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 (real exports, real imports, and the trade balance). These findings are robust under two fundamentally different identification schemes. 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. In addition, we evaluate a standard international macroeconomic model and discuss the mechanisms that help to replicate our empirical findings.

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1 Introduction

This paper 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, we refer to them as news TFP shocks. We empirically show that the international transmission of these two types of TFP shocks is strikingly different. Therefore, empirical studies that do not carefully distinguish these two shocks can reach incomplete and even misleading results on the international transmission of country-specific technology changes. We also examine the mechanisms that may help theoretical models to replicate our empirical findings, shedding light on future theoretical studies on this issue.

Recently, there has been a revived and growing interest in the role of news shocks in explaining business cycles. In the empirical studies, news TFP shocks are found to account for a large fraction of US business cycles.\footnote{For instance, see Beaudry and Portier (2006), Barsky and Sims (2011) and Schmitt-Grohé and Uribe (2012).} Therefore, 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 2014), Enders and Muller (2009), Enders, Muller, and Scholl (2011), and Juvenal (2011). However, none of these studies make a distinction between news and contemporaneous components of productivity shocks. The findings in our paper complement theirs and shed light on some puzzling results in these previous studies, highlighting the importance of distinguishing these two shocks in empirical studies.

In our empirical exercises, we focus on the effects of US news and contemporaneous 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). This focus is motivated by the fact that both trade volume and international relative prices play important roles in the international transmission of country-specific productivity shocks. In particular, relative price movements are a major channel for trade adjustment and induce important cross-country wealth effects.\footnote{For instance, see Cole and Obstfeld (1991) and Corsetti, Dedola, and Leduc (2008), among others.} Furthermore, we examine the roles of these two TFP shocks in accounting for 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 expected changes in future fundamentals rather than current fundamental changes, for instance, Engel and West (2005) and Chen, Rogoff, and Rossi (2010), among others. Although some empirical studies examine 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.\textsuperscript{3} Our work also fills this gap in the literature.

We first identify news and contemporaneous shocks to US TFP in the SVAR framework by employing the identification strategy in Barsky and Sims (2011), and then study the international transmissions of these two TFP shocks.\textsuperscript{4} We also investigate the relative importance of these two shocks in explaining US real exchange rate movements. Then we estimate and evaluate a standard international macroeconomic model, using our estimated VAR impulse responses.

Quarterly data for the US and an aggregate of the rest of G7, which is referred to as the rest of the world (ROW), are used in this paper. 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. 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. That real appreciation is very persistent, lasting for more than 16 quarters. We define the exchange rate such that a decrease 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

\textsuperscript{3}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 (2013) 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.

\textsuperscript{4}As Lorenzoni (2011) points out, our SVAR approach to studying the effects of news shocks implies that we restrict our attention to perfectly anticipated shocks and do not consider other types of news about future TFP, such as noise shocks in Lorenzoni (2009) and Blanchard, L’Huillier, and Lorenzoni (2013).
quarters before converging back to its initial level.

We also find that both news and contemporaneous TFP shocks generate co-movement among US-ROW relative macroeconomic aggregates although the dynamics of the aggregates are different under these two shocks. Following a positive news TFP shock, US TFP only increases gradually with a delay of more than one year. In contrast, US-ROW relative consumption, investment, GDP, and hours all rise substantially and peak before US TFP starts to increase significantly, with a sharp increase in relative consumption leading the increases in relative investment, GDP, and hours. This pattern is consistent with the narrative of expectations-driven business cycles as documented in Beaudry and Portier (2006) and Beaudry, Nam, and Wang (2011). On the other hand, following a positive contemporaneous TFP shock, US TFP jumps immediately and then declines gradually over time. US-ROW relative consumption, investment, and GDP all increase immediately with TFP and these increases are persistent, which is consistent with productivity-driven business cycles as predicted by standard international macroeconomic models.

We highlight three findings for the effects of news and contemporaneous TFP shocks on US trade variables. First, the terms of trade has similar dynamics to the real exchange rate. 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 also quite distinct for these two TFP shocks. 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
In the last part of the paper, we evaluate a group of standard international business cycle models (e.g., Chari, Kehoe, and McGrattan, 2002). We find that the standard international business cycle models have difficulties in replicating, both qualitatively and quantitatively, 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. We briefly discuss the mechanisms that may help to replicate our empirical findings.

The remainder of the paper is organized in three sections. Section 2 describes our benchmark identification strategy and data set. Our main empirical results are also reported in this section. Section 3 evaluates standard international business cycle models and section 4 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). The identification scheme of Barsky and Sims imposes a minimum of identifying restrictions only on a measure of TFP and allows the data to speak for itself. It can also be easily applied to large VAR systems. Specifically, their identification scheme assumes that news and contemporaneous shocks to TFP fully explain variation in observed TFP as a measure of true technology. 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. We leave the details on this identification scheme to an appendix on the

\footnote{In Monte Carlo exercises that are not reported in this paper, we find that their identification approach can correctly uncover the theoretical IRFs to news TFP shocks in standard international business cycle models with news and contemporaneous TFP shocks and several other shocks. Nevertheless, we admit that every identification scheme has its own shortcomings, and thus we take the sign restriction approach as an alternative identification approach in our robustness check.}

\footnote{As in Barsky and Sims (2011), the truncation horizon \( H \) is set equal to 40 quarters. Our results are robust to other choices of \( H \).}
authors’ websites.

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.\footnote{Details about the data sources can be found in an appendix on the authors’ websites.}

As in Barsky and Sims (2011), our measure of US TFP is the US quarterly factor-utilization-adjusted TFP series provided in Fernald (2009).\footnote{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.} This TFP series is adjusted for capital utilization and labor effort, which is crucial to implement the identification scheme of Barsky and Sims (2011) because it imposes 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 (2010) 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 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.\footnote{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 later.} 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 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.\(^\text{10}\) 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. Larger VAR models are also considered in the robustness check that uses the sign restrictions approach.

### 2.2 Effects of Surprise and Anticipated TFP Shocks on International Prices

This subsection presents the impulse response functions (IRFs) to identified news and contemporaneous US TFP shocks in our benchmark VAR model. