.e., p in ε^n_{t-p}) equal to 3. In fact, we consider the range from 0 to 7 for the anticipation horizon p, and apply the IRFME to each value of p. It is found that the anticipation horizon of 3 achieves the minimum value of the loss function. The standard errors reported in Table 4 are calculated by applying the asymptotic delta method.

[20] The estimation results for the LCP model are available upon request.

Enders and Muller (2009). As we mentioned at the end of Section 2.2, Corsetti, Dedola, and Leduc's (2008) theoretical study shows that when the trade price elasticity is sufficiently low and the international financial markets are incomplete, the real exchange rate appreciates following a positive contemporaneous shock to home TFP. We find that a low trade price elasticity is required if the model tends to match the observed appreciation of the real exchange rate in response to a positive news TFP shock.

Our estimates of other parameters are consistent with the values estimated by previous studies. Our estimate of the investment adjustment cost parameter (κ) is between 1.60 and 5.77, which is close to the values estimated in Altig (2011). The parameter that determines the elasticity of capital utilization to the rental rate of capital (δ_2/δ_1) is estimated to be between 0.25 and 1.03. The estimated value of 1.03 resulting from matching the IRFs only to news TFP shocks is larger than the median estimate of 0.34 in Schmitt-Grohé and Uribe (2012), but in this case its standard error of 0.65 is also large. Our estimate of the Calvo parameter (α) is found to be between 0.71 and 0.76, which is close to the value of 0.75 commonly used in the literature. This estimate is also consistent with evidence from goods-level prices data. Nakamura and Steinsson (2008) study BLS microdata that underlies the US consumer and producer price indices. They find that the duration of prices is between 8 to 11 months excluding sales and product substitutions.

Our estimates of monetary policy parameters suggest that the central bank only changes its short-term interest rate gradually with the estimate of the interest rate smoothing parameter (Θ_i) between 0.68 and 0.86. The central bank strongly targets the inflation rate with the estimate of the inflation targeting parameter (Θ_π) between 1.54 and 2.19, and puts some weight on the output gap with its coefficient estimate (Θ_y) less than 0.24. Similar monetary policy behavior is also documented in Clarida, Gali, and Gertler (2000). The AR(1) coefficient of contemporaneous TFP shocks (ξ^u) is estimated to be around 0.89, which is also within the range of the persistence of TFP shocks commonly used in the literature. Our estimate of the parameter that governs the degree of diffusion of news TFP shocks (ξ^s) is between 0.56 and 0.76. Finally, news TFP shocks are estimated to be more volatile than contemporaneous TFP shocks ($\sigma_{\varepsilon^n} = 0.89$ in percent versus $\sigma_{\varepsilon^c} = 0.67$ in percent when matching the IRFs to both TFP shocks).

Figure 4 shows the theoretical model IRFs based on three sets of the parameter estimation results in Table 4, and compares them with the empirical VAR IRFs. The left and right panels are the IRFs to news and contemporaneous TFP shocks, respectively. The red lines with triangles represent the model IRFs resulting from matching the IRFs to both TFP shocks. In this case, the model response of relative consumption to a positive news TFP shock is not as strong as in the data, and the model fails to generate the observed appreciation of the real exchange rate following the news shock. If we only match the IRFs to the news shock (the green lines with squares in the left panel), the model does well in replicating the VAR response of

relative consumption to the news shock. The real exchange rate in the model appreciates on impact of the news shock by almost 0.67% (less than 1.15% in the data), but this appreciation is enormously persistent. That is, the model fails to replicate the J-shaped appreciation response of the real exchange rate in the data, even if the trade price elasticity is low enough to switch the sign of the real exchange rate from depreciation to appreciation.

The model responses following a positive contemporaneous TFP shock are almost the same no matter if we match the IRFs to both TFP shocks (the red lines with triangles in the right panel) or only to contemporaneous TFP shocks (the green lines with squares in the right panel). In particular, the model cannot generate the hump-shaped response of the real exchange rate in the data. Moreover, the model requires a relatively high trade price elasticity to generate the depreciation of the real exchange rate, so the model response of the real exchange rate cannot be as strong as in the data.

The estimated model IRFs of relative consumption, investment, GDP, and hours match the data relatively well, especially when matching the IRFs only to news TFP shocks. The model can replicate the gradual increase in relative investment and GDP following a positive news shock, though they peak later than in the data. Relative consumption in the model also shows a similar pattern in the data: it increases strongly on impact of the news TFP shock and this increase is very persistent. In the case of the contemporaneous TFP shocks, the model can match the observed dynamics of relative consumption and investment, but performs less well for relative GDP and hours worked.[21]

All in all, our theoretical model, which is similar to existing standard international business cycle models, is not successful in replicating the observed dynamics of the real exchange rate following both TFP shocks, though the model can match our empirical impulse responses of other variables relatively well. In particular, this kind of model only relies on a low trade price elasticity to generate the appreciation of the real exchange rate in response to a positive (news or contemporaneous) TFP shock. This feature may not be enough to understand the observed dynamics of the real exchange rate in the data.[22]

4 Robustness Check and Discussion

In this section, we show that our results of the international transmission of news and contemporaneous shocks to US TFP in Section 2 are robust to an alternative identification scheme, the sign restrictions

[21] It is worthwhile to note that the estimation results for all three cases are robust to exclusion of the IRF of relative hours.

[22] Corsetti, Dedola, and Leduc (forthcoming) and Enders and Muller (2009) document the appreciation of the US real exchange rate following a positive US productivity shock. They emphasize the role of the low trade price elasticity in replicating the observed real appreciation. However, the low trade price elasticity still cannot explain the delayed overshooting of the real exchange rate in the data, although it can explain the observed negative correlation between the real exchange rate and relative consumption (i.e., the Backus-Smith puzzle) as shown in Corsetti, Dedola, and Leduc (2008).

method.[23] Barsky and Sims' (2011) strategy used in our benchmark identification scheme only relies on assumptions about a measure of TFP to identify news and contemporaneous TFP shocks. Although their method imposes a minimum of theoretical restrictions on a measure of TFP and allows the data to speak for itself, the news TFP shocks identified from their method may contain some structural shocks that are not truly "news." For instance, Jinnai (2013) proposes a structural model with R&D shocks and shows that Barsky and Sims' method identifies this shock as a news shock, though it is not news about future technology.

We first derive the sign restrictions to identify news and contemporaneous TFP shocks in our VAR systems from the structural model introduced in Section 3. Since our sign restrictions are derived from a structural model that explicitly incorporates news TFP shocks, our sign restrictions strategy is less likely than Barsky and Sims' strategy to confound true news TFP shocks with other structure shocks (e.g., R&D shocks) that can affect TFP in the future but have no immediate impact on it. We show that our sign restrictions strategy and Barsky and Sims' strategy yield very similar results and complement each other, though these two identification strategies are fundamentally different.

Besides a robustness check, the results of our sign restrictions strategy also serve to connect our paper to related studies in the literature, in particular, Corsetti, Dedola, and Leduc (2006 and forthcoming), Enders and Muller (2009), Enders, Muller, and Scholl (2011), and Juvenal (2011). Our results here can reconcile some conflicting findings in these previous studies.

4.1 Sign Restrictions

To identify a structural shock of interest, the sign restrictions method imposes sign restrictions on the impulse responses of a set of variables in a VAR model and these sign restrictions are usually rationalized on the basis of economic theory. We mainly use the two-country DSGE model introduced in Section 3 to derive our sign restrictions for identifying news and contemporaneous TFP shocks. Following Enders, Muller, and Scholl (2011), we first set a plausible range for each model parameter value that is summarized in Table 5, and then randomly take 100,000 draws of a set of the model parameter values, assuming a uniform and independent distribution. For each draw, we calculate the theoretical model impulse responses to a one-percentage point positive news or contemporaneous shock to home (US) TFP. Next, we calculate the 95% confidence bounds of the model impulse responses and use these confidence bounds to draw our sign restrictions for identifying news and contemporaneous shocks to US TFP. To implement our sign restrictions, we take the penalty-function approach by following Uhlig (2005) and Mountford and Uhlig (2009).

[23] The sign restrictions method has been widely used in the recent SVAR literature. For example, see Faust and Rogers (2003), Farrant and Peersman (2006), Dedola and Neri (2007), and Peersman and Straub (2009), among others.

Figure 5 displays the 95% confidence bounds of the theoretical model impulse responses of 8 variables in the PCP model: home TFP, relative consumption, relative investment, relative GDP, relative inflation, the relative nominal interest rate, the home real exchange rate, and the home trade balance. Figure 6 shows the corresponding confidence bounds in the LCP model. In each figure, the left and right panels correspond to positive news and contemporaneous shocks to home TFP, respectively. As in Enders, Muller, and Scholl (2011), we consider two value ranges for the trade price elasticity, so in each panel, the blue area represents the confidence bound for the range of the low trade price elasticity ($\theta \in [0.1, 0.33]$), and the area between the two dotted lines is the confidence bound for the range of the high elasticity ($\theta \in [1, 4]$).

In Figures 5 and 6, we consider two new variables, relative inflation and the relative nominal interest rate, which have not been included in our previous VAR models. These two additional variables help identify news and contemporaneous shocks to US TFP in our sign restrictions strategy. Theoretically, news and contemporaneous TFP shocks have similar effects on relative consumption, investment, and GDP in that both shocks increase these three variables. Therefore, we cannot identify these two TFP shocks separately by imposing sign restrictions on these three variables without the help of other variables that can distinguish the effects of two TFP shocks (and other structural shocks).[24] So the relative inflation and nominal interest rates are added to our VAR systems to achieve better identification under the sign restrictions method. In particular, theoretical models predict that both the relative nominal interest and inflation rates decrease in response to a positive contemporaneous shock to home TFP, while the relative nominal interest rate rises following a positive news shock to home TFP.

The two left panels of Figures 5 and 6 display the confidence bounds of the model impulse responses to a one-percentage point increase in news shocks to home TFP. Note that the size of the (news and contemporaneous) shock only affects the scales of model impulse responses, but does not change their signs. First, the sign of relative consumption is unambiguously positive at all horizons. This does not depend on the range of the trade price elasticity (low or high) or the choice of the pricing currency (PCP or LCP). Second, relative investment and relative GDP become unambiguously positive after a few quarters following the shock: indeed, relative investment increases with a delay of around 8 quarters and relative GDP increases with a delay of 4 quarters. Third, the relative nominal interest is unambiguously positive for the first 4 quarters. However, the sign of relative inflation is ambiguous for the first several quarters. Finally, home TFP is zero for the first 4 quarters by construction and the signs of the real exchange rate and the trade balance are ambiguous at all horizons.[25]

[24] TFP is obviously one variable that helps distinguish the effects of news and contemporaneous TFP shocks.

[25] In simulation, we set the anticipation horizon of news TFP shocks equal to 3, based on our model estimation exercises in Section 3.

As a result, we imposes the following sign restrictions, which are also summarized in Panel A of Table 6, to identify a positive news shock to US TFP: (1) the IRF of US TFP is zero on impact; (2) the IRF of relative consumption is positive for the first 8 quarters following the shock; (3) the IRF of relative investment is positive for 8 quarters after the first 8 quarters; (4) the IRF of relative GDP is positive for 8 quarters after the first 4 quarters; (5) the IRF of the relative nominal interest rate is positive for the first 4 quarters; and (6) the IRFs of other variables in the VAR systems are left unrestricted.[26] Note that the positive sign restriction on the relative nominal interest rate excludes an expansionary monetary shock.[27]

The two right panels of Figures 5 and 6 show the confidence bounds of the model impulse responses to a one-percentage point increase in contemporaneous shocks to home TFP. First, relative investment and GDP increase on impact and are unambiguously positive for the first several years and relative consumption becomes unambiguously positive after the impact of the shock. This is true for both PCP and LCP models. Second, relative inflation turns negative after the impact of the shock and the relative nominal interest rate is unambiguously negative for the first 6 quarters. Juvenal (2011) also shows in a two-country DSGE model that the relative nominal interest rate is negative following a positive contemporaneous shock to home TFP. It is the opposite in the case of a positive news shock to home TFP, which helps to distinguish these two TFP shocks. Finally, home TFP increases on impact and this increase is very persistent over time by construction. The signs of the real exchange rate and the trade balance are ambiguous at all horizons.

Therefore, we impose the following sign restrictions to identify a positive contemporaneous shock to US TFP that is orthogonal to the news TFP shocks: (1) the IRF of US TFP is positive for the first 28 quarters (i.e., 7 years); (2) the IRF of relative consumption is positive for 8 quarters after the first quarter; (3) the IRF of relative investment is positive for the first 8 quarters; (4) the IRF of relative GDP is also positive for the first 8 quarters; (5) the IRF of relative inflation is negative for the first 3 quarters; (6) the IRF of the relative nominal interest rate is negative for the first 6 quarters; and (7) the IRFs of other variables in the VAR systems are left unrestricted.[28]

In Table 6, Panel A summarizes our sign restrictions to identify positive news and contemporaneous

[26] As sensitivity analysis, we try alternative horizons over which the sign restrictions are imposed. For instance, all else being equal, the IRF of relative investment is restricted to be positive for 4 quarters after the first 4 quarters (rather than for 8 quarters after the first 8 quarters). The results are robust to these alternative setups.

[27] Another potential shock our sign restrictions could identify is a positive home-country (US-specific) demand shock. However, our estimated IRFs of US TFP and relative inflation indicate that our sign restrictions indeed identify positive news TFP shocks, since the identified shock is associated with the eventual increase in US TFP and the short-run decrease in relative inflation rather than the increase.

[28] We impose the negative sign on the IRF of relative inflation from the impact, even if the PCP model implies such a negative sign after the impact. Except for the sign restriction on the IRF of US TFP, these sign restrictions are almost the same as those imposed to identify a positive (contemporaneous) US technology shock in Enders, Muller, and Scholl (2011). Juvenal (2011) also imposes positive sign restrictions on the IRFs of relative output and consumption and negative sign restrictions on the IRFs of relative inflation and the relative nominal interest rate to identify a positive (contemporaneous) shock to US productivity.

shocks to US TFP. As suggested by the confidence bounds of the model impulse responses, we will identify a positive news TFP shock that has no immediate impact on US TFP and induces simultaneous increases in relative consumption, investment, and GDP with relative consumption leading relative investment and GDP. In addition, the relative nominal interest rate also increases in the short run following the shock. The positive contemporaneous TFP shock that we will identify has a very persistent effect on US TFP from the impact of the shock and also induces an economic boom with immediate increases in relative investment and GDP, followed by an increase in relative consumption. Unlike the positive news TFP shock, the positive contemporaneous TFP shock imposes downward pressure on the relative inflation and nominal interest rates in the short run.

4.2 The Results under Sign Restrictions and Discussion

Figure 7 shows the IRFs in the eight-variable VAR model to positive news and contemporaneous TFP shocks identified by our sign restrictions in Panel A of Table 6. Figure 8 displays the IRFs of the terms of trade and three trade variables in the nine-variable VAR models, in which the real exchange rate in the eight-variable VAR model is replaced by the terms of trade and one trade variable is also added to the system.[29] The median responses and the confidence intervals are plotted in the figures, and the vertical gray areas represent the horizons over which the sign restrictions are imposed.

The IRF results in Figures 7 and 8 indicate that our results on the international transmission of news and contemporaneous TFP shocks in Section 2 are very robust to our sign restrictions strategy. In addition, several findings of our sign restrictions results are very interesting. First, following a positive news TFP shock, US TFP stays around zero for about 6 quarters before it rises above zero. The subsequent increase in US TFP is significant and also very persistent (lasting for more than 40 quarters), though we do not impose such a restriction ex ante. Comparing with our results in Section 2, US TFP displays an even more delayed response here.[30] Second, the relative nominal interest rate increases significantly following a positive news TFP shock. This increase is very persistent, lasting for around 20 quarters. In fact, such a response of the relative nominal interest rate occurs even when we do not impose the positive sign restriction on it, which will be discussed shortly. Third, positive news TFP shocks are not associated with US inflation relative to

[29] The eight-variable VAR model results from adding two variables, relative inflation and the relative nominal interest rate, to our benchmark six-variable system. The nine-variable VAR models are obtained by replacing the real exchange rate in the eight-variable system with the terms of trade and adding the trade balance, real exports, or real imports. The reported IRF of the terms of trade in Figure 8 is estimated in the nine-variable system with the terms of trade and the trade balance. The IRFs of other variables in the nine-variable systems are almost the same as the corresponding IRFs in Figure 7.

[30] Jinnai (2013) shows in his theoretical model that TFP does not move on impact of a positive R&D shock, but increases quickly after the impact. So the more delayed response of TFP to our identified news TFP shock suggests that our sign restrictions strategy are unlikely to confound true news TFP shocks with R&D shocks.

the ROW: that is, relative inflation decreases in the first several quarters following the news shock.[31] Finally, the IRF of real exports to a positive news shock displays a similar pattern as that presented in Section 2, but such a response is now found to be less significant. In contrast, the response of real imports to a positive contemporaneous shock is much stronger and more significant than the one in Section 2.

Our main results for news TFP shocks hold qualitatively well under alternative sign restrictions. We consider three alternative sign restrictions that can potentially identify news TFP shocks by removing the restrictions on TFP and the relative nominal interest rate or one of these two restrictions. These three alternative sign restrictions are summarized in Panel B of Table 6.

Figure 9 presents the impulse responses in the eight-variable system under these alternative sign restrictions. The estimated IRFs are very similar across three alternative sign restrictions and our benchmark sign restrictions (the left panel of Figure 7). First, it is interesting to note that US TFP tends to increase with a delay even if we do not impose the zero restriction on US TFP. One shortcoming of our benchmark identification scheme in Section 2 is that we use US TFP rather than US-ROW relative TFP because of the data availability issue, so the identified news (and contemporaneous) TFP shocks could contain both global and US-specific components. The results in Figure 9 show that our results are robust even when we do not impose any restrictions on US TFP, indicating that we are likely to pick up a US-specific news component of TFP. Second, the relative nominal interest rate increases strongly on impact and its subsequent increase is quite persistent even if we do not impose the positive sign restriction on the relative nominal interest rate. Moreover, such an increase in the relative nominal interest rate and the delayed overshooting of the real appreciation following the news shock are linked well with the UIP puzzle in the data, which suggests that news TFP shocks could contribute to this empirical puzzle as well.

In the rest of this subsection, we discuss related empirical studies on the international transmission of US productivity shocks, in particular Corsetti, Dedola, and Leduc (2006 and forthcoming), Enders and Muller (2009), Enders, Muller, and Scholl (2011), and Juvenal (2011). We reconcile some conflicting results in these studies by connecting their findings with ours.

Enders and Muller (2009) identify US labor productivity shocks using long-run restrictions as in Gali (1999). They document that the US real exchange rate appreciates strongly on impact of the identified positive labor productivity shock and continues to appreciate for several quarters before converging back to its initial level. Such a response is similar to that of our identified news TFP shock. Enders, Muller, and Scholl (2011) identify US economy-wide technology shocks with the sign restrictions method. They find that

[31] This finding is also consistent with Beaudry, Nam, and Wang (2011) and Christiano et al. (2008). Moreover, this response of relative inflation indicates that we are not likely to capture US demand shocks, since positive demand shocks are generally associated with inflation.

the US real exchange rate slightly appreciates on impact of the identified positive technology shock, but actually depreciates in the medium run. The overall pattern of this response is hump-shaped, and is now similar to that of our identified contemporaneous TFP shock. We argue that the discrepancy in these findings is because the long-run restrictions employed in Enders and Muller (2009) identify the shock similar to our news TFP shocks, while the sign restrictions implemented in Enders, Muller, and Scholl (2011) identify the shock closely related to our contemporaneous TFP shocks.[32]

In fact, our sign restrictions for identifying contemporaneous TFP shocks are almost the same as those of Enders, Muller, and Scholl (2011). So it is not surprising that the IRF of the real exchange rate to our contemporaneous TFP shock displays a hump-shaped pattern similar to what is found in Enders, Muller, and Scholl (2011). Moreover, our IRFs of other relative variables (i.e., relative consumption, investment, GDP, inflation, and interest rate) to the contemporaneous TFP shock (the right panel of Figure 7) are also similar to the corresponding IRFs in their paper. In contrast, the left panels of Figures 1 and 7 show that our identified news TFP shocks have a very persistent long-run effect on US TFP. In addition, our FEV decomposition results in Table 1 indicate that our identified news TFP shocks explain about two-thirds of the FEV of US TFP even at the horizon of 40 quarters. Thus, it is likely that Enders and Muller's (2009) identified labor productivity shocks from long-run restrictions are closely related to our news TFP shocks. As a result, the IRFs of the real exchange rate and other variables (e.g., relative consumption, investment, and the trade balance) to their labor productivity shock and our news TFP shock are very similar.

In this paper, we found that the estimated responses of both real exports and real imports to news and contemporaneous TFP shocks are significant. More importantly, the responses following the contemporaneous TFP shock are well in line with the predictions of international business cycle models. In particular, US real exports are found to increase strongly and persistently following our identified positive contemporaneous shock to US TFP (see the right panel of Figure 2 or Figure 8). In contrast, Corsetti, Dedola, and Leduc (forthcoming) identify US manufacturing productivity shocks employing sign restrictions, but do not find any significant response of US real exports to their identified productivity shock, even if productivity gains are generally perceived as main drivers of exports. Interestingly, the median response of US exports to the productivity shock in Corsetti, Dedola, and Leduc (forthcoming) is qualitatively very similar to the median response of US exports to our news TFP shock.[33] In their study, however, the median response of US exports following the productivity shock is below zero at most periods, leading to their statement, "the response of

[32]In both Enders and Muller (2009) and Enders, Muller, and Scholl (2011), the US real exchange rate is measured by the OECD MEI effective real exchange rate series. When we use this series as our measure of the real exchange rate, our results are very robust to this measure.

[33]See Figure 1 in Corsetti, Dedola, and Leduc (forthcoming), comparing with the left panel of Figure 2 or Figure 8 in this paper.

real exports is inconclusive."

On the other hand, the IRFs of other variables (i.e., relative consumption, investment, nominal interest rate, the trade balance, real imports, the real exchange rate, and the terms of trade) to their manufacturing productivity shock are very similar to the IRFs to our news TFP shock.[34] In fact, Corsetti, Dedola, and Leduc's (forthcoming) findings on the international transmission of US manufacturing productivity shocks corroborate the findings in their early work, Corsetti, Dedola, and Leduc (2006), which uses long-run restrictions as in Gali (1999) to identify labor productivity shocks in the US manufacturing sector. Moreover, Corsetti, Dedola, and Leduc's (forthcoming) sign restrictions for identifying US manufacturing productivity shocks include a positive sign restriction on the impulse response of the US-ROW relative manufacturing labor productivity over 5 years. So their sign restrictions are likely to pick up the effects of the structural shock that have a persistent long-run effect on the relative manufacturing labor productivity. As a result, their manufacturing productivity shocks identified from such sign restrictions might be closely related to our news TFP shocks and the labor productivity shocks identified by Enders and Muller (2009).[35]

Finally, we found in Section 2.4 that news and contemporaneous TFP shocks together explain almost 40% of the FEV of the US real exchange rate at business cycle frequencies. Using the sign restrictions method to identify US TFP shocks, however, Juvenal (2011) finds that her identified TFP shocks only account for around 10% of the FEV of the US real exchange rate at frequencies between 8 and 20 quarters. Such different results are due to the fact that Juvenal (2011) imposes sign restrictions to identify contemporaneous TFP shocks, but not news TFP shocks. Like Enders, Muller, and Scholl (2011), Juvenal (2011) imposes negative sign restrictions on the relative interest rate and the relative inflation rate following a positive TFP shock. Therefore, her identified TFP shocks are likely to only capture the contemporaneous component of TFP shocks. In fact, our identified contemporaneous TFP shocks also found to explain about 10% of the FEV of the US real exchange rate, which is in the same range as Juvenal's (2011) results.

The above discussions highlight the importance of distinguishing news and contemporaneous TFP shocks in empirical studies on the international transmission of productivity shocks. Omitting news TFP shocks is likely to only reveal incomplete and sometimes contradictory results in the study.

[34] There is some qualitative difference between the responses of the relative nominal interest rate to our news TFP shocks and their productivity shocks. As shown in Figures 7 and 9, the relative nominal interest rate rises sharply on impact of our news TFP shock and decreases monotonically until around the 20th quarter. In contrast, it does not move significantly on impact of their manufacturing productivity shock, but turns positive and peaks after 12 quarters, exhibiting a hump-shaped response.

[35] We do not argue that Corsetti, Dedola, and Leduc (forthcoming) actually identify news productivity shocks in the US manufacturing sector.

5 Conclusion

International relative prices and international trade are important channels for the transmission of country-specific TFP changes across borders, which is a crucial international macroeconomic issue. Previous empirical studies on this issue either only focus on contemporaneous TFP shocks, or at the most, do not make a clear distinction between contemporaneous and news TFP shocks. However, the recent empirical studies on news shocks suggest that news TFP shocks are important, in particular, more important than contemporaneous TFP shocks, in driving US business cycles. Moreover, news and contemporaneous TFP shocks are found to induce distinct dynamics for US macro aggregates. Therefore, it is of interest to compare the international transmission of news and contemporaneous US TFP shocks, especially their effects on international relative prices and trade.

In this paper we find that news and contemporaneous US TFP shocks induce substantially different dynamics for international relative prices and international trade. The US real exchange rate appreciates strongly and persistently in response to a positive news TFP shock, displaying a horizontally J-shaped response. However, it only appreciates slightly on impact of a positive contemporaneous TFP shock and then depreciates persistently in the following periods, displaying a hump-shaped response. Similar responses following these two TFP shocks are also found for the US terms of trade. Such distinct dynamics of the US terms of trade have strikingly different effects on the US trade balance, real exports, and real imports. In particular, the terms of trade stabilizes the trade balance in the short run following favorable news TFP shocks, but destabilizes the trade balance following favorable contemporaneous TFP shocks. The terms of trade movements also lead to the opposite cross-country wealth effects for these two TFP shocks.

The findings in this paper, taken together, highlight the importance of distinguishing news and contemporaneous US TFP shocks when studying issues such as the international transmission of US-specific productivity shocks and the role of TFP shocks in driving exchange rates: omitting news shocks to TFP may generate incomplete and sometimes self-contradictory results. Our empirical findings, which are robust to fundamentally different identification schemes, reconcile some puzzling results in the related literature and thus lead to a better understanding of this topic.

We also evaluate a standard international business cycle model with our empirical findings. It suggests that existing standard international macroeconomic models cannot generate the observed dynamics of the real exchange rate following both news and contemporaneous TFP shocks. If we allow a low trade price elasticity as suggested by Corsetti, Dedola, and Leduc (2008), the model can generate the appreciation of the real exchange rate following a positive news TFP shock, but it fails to replicate the delayed overshooting

of the real exchange rate in the data (i.e., a horizontally J-shaped response). In addition, the model with such a low trade price elasticity cannot simultaneously replicate the observed real depreciation induced by a positive contemporaneous TFP shock. On the other hand, the model with a relatively high trade price elasticity induces a real depreciation for a positive contemporaneous TFP shock, but cannot generate a real appreciation following a positive news TFP shock. In addition, exchange rate volatility in the model is much smaller than in the data and does not exhibit the observed overshooting either. The theoretical evaluation of our empirical findings poses challenges to the existing literature on the international transmission of productivity shocks and merits further investigation.

One promising avenue to explore in the future is to incorporate a financial channel of the exchange rate determination into standard international macroeconomic models. Intuitively, expected improvements in US technology may lead to an increase in the demand for US financial assets, which should cause an appreciation of the dollar with everything else constant. In this case, we may not have to rely entirely on the international trade price elasticity to generate a real appreciation following a positive news TFP shock. Most trade in US dollars is for the purpose of financial investment rather than international trade. In addition, the asset pricing approach has gained more support in recent empirical studies on exchange rate determination (e.g., Engel and West, 2005). We believe that theoretical explorations along this line will be fruitful in the future.

References

[1] Altig, D., L. Christiano, M. Eichenbaum, and J. Lindé, 2011. "Firm Specific Capital, Nominal Rigidities and The Business Cycle," *Review of Economic Dynamics* 14(2): 225-247.

[2] Backus, D., P. Kehoe, and F. Kydland, 1994. "Dynamics of The Trade Balance and The Terms of Trade: The J-curve?" *American Economic Review* 84(1): 84-103.

[3] Barsky, R. and E. Sims, 2011. "News Shocks and Business Cycles," *Journal of Monetary Economics* 58: 273-289.

[4] Beaudry, P., D. Nam, and J. Wang, 2011. "Do Mood Swings Drive Business Cycles and is it Rational?" NBER Working Paper No. 17651.

[5] Beaudry, P. and F. Portier, 2004. "An Exploration into Pigou's Theory of Cycles," *Journal of Monetary Economics* 51(6): 1183-1216.

[6] Beaudry, P. and F. Portier, 2006. "Stock Prices, News, and Economic Fluctuations," *American Economic Review* 96(4): 1293-1307.

[7] Beaudry, P. and F. Portier, 2007. "When Can Changes in Expectations Cause Business Cycle Fluctuations in Neo-Classical Settings?" *Journal of Economic Theory* 135(1): 458-477.

[8] Bergin, P., 2006. "How Well Can The New Open Economy Macroeconomics Explain The Exchange Rate and Current Account?" *Journal of International Money and Finance* 25: 675-701.

[9] Boivin, J. and M. Giannoni, 2006. "Has Monetary Policy Become More Effective?" *Review of Economics and Statistics* 88(3): 445-462.

[10] Calvo, G. A., 1983. "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics* 12: 383-398.

[11] Chari, V. V., P. Kehoe, and E. McGrattan, 2002. "Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates?" *Review of Economic Studies* 69(3): 533-563.

[12] Chen, Y., K. Rogoff, and B. Rossi, 2010. "Can Exchange Rates Forecast Commodity Prices?" *Quarterly Journal of Economics* August 2010: 1145-1194.

[13] Christiano, L., M. Eichenbaum, and C. Evans, 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy* 113(1): 1-45.

[14] Christiano, L., C. Ilut, R. Motto, and M. Rostagno, 2008. "Monetary Policy and Stock Market Boom-Bust Cycles," Working Paper No. 955, European Central Bank.

[15] Clarida, R. and J. Gali, 1994. "Sources of Real Exchange Rate Fluctuations: How Important are Nominal Shocks?" *Carnegie-Rochester Conference Series on Public Policy* 41: 1-56.

[16] Clarida, R., J. Gali, and M. Gertler, 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics* February 2000, 147-180.

[17] Cochrane, J., 1994. "Shocks," *Carnegie-Rochester Conference Series on Public Policy* 41: 295-364.

[18] Cole, H. and M. Obstfeld, 1991. "Commodity Trade and International Risk Sharing: How Much Do Financial Markets Matter?" *Journal of Monetary Economics* 28: 3-24.

[19] Corsetti, G., L. Dedola, and S. Leduc, 2006. "Productivity, External Balance and Exchange Rates: Evidence on the Transmission Mechanism Among G7 Countries," in L. Reichlin and K. West (eds.) NBER International Seminar on Macroeconomics 2006.

[20] Corsetti, G., L. Dedola, and S. Leduc, 2008. "International Risk Sharing and the Transmission of Productivity Shocks," *Review of Economic Studies* 75: 443-473.

[21] Corsetti, G., L. Dedola, and S. Leduc, forthcoming. "The International Dimension of Productivity and Demand Shocks in the US Economy," *Journal of European Economic Association.*

[22] Cumby, R., 1988. "Is It Risk? Explaining Deviations from Uncovered Interest Parity," *Journal of Monetary Economics* 22: 279-299.

[23] Enders, Z. and G. Muller, 2009. "On the International Transmission of Technology Shocks," *Journal of International Economics* 78: 45-59.

[24] Enders, Z., G. Muller, and A. Scholl, 2011. "How do Fiscal and Technology Shocks Affect Real Exchange Rates? New Evidence for the United States," *Journal of International Economics* 83: 53-69.

[25] Engel, C. and K. D. West, 2005. "Exchange Rates and Fundamentals," *Journal of Political Economy* 113: 485-517.

[26] Engel, C. and K. D. West, 2010. "Global Interest Rates, Currency Returns, and the Real Value of the Dollar," *American Economic Review, Papers and Proceedings* 100(2): 562-67.

[27] Fama, E., 1990. "Stock Returns, Expected Returns, and Real Activity," *Journal of Finance* 45(4): 1089-1108.

[28] Farrant, K. and G. Peersman, 2006. "Is the Exchange Rate a Shock Absorber or a Source of Shocks? New Empirical Evidence," *Journal of Money, Credit and Banking* 38(4): 939-961.

[29] Faust, J. and J. Rogers, 2003. "Monetary Policy's Role in Exchange Rate Behavior," *Journal of Monetary Economics* 50: 1403-1424.

[30] Fernald, J., 2009. "A Quarterly, Utilization-Adjusted Series on Total Factor Productivity," Working Paper, Federal Reserve Bank of San Francisco.

[31] Ferrero, A., M. Gertler, and L. Svensson, 2010. "Current Account Dynamics and Monetary Policy," in J. Gali and M. Gertler (eds.) *International Dimensions of Monetary Policy*, University of Chicago Press, February 2010.

[32] Froot, K. and R. Thaler, 1990. "Anomalies: Foreign Exchange," *Journal of Economic Perspectives* 4(3): 179-192.

[33] Fujiwara, I., Y. Hirose, and M, Shintani, 2011. "Can News Be a Major Source of Aggregate Fluctuations? A Bayesian DSGE Approach," *Journal of Money, Credit and Banking* 43(1): 1-29.

[34] Gali, J., 1999. "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?" *American Economic Review* 89: 249-271.

[35] Heathcote, J. and F. Perri, 2002. "Financial Autarky and International Business Cycles," *Journal of Monetary Economics* 49: 601-627.

[36] Iacoviello, M., 2005. "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle," *American Economic Review* 95(3): 739-764.

[37] Jaimovich, N. and S. Rebelo, 2009. "Can News About the Future Drive the Business Cycle?" *American Economic Review* 99(4): 1097-1118.

[38] Jinnai, R. 2013. "R&D Shocks and Real Shocks," Manuscript, Texas A & M University.

[39] Juvenal, L., 2011. "Sources of Exchange Rate Fluctuations: Are They Real or Nominal?" *Journal of International Money and Finance* 30: 849-876.

[40] Kollmann, R., 2002. "Monetary policy rules in the open economy: effects on welfare and business cycles," *Journal of Monetary Economics* 49: 989-1015.

[41] Kurmann, A. and C. Otrok, forthcoming. "News Shocks and the Slope of the Term Structure of Interest Rates," *American Economic Review*.

[42] Mountford, A. and H. Uhlig, 2009. "What Are the Effects of Fiscal Policy Shocks?" *Journal of Applied Econometrics* 24: 960-992.

[43] Nakamura, E. and J. Steisson, 2008. "Five Facts About Prices: A Revaluation of Menu Cost Models," *Quarterly Journal of Economics*, November 2008, 1415-1464.

[44] Nam, D. and J. Wang, 2010a. "Understanding the Effect of Productivity Changes on International Relative Prices: The Role of News Shocks," Globalization and Monetary Policy Institute Working Paper No. 61.

[45] Nam, D. and J. Wang, 2010b. "The Effects of News About Future Productivity on International Relative Prices: An Empirical Investigation," Globalization and Monetary Policy Institute Working Paper No. 64.

[46] Opazo, L., 2006. "The Backus-Smith Puzzle: The Role of Expectations," Working Papers, Central Bank of Chile 395.

[47] Raffo, A., 2010. "Technology Shocks: Novel Implications for International Business Cycles," International Finance Discussion Papers, No.992, Board of Governors of the Federal Reserve System.

[48] Schmitt-Grohé, S. and M. Uribe, 2003. "Closing Small Open Economy Models," *Journal of International Economics* 61: 163-185.

[49] Schmitt-Grohé, S. and M. Uribe, 2012. "What's News In Business Cycles?" *Econometrica* 80(6): 2733-2764.

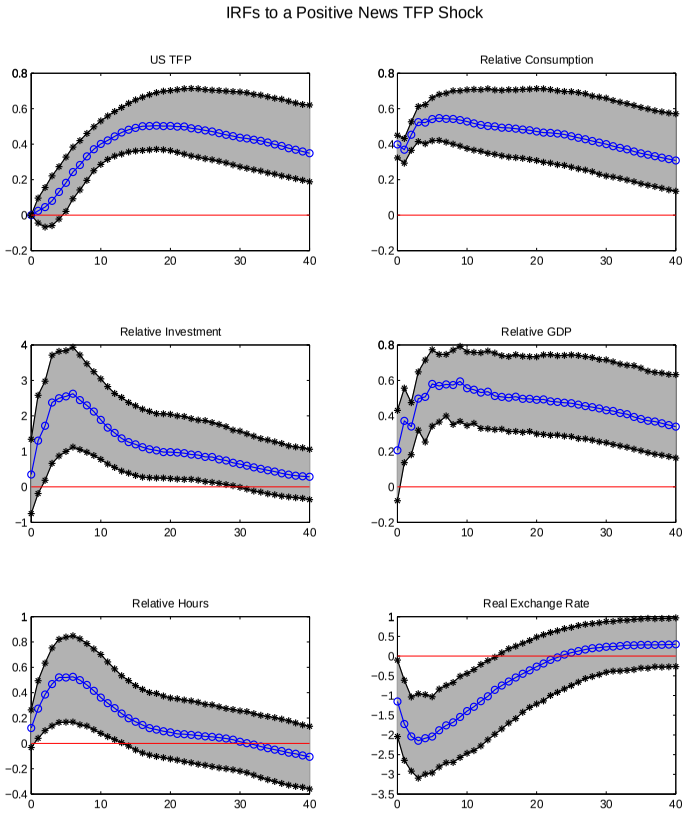
[50] Schwert, W., 1990. "Stock Returns and Real Activity: A Century of Evidence," *Journal of Finance* 45(4): 1237-57.

[51] Senhadji, A., 1998. "Dynamics of The Trade Balance and The Terms of Trade in LDCs: The S-curve," *Journal of International Economics* 46: 105-131.

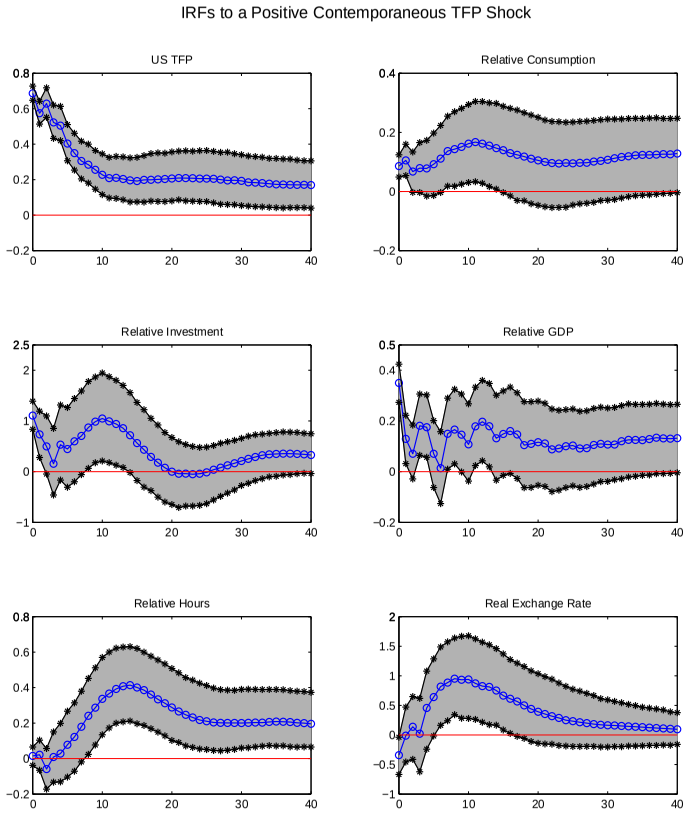
[52] Uhlig, H., 2005. "What Are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure," *Journal of Monetary Economics* 52: 381-419.

Figure 1: Impulse Response Functions to News and Contemporaneous TFP Shocks

Impulse Responses to a Positive News TFP Shock



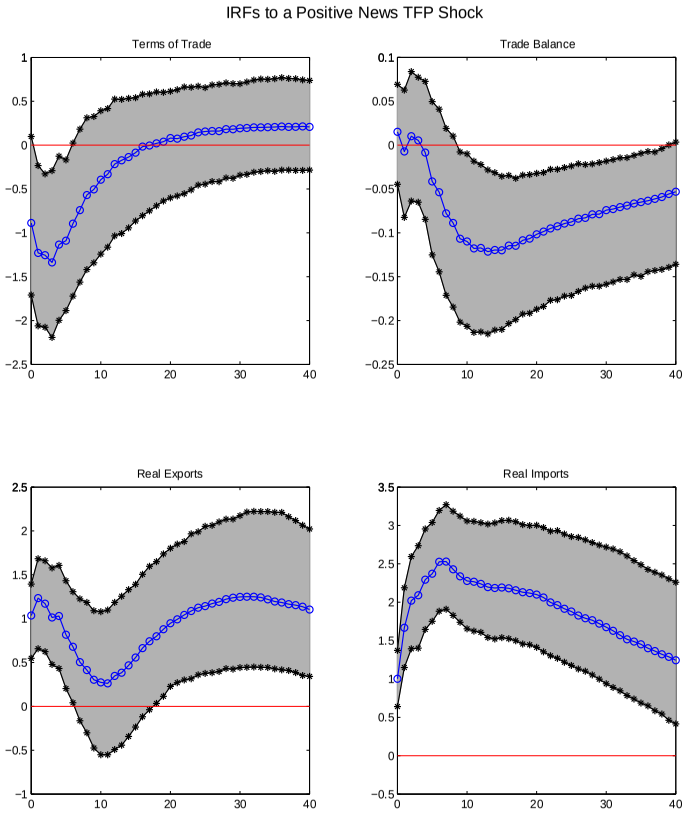
Impulse Responses to a Positive Contemporaneous TFP Shock



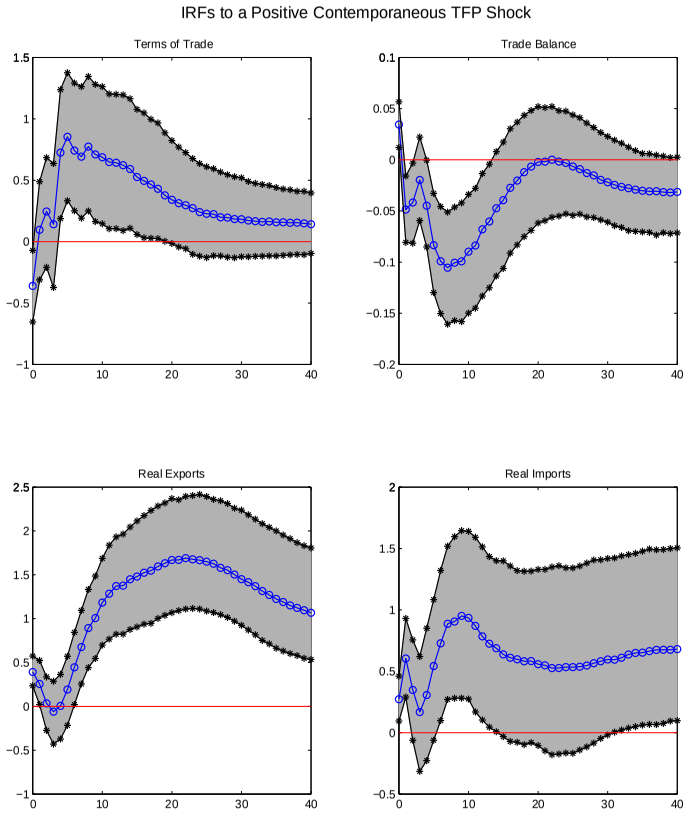
Note: This figure has two panels each of which displays the impulse responses of six variables in the benchmark system to positive news (left panel) and contemporaneous (right panel) TFP shocks. The line with circles represents the median response and the gray area between the two starred lines represents the confidence interval with the 16th and 84th quantiles. The unit of the vertical axis is the percentage deviation from the situation without the shock and the unit of the horizontal axis is quarter.

Figure 2: Impulse Response Functions of Terms of Trade, Trade Balance, Real Exports, and Real Imports

Impulse Responses to a Positive News TFP Shock

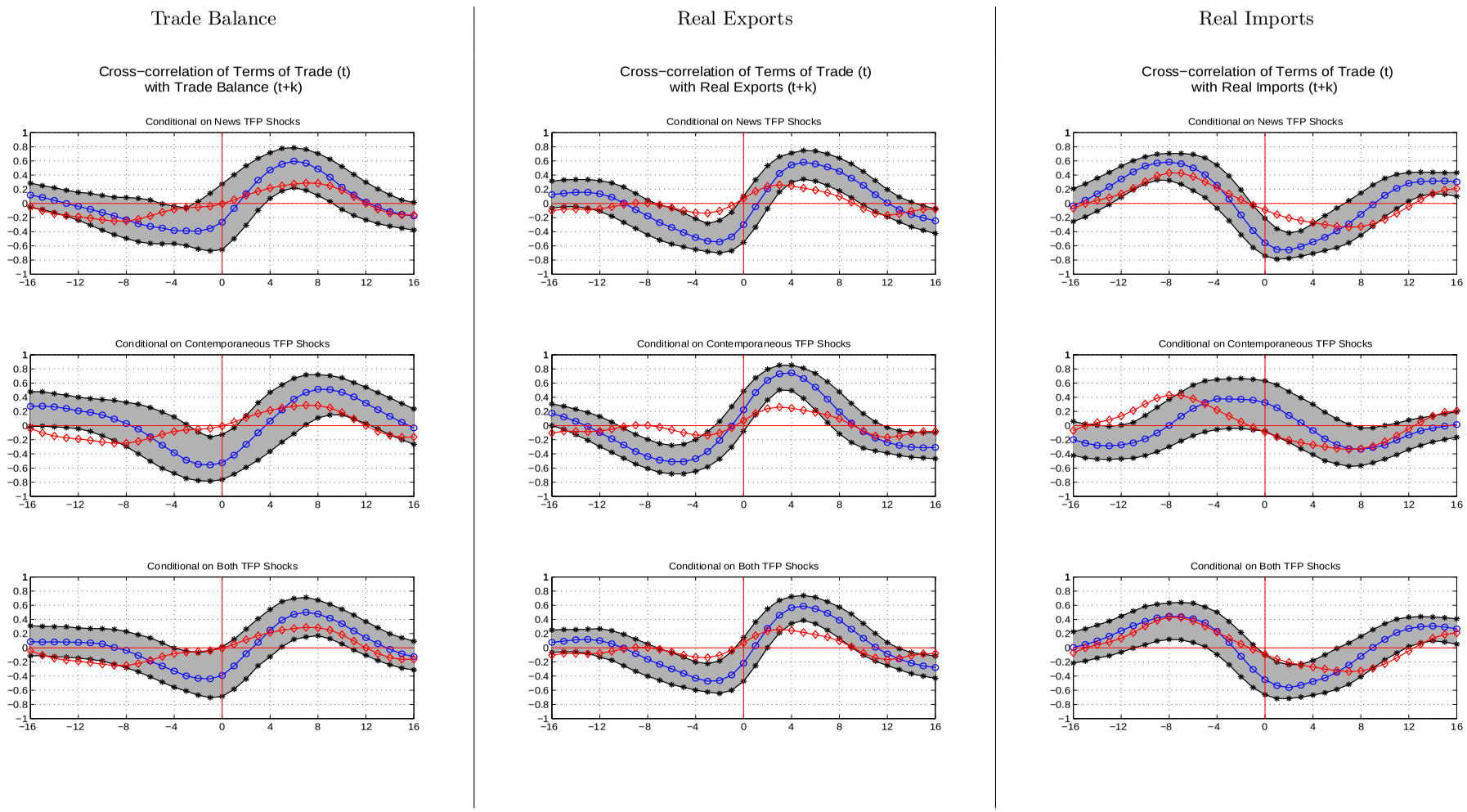


Impulse Responses to a Positive Contemporaneous TFP Shock



Note: This figure has two panels that display the impulse responses of the terms of trade, trade balance, real exports, and real imports in the seven-variable systems to positive news (left panel) and contemporaneous (right panel) TFP shocks, respectively.

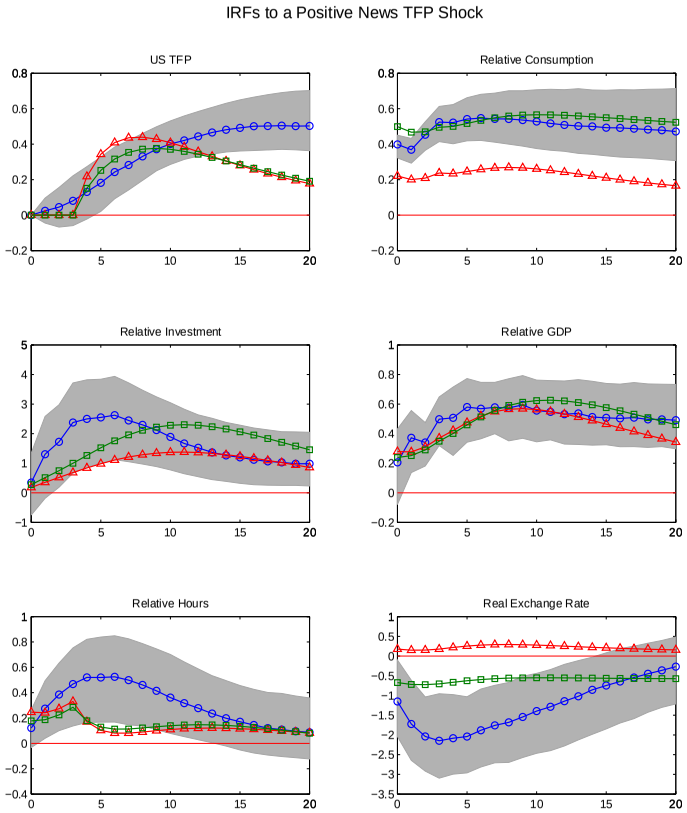
Figure 3: Cross-correlations of Terms of Trade with Trade Balance, Real Exports, and Real Imports



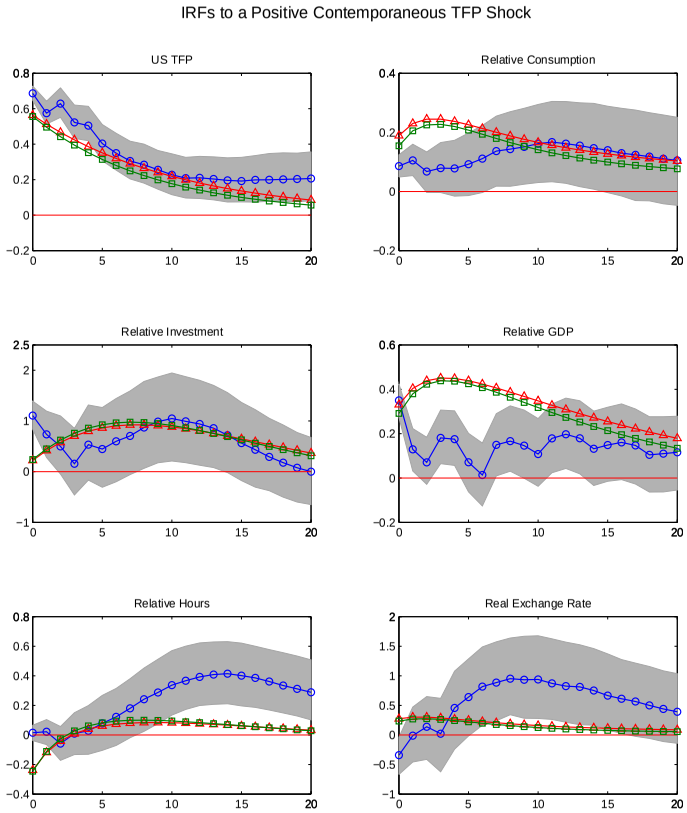
Note: This figure has three panels each of which displays the cross-correlations of the terms of trade at time t with the trade balance (left panel), real exports (middle panel), and real imports (right panel) at time t+k. In each panel, the top, middle, and bottom charts are the conditional cross-correlations on identified news TFP shocks, on identified contemporaneous TFP shocks, and on both shocks, respectively. In each chart, the unconditional cross-correlations in the data are also plotted in the red line with diamonds. The line with circles represents the median cross-correlations and the gray area between the two starred lines represents the confidence interval with the 16th and 84th quantiles.

Figure 4: Estimated Theoretical Model Impulse Response Functions

Impulse Responses to a Positive News TFP Shock



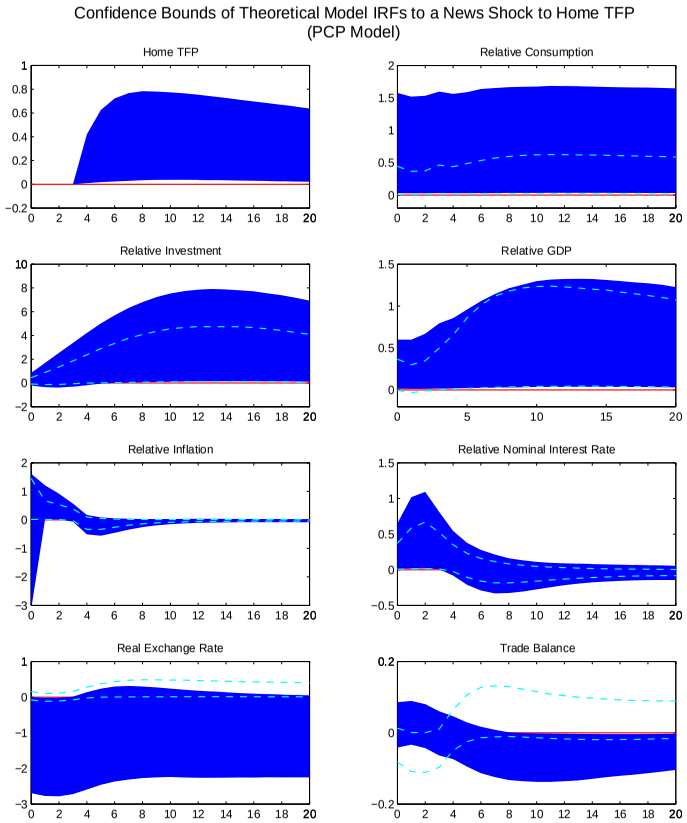
Impulse Responses to a Positive Contemporaneous TFP Shock



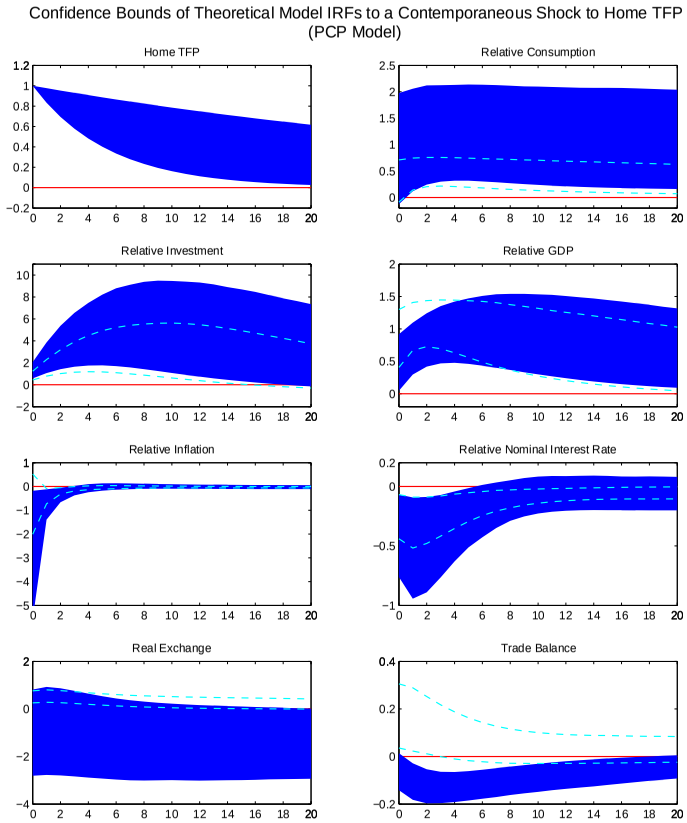
Note: The red lines with triangles represent the theoretical model impulse responses resulting from matching the impulse responses to both news and contemporaneous TFP shocks. In each panel, the green lines with squares represent the theoretical model impulse responses when matching the impulse responses to each TFP shock. For the purpose of comparison, the median VAR impulse response (the blue line with circles) and the confidence interval (the gray area) are also plotted.

Figure 5: Confidence Bounds of Theoretical Model Impulse Responses: PCP Model

Confidence Bounds of IRFs to a News TFP Shock



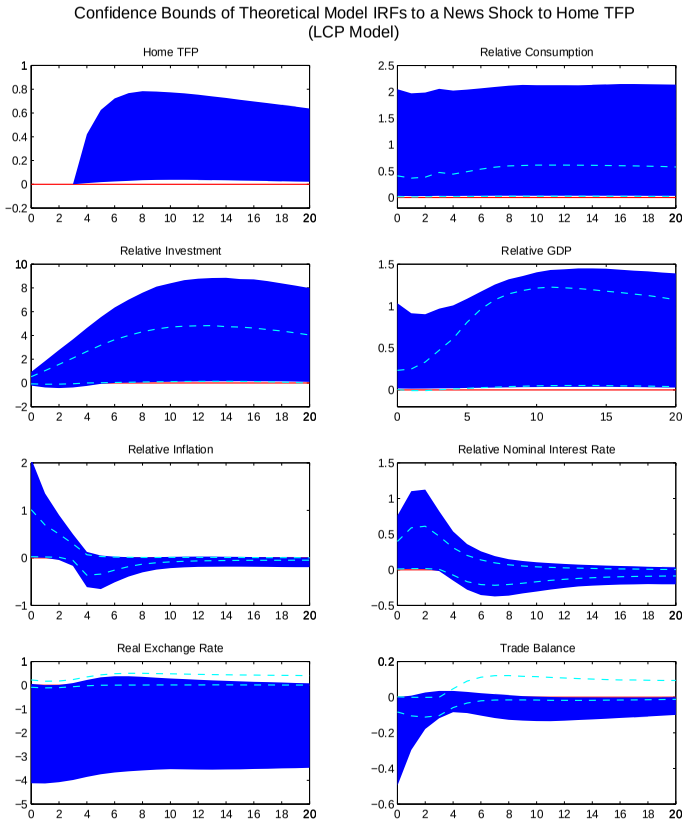
Confidence Bounds of IRFs to a Contemporaneous TFP Shock



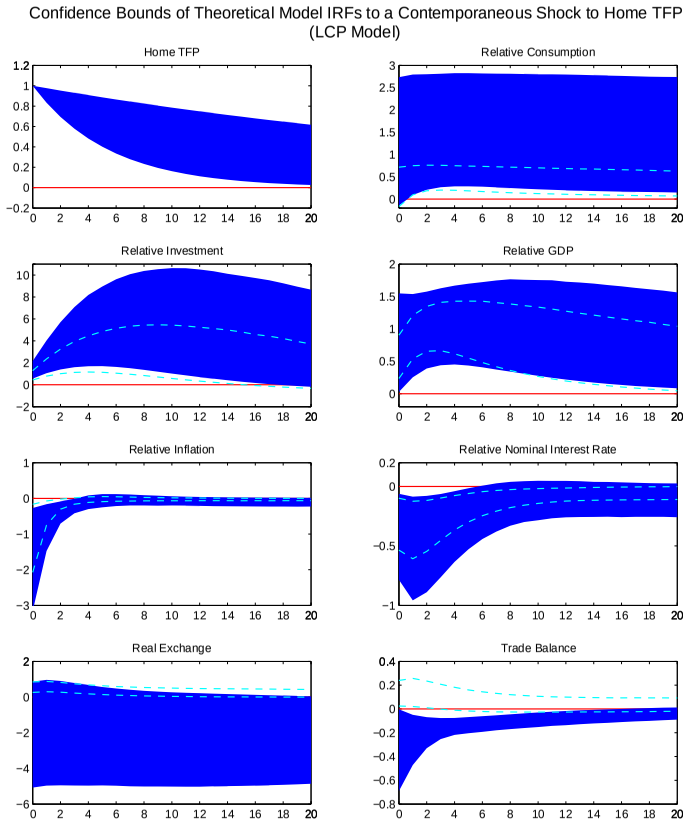
Note: This figure displays the 95% confidence bounds of theoretical PCP model impulse responses to positive news (left panel) and contemporaneous (right panel) shocks to home TFP over 100,000 random draws of the model parameter values. The blue area represents the confidence bound for the low range of the trade price elasticity, [0.1,0.33], and the area between the two dotted lines is the confidence bound for the high range, [1,4].

Figure 6: Confidence Bounds of Theoretical Model Impulse Responses: LCP Model

Confidence Bounds of IRFs to a News TFP Shock



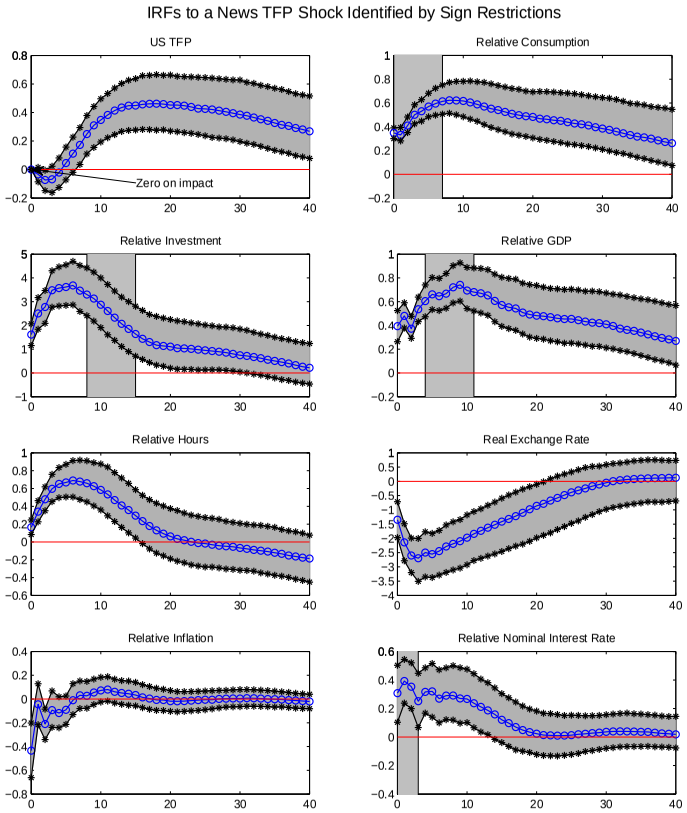
Confidence Bounds of IRFs to a Contemporaneous TFP Shock



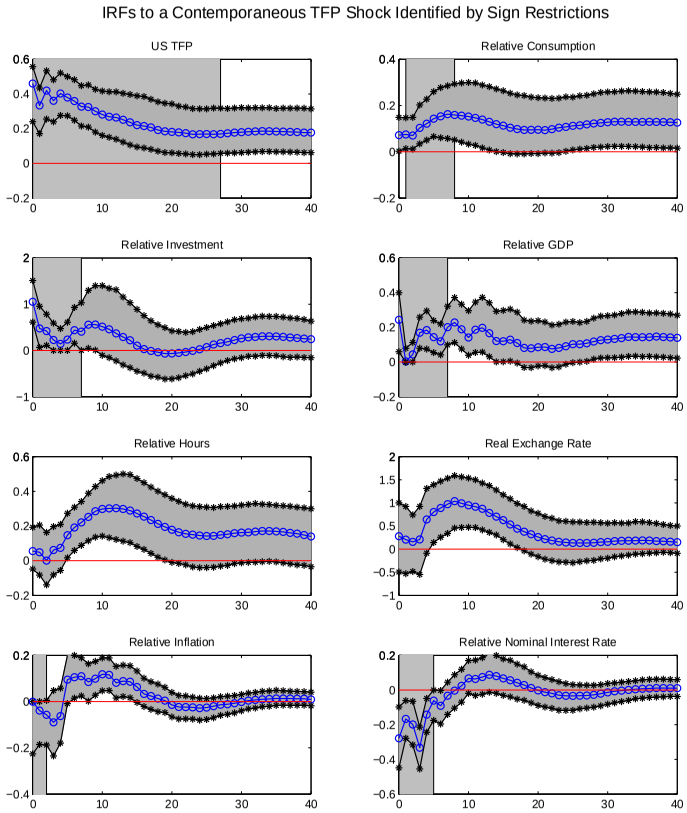
Note: This figure displays the 95% confidence bounds of theoretical LCP model impulse responses to positive news (left panel) and contemporaneous (right panel) shocks to home TFP. Also see the note below Figure 5.

Figure 7: Impulse Response Functions: Sign Restrictions Method

Impulse Responses to a Positive News TFP Shock



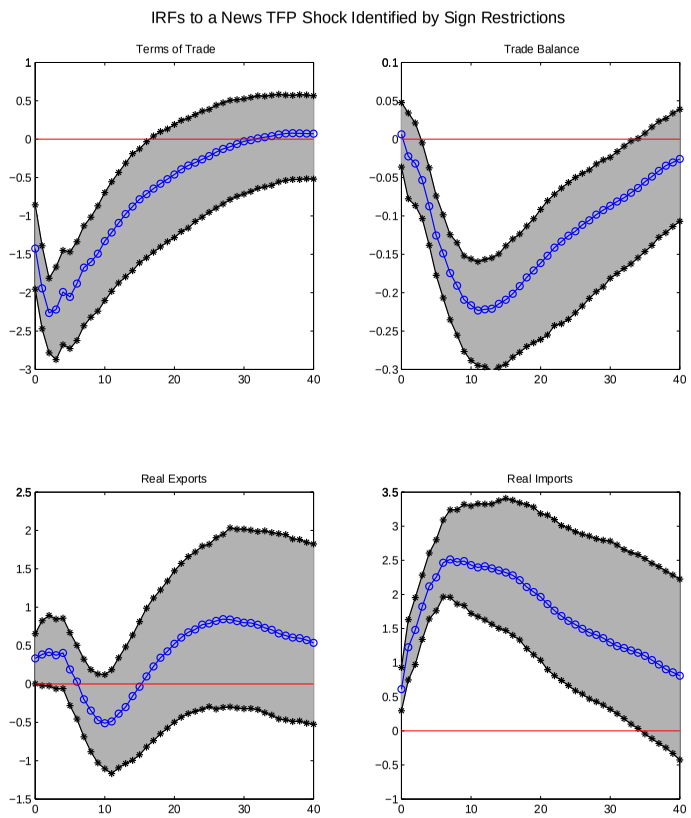
Impulse Responses to a Positive Contemporaneous TFP Shock



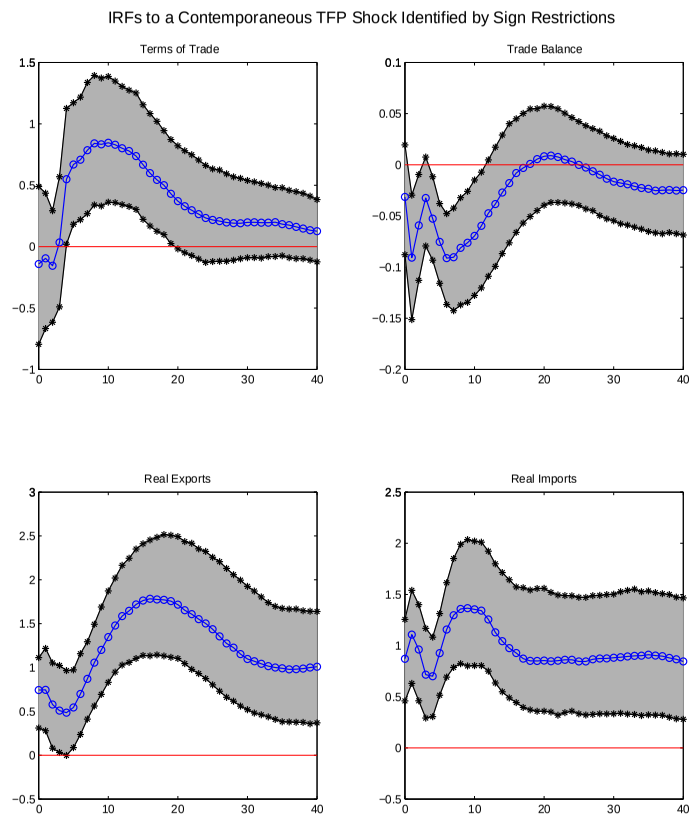
Note: This figure has two panels each of which displays the impulse responses in the eight-variable VAR system to news (left panel) and contemporaneous (right panel) TFP shocks. The shocks are identified by imposing the sign restrictions described in Panel A of Table 6 and the vertical gray area represents the period on which the sign restrictions are imposed.

Figure 8: Impulse Responses Functions of Terms of Trade and Three Trade Variables: Sign Restrictions Method

Impulse Responses to a Positive News TFP Shock



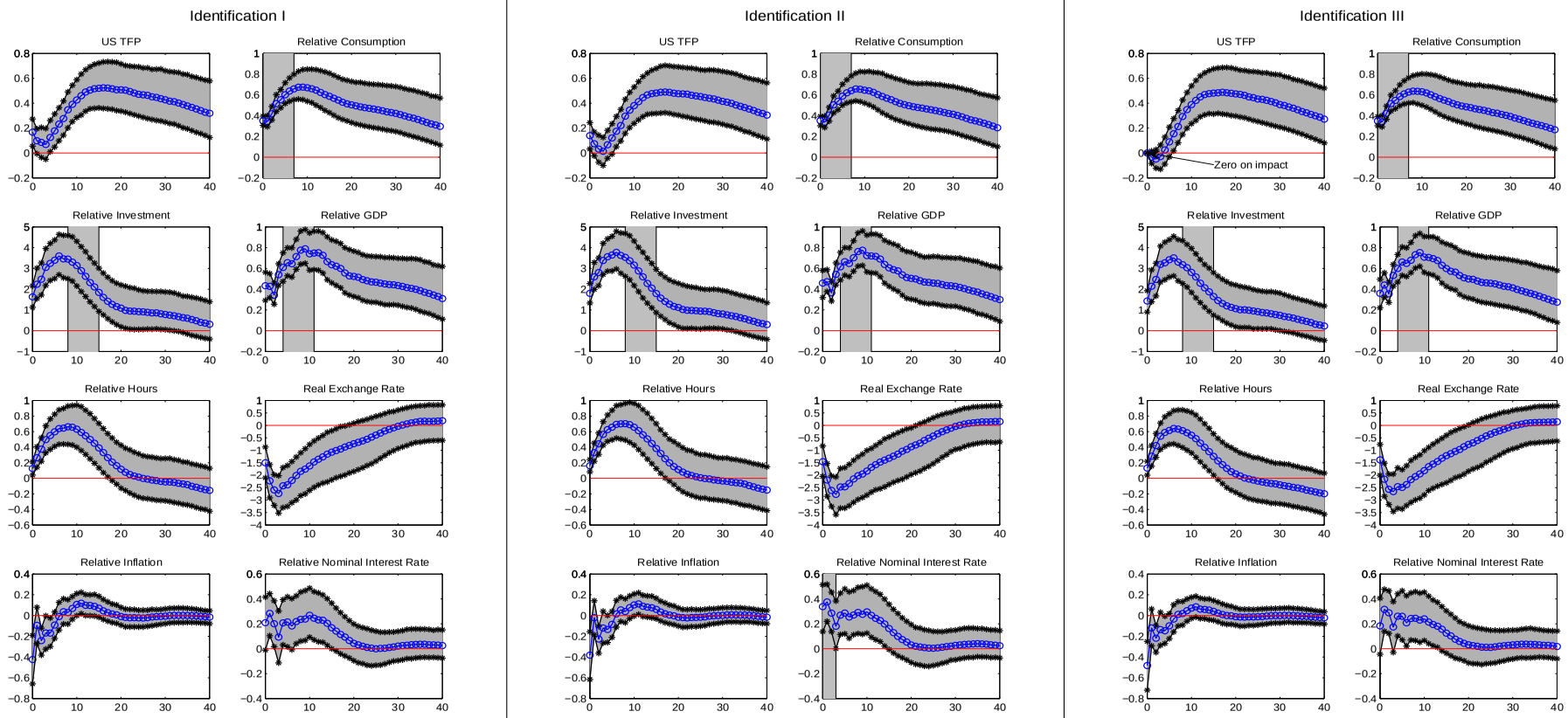
Impulse Responses to a Positive Contemporaneous TFP Shock



Note: This figure has two panels each of which displays the impulse responses of the terms of trade, trade balance, real exports, and real imports in the nine-variable VAR systems to each of news (left panel) and contemporaneous (right panel) TFP shocks. The shocks are identified by imposing the sign restrictions described in Panel A of Table 6 and the vertical gray area represents the period on which the sign restrictions are imposed.

Figure 9: Impulse Response Functions to a News TFP Shock: Alternative Sign Restrictions

Identification I | Identification II | Identification III



Note: This figure has three panels each of which displays the impulse responses in the eight-variable VAR model to the shock identified by imposing Identifications I, II, and III, which are described in Panel B of Table 6. The vertical gray area represents the period on which the sign restrictions are imposed.

Table 1: Forecast Error Variance Decomposition

	Share of FEV Attributable to News TFP Shocks						Share of FEV Attributable to Contemporaneous TFP Shocks						Sum of Two Shares					
	h=0	h=4	h=8	h=16	h=24	h=40	h=0	h=4	h=8	h=16	h=24	h=40	h=0	h=4	h=8	h=16	h=24	h=40
US TFP	0.00	0.02	0.12	0.39	0.52	0.57	1.00	0.87	0.74	0.50	0.39	0.30	1.00	0.91	0.88	0.91	0.92	0.89
	[0.00, 0.00]	[0.01, 0.08]	[0.04, 0.24]	[0.27, 0.54]	[0.37, 0.67]	[0.40, 0.73]	[1.00, 1.00]	[0.80, 0.92]	[0.63, 0.83]	[0.37, 0.64]	[0.25, 0.53]	[0.16, 0.46]	[1.00, 1.00]	[0.86, 0.95]	[0.81, 0.94]	[0.85, 0.95]	[0.87, 0.96]	[0.80, 0.94]
Relative Consumption	0.70	0.75	0.76	0.75	0.74	0.70	0.03	0.03	0.04	0.06	0.06	0.06	0.75	0.80	0.82	0.83	0.84	0.81
	[0.49, 0.85]	[0.55, 0.87]	[0.56, 0.88]	[0.54, 0.88]	[0.53, 0.87]	[0.47, 0.84]	[0.01, 0.06]	[0.01, 0.07]	[0.01, 0.10]	[0.01, 0.16]	[0.01, 0.17]	[0.02, 0.19]	[0.53, 0.89]	[0.60, 0.90]	[0.63, 0.92]	[0.65, 0.92]	[0.64, 0.92]	[0.60, 0.91]
Relative Investment	0.05	0.21	0.30	0.32	0.34	0.33	0.11	0.03	0.04	0.06	0.07	0.07	0.18	0.25	0.35	0.42	0.43	0.44
	[0.00, 0.20]	[0.05, 0.48]	[0.08, 0.57]	[0.10, 0.59]	[0.11, 0.58]	[0.12, 0.56]	[0.06, 0.16]	[0.02, 0.07]	[0.02, 0.10]	[0.02, 0.16]	[0.03, 0.16]	[0.03, 0.16]	[0.10, 0.31]	[0.09, 0.52]	[0.14, 0.62]	[0.20, 0.66]	[0.22, 0.66]	[0.23, 0.66]
Relative GDP	0.07	0.30	0.44	0.53	0.57	0.58	0.13	0.08	0.06	0.07	0.07	0.07	0.22	0.39	0.52	0.63	0.67	0.69
	[0.01, 0.21]	[0.11, 0.50]	[0.21, 0.63]	[0.29, 0.71]	[0.33, 0.74]	[0.34, 0.76]	[0.08, 0.19]	[0.04, 0.13]	[0.03, 0.12]	[0.03, 0.15]	[0.03, 0.16]	[0.02, 0.17]	[0.13, 0.35]	[0.21, 0.58]	[0.29, 0.70]	[0.40, 0.78]	[0.44, 0.82]	[0.46, 0.83]
Relative Hours	0.06	0.20	0.23	0.21	0.19	0.18	0.00	0.01	0.03	0.11	0.14	0.14	0.07	0.22	0.28	0.36	0.37	0.35
	[0.01, 0.22]	[0.04, 0.46]	[0.04, 0.51]	[0.05, 0.45]	[0.05, 0.40]	[0.06, 0.36]	[0.00, 0.02]	[0.00, 0.03]	[0.01, 0.07]	[0.04, 0.22]	[0.04, 0.26]	[0.04, 0.26]	[0.01, 0.23]	[0.05, 0.49]	[0.08, 0.55]	[0.17, 0.59]	[0.20, 0.57]	[0.20, 0.54]
Real Exchange Rate	0.10	0.27	0.32	0.31	0.29	0.30	0.01	0.02	0.04	0.07	0.08	0.08	0.11	0.29	0.37	0.41	0.40	0.41
	[0.01, 0.27]	[0.09, 0.50]	[0.11, 0.54]	[0.11, 0.51]	[0.11, 0.49]	[0.12, 0.49]	[0.00, 0.03]	[0.01, 0.04]	[0.02, 0.10]	[0.02, 0.15]	[0.03, 0.16]	[0.03, 0.17]	[0.03, 0.28]	[0.11, 0.52]	[0.16, 0.60]	[0.20, 0.61]	[0.20, 0.60]	[0.22, 0.60]

Note: This table reports the shares of the forecast error variances (FEVs) of variables in the benchmark six-variable system attributable to the identified news (left panel) and contemporaneous (middle panel) TFP shocks. The right panel is the sum of these two shares. The number represents the median share, and the numbers in brackets are the 16th and 84th quantiles. The letter h refers to the forecast horizon.

Table 2: Business Cycle Volatility and Correlation with Real Exchange Rate

	A. Business Cycle Variance Decomposition		B. Relative Standard Deviation			C. Correlation with Real Exchange Rate		
	Variance Contribution of News TFP Shocks	Variance Contribution of Cont. TFP Shocks	Data	Counterfactual Data Conditional on News TFP Shocks	Counterfactual Data Conditional on Cont. TFP Shocks	Data	Counterfactual Data Conditional on News TFP Shocks	Counterfactual Data Conditional on Cont. TFP Shocks
Relative Consumption	0.71	0.10	0.64	0.97	0.66	-0.27	-0.90	0.12
	[0.48, 0.95]	[0.04, 0.23]		[0.75, 1.23]	[0.44, 0.96]		[-0.97, -0.64]	[-0.52, 0.62]
Relative Investment	0.35	0.13	5.79	5.94	6.83	-0.20	-0.72	0.25
	[0.12, 0.76]	[0.05, 0.31]		[4.55, 7.84]	[4.63, 9.64]		[-0.92, -0.07]	[-0.43, 0.65]
Relative GDP	0.32	0.10	1.01	0.58	0.31	-0.01	-0.79	-0.15
	[0.17, 0.53]	[0.05, 0.18]		–	–		[-0.94, -0.28]	[-0.65, 0.40]
Relative Hours	0.31	0.17	1.31	1.29	1.79	-0.17	-0.76	0.43
	[0.09, 0.72]	[0.06, 0.39]		[0.87, 1.70]	[1.02, 2.64]		[-0.92, -0.16]	[-0.23, 0.82]
Real Exchange Rate	0.30	0.11	5.15	4.91	5.61			
	[0.11, 0.59]	[0.04, 0.26]		[2.78, 8.35]	[3.20, 8.84]			

Note: Panel A reports the ratio of the variance of the counterfactual data conditional on each identified TFP shock to the variance of the actual data. Panel B reports the standard deviations relative to the standard deviation of relative GDP for the actual data (left column) and the counterfactual data (middle and right columns), where for relative GDP, the level of its standard deviation in percent is reported. Panel C reports the correlations with the real exchange rate for the actual data (left column) and the counterfactual data (middle and right columns). Cont. represents contemporaneous. All statistics reported in all three panels are calculated after applying the band pass filter to the (actual and counterfactual) data. For the counterfactual data, the number represents the median, and the numbers in brackets are the 16th and 84th quantiles.

Table 3: Calibrated Parameter Values

Parameter	Description	Value
σ	Risk aversion	2
γ	Consumption weight in utility	It is chosen such that hours worked is one third in the steady state.
ψ	Parameter that determines the steady state discount factor	It is calibrated to have the discount factor of 0.99 in the steady state.
δ_0	Steady state capital depreciation rate	0.025
δ_1	Parameter that governs the steady state capital utilization rate	It is chosen to ensure that the capital utilization rate equals one in the steady state.
ω	Home bias	0.88
φ	Capital share	0.36
ϕ	Elasticity of substitution between differentiated intermediate goods	6

Table 4: Estimated Parameter Values

		Matching IRFs to Both TFP Shocks	Matching IRFs to News TFP Shocks	Matching IRFs to Cont. TFP Shocks
Parameter	Description	Estimate (S.E.)	Estimate (S.E.)	Estimate (S.E.)
κ	Investment adjustment costs	5.77 (1.66)	1.60 (1.36)	5.13 (1.69)
δ_2/δ_1	Elasticity of capital utilization to the rental rate of capital in the steady state	0.55 (0.38)	1.03 (0.65)	0.25 (0.25)
θ	Trade price elasticity	1.19 (0.24)	0.28 (0.03)	1.23 (0.30)
α	Calvo parameter	0.76 (0.06)	0.72 (0.11)	0.71 (0.08)
Θ_i	Interest smoothing coefficient	0.72 (0.09)	0.68 (0.23)	0.86 (0.12)
Θ_π	Inflation targeting coefficient	1.54 (0.28)	1.55 (0.31)	2.19 (0.67)
Θ_y	Output gap coefficient	0.24 (0.09)	0.01 (0.15)	0.24 (0.25)
ξ^u	Persistence of contemporaneous TFP shocks	0.91 (0.01)		0.89 (0.01)
σ_{ε^c}	Standard deviation of contemporaneous TFP shocks	0.67 (0.05)		0.56 (0.02)
ξ^s	Degree of diffusion of news TFP shocks	0.56 (0.02)	0.76 (0.04)	
σ_{ε^n}	Standard deviation of news TFP shocks	0.89 (0.10)	0.99 (0.16)	

Note: This table reports the estimates of the model parameters under the PCP with their standard errors (S.E.). When matching the IRFs only to news TFP shocks, the parameter ξ^u is set equal to its estimate of 0.91 resulting from matching the IRFs to both TFP shocks. The estimates of standard deviations of two TFP shocks are reported in percent. Cont. represents contemporaneous.

Table 5: Model Parameter Value Ranges used in Simulation for Confidence Bounds of Theoretical Model Impulse Responses

Parameter	Description	Range
σ	Risk aversion	[1, 10]
γ	Consumption weight in utility	[0.02, 0.89]
β	Steady state discount factor	[0.982, 0.99]
κ	Investment adjustment costs	[2.05, 2.91]
δ_0	Steady state capital depreciation rate	[0.0038, 0.0602]
δ_2/δ_1	Elasticity of capital utilization to the rental rate of capital in the steady state	[0.1, 1]
ω	Home bias	[0.84, 0.92]
θ	Trade price elasticity	Low: [0.1, 0.33] or High: [1, 4]
φ	Capital share	[0.15, 0.39]
ϕ	Elasticity of substitution between differentiated intermediate goods	[3.5, 15]
α	Calvo parameter	[0.55, 0.77]
Θ_i	Interest smoothing coefficient	[0.65, 0.9]
Θ_π	Inflation targeting coefficient	[1.5, 2.5]
Θ_y	Output gap coefficient	[0.5, 1]
ξ^u	Persistence of contemporaneous TFP shocks	[0.89, 98]
ξ^s	Degree of diffusion of news TFP shocks	[0.5, ξ^u]

Note: This table reports the ranges of the model parameter values used in the simulation of generating the confidence bounds of theoretical model impulse responses. Most of the parameter value ranges are taken from Enders, Muller, and Scholl (2011). The steady state discount factor β determines the value of the parameter ψ, and the parameter δ_1 is chosen to ensure that the capital utilization rate equals one in the steady state.

Table 6: Sign Restrictions for Identifying News and Contemporaneous TFP Shocks

A. Sign Restrictions

	US TFP	Relative Consumption	Relative Investment	Relative GDP	Relative Inflation	Relative Interest Rate	Other Variables
News TFP Shocks	0 [0, 0]	+ [0, 7]	+ [8, 15]	+ [4, 11]		+ [0, 3]	
Contemporaneous TFP Shocks	+ [0, 27]	+ [1, 8]	+ [0, 7]	+ [0, 7]	- [0, 2]	- [0, 5]	

B. Alternative Sign Restrictions for Identifying News TFP Shocks

	US TFP	Relative Consumption	Relative Investment	Relative GDP	Relative Inflation	Relative Interest Rate	Other Variables
Identification I		+ [0, 7]	+ [8, 15]	+ [4, 11]			
Identification II		+ [0, 7]	+ [8, 15]	+ [4, 11]		+ [0, 3]	
Identification III	0 [0, 0]	+ [0, 7]	+ [8, 15]	+ [4, 11]			

Note: Panel A describes the sign restrictions to identify positive news and contemporaneous shocks to US TFP. The impulse response of a variable in a VAR model is restricted to be non-negative (+), non-positive (-), zero (0) or unrestricted (blank). The numbers in brackets are the lower and upper bounds of the horizon period over which the sign restriction is imposed. Panel B shows three alternative sign restrictions for identifying news TFP shocks, called Identifications I, II, and II, respectively.

Appendix A Optimization Problem in Identifying News Shocks

This appendix describes Barsky and Sims' (2011) strategy to identify news and contemporaneous TFP shocks. For any VAR model, the reduced-form moving average representation for a vector of variables in levels, $Y_t : N \times 1$, can be expressed as:

$$Y_t = B(L)\, u_t,$$

where $B(0) = I_N$ and u_t is reduced-form innovations with a variance-covariance matrix of Σ_u. The relationship between the reduced-form innovations u_t and the structural shocks ϵ_t is given by a non-unique impact matrix A_0:

$$u_t = A_0 \epsilon_t,$$

where $A_0 A_0' = \Sigma_u$ and the variances of structural shocks are normalized to unity (i.e., $E[\epsilon_t \epsilon_t'] = I_N$). Let $\widetilde{A}_0$ denote an arbitrary orthogonalization of Σ_u, that is, $\widetilde{A}_0 \widetilde{A}_0' = \Sigma_u$ (e.g., $\widetilde{A}_0$ is the Cholesky decomposition of Σ_u) and Q denote an orthonormal matrix of conformable size, that is, $DD' = I_N$. Then, the matrix $\widetilde{A}_0 Q$ spans the space of possible orthogonalizations of Σ_u:

$$u_t = A_0 \epsilon_t = \widetilde{A}_0 Q \epsilon_t.$$

The h-step ahead forecast error of Y_{t+h} in terms of the structural shocks over the space of possible orthogonalizations is:

$$Y_{t+h} - E_t[Y_{t+h}] = \sum_{\tau=0}^{h} B_\tau \widetilde{A}_0 Q \epsilon_{t+h-\tau},$$

where $B_\tau \widetilde{A}_0 Q$ is the coefficient matrix of the structural moving average representation at horizon τ. Then, the share of the forecast error variance (FEV) of variable i attributable to structural shock j at horizon h, which is denoted by $\Omega_i^{(j)}(h)$, is expressed as:

$$\Omega_i^{(j)}(h) = \left(\sum_{\tau=0}^{h} \left(B_{i,\tau} \widetilde{A}_0 q^{(j)} \right) \left(B_{i,\tau} \widetilde{A}_0 q^{(j)} \right)' \right) \Big/ \left(\sum_{\tau=0}^{h} B_{i,\tau} \Sigma_u B_{i,\tau}' \right) = q^{(j)} \mathbf{F}_i(h)\, q^{(j)\prime},$$

where $B_{i,\tau}$ is the ith row of B_τ and $q^{(j)}$ is the jth column of Q.

Without loss of generality, let observed TFP occupy the first position in a vector of variables Y_t, and let $\epsilon_t^{(1)}$ and $\epsilon_t^{(2)}$ denote the first and second structural shocks that represent the contemporaneous and news TFP shocks, respectively. Then, it is assumed that $\epsilon_t^{(1)}$ and $\epsilon_t^{(2)}$ account for all of the FEV of TFP at all

horizons:

$$\Omega_1^{(1)}(h) + \Omega_1^{(2)}(h) = 1, \quad \forall\, h.$$

With contemporaneous TFP shocks identified as the reduced-form innovations to TFP, the share of the FEV of TFP attributable to contemporaneous TFP shocks (i.e., $\Omega_1^{(1)}(h)$) is invariant to all alternative identifications of the other $N-1$ structural shocks at all horizons. As a result, news TFP shocks are identified by making the above expression hold as much close as possible over all horizons up to a truncation horizon denoted by H. It amounts to solving the following maximization problem:

$$q^* = \arg\max_{q^{(2)}} \sum_{h=0}^{H} \Omega_1^{(2)}(h) = q^{(2)}\mathbf{F}_1(h)\, q^{(2)\prime},\ s.t.\ \ (1)\ \ q^{(2)\prime}q^{(2)} = 1;\ \ (2)\ \ q_1^{(2)} = 0,$$

where $q_1^{(2)}$ represents the first element of an orthonormal vector $q^{(2)}$ and the constraint $q_1^{(2)} = 0$ means that news TFP shocks have no immediate impact on TFP. The objective function in the above maximization problem can be expressed as:

$$q^{(2)}\mathbf{F}_1(H)\, q^{(2)\prime} \text{ with } \mathbf{F}_1(H) = \sum_{h=0}^{H} \mathbf{F}_1(h) \text{ is an } N \times N \text{ symmetric matrix,}$$

and the corresponding Lagrangian can be expressed as $\mathcal{L}(q) = q\mathbf{F}_1(H)\, q' - (q'q - 1)$, where the superscript of $q^{(2)}$ is dropped. Since $q_1 = 0$, this Lagrangian implies that $q^* = (0, q_{\mathbf{2}}^{*\prime})'$, where $q_{\mathbf{2}}^*$ is the eigenvector corresponding to the largest eigenvalue of the $(N-1)\times(N-1)$ sub-matrix of $\mathbf{F}_1(H)$ (i.e., the one obtained from eliminating the first row and the first column of $\mathbf{F}_1(H)$).

Appendix B Rest of the World Data

The "rest of the world" (ROW) data comprises the rest of the G7 countries: Canada, France, Germany, Italy, Japan, and the UK. We obtain the data from the following sources:

- US TFP – the factor-utilization-adjusted TFP series from John Fernald's website.
- US real exports – US real exports of goods and service (chained 2005 US dollar) from the US Bureau of Economic Analysis (BEA).
- US real imports – US real imports of goods and service (chained 2005 US dollar) from the BEA.
- US trade balance – US nominal net exports divided by nominal GDP. Both nominal net exports and GDP are from the BEA.

- Consumption – real private consumption expenditure obtained from the OECD Main Economic Indicator (MEI) for all of the rest of the G7 countries; US: BEA.

- Investment – Canada: Statistics Canada; France: OECD (Economic Outlook); Germany: Deutsche Bundesbank and Haver Analytics; Italy: Eurostat; Japan: OECD (Economic Outlook); UK: Office for National Statistics (ONS); US: BEA.

- GDP – Canada: Statistics Canada; Germany: Statistical Office of the European Communities; France: OECD (MEI); Italy: Istituto Nazionale di Statistica; Japan: IMF and OECD (national accounts); UK: ONS; US: BEA.

- Hours worked – Total hours worked are calculated from hours worked per employee and total employment in the rest of the G7 countries. Both hours worked per employee and total employment in each country are obtained from OECD (Economic Outlook); US: US Bureau of Labor Statistics (BLS).

- The US real exchange rate is aggregated from the bilateral real exchange rates between the US and the rest of the G7 countries. The bilateral real exchange rates are calculated from CPIs and the bilateral nominal exchange rates between the US dollar and the currencies in the rest of the G7 countries. The terms of trade is aggregated from the bilateral terms of trade between the US and the rest of the G7 countries. The bilateral terms of trade is calculated from the bilateral nominal exchange rate and the export deflators.

  - Bilateral nominal exchange rate – Canada, Japan, and UK: IMF; Germany, France, and Italy: IMF and European Commission.

  - CPI – Canada, France, and UK: OECD; Germany: Deutsche Bundesbank; Italy and Japan: G10 dataset of Haver Analytics; US: BLS.

  - Export deflator – all G7 countries: OECD (Economic Outlook).

- Nominal interest rate (all data for the rest of the G7 countries are taken from the IMF) – Canada: overnight financing rate and 3-month Treasury bills rate; Germany: interbank overnight rate; France: day-to-day loans against private bills; Italy: 3-month interbank deposits rate; Japan: Tokyo overnight call money rate; UK: interbank overnight offer rate; US: interbank overnight fed funds rate from Federal Reserve database.

- Inflation rate – CPI inflation calculated from the above CPI data.

We construct the ROW real consumption, investment, GDP, and hours worked by first calculating quarterly growth rates and then aggregating the growth rates weighted by each country's GDP share in the group's total GDP. The GDP shares after 1980 are calculated from the PPP-based GDP shares of the world total that we obtain from the International Monetary Fund. The GDP shares from 1973 to 1979 are calculated from the PPP US dollar GDP in the G7 countries that we obtain from OECD Economic Outlook.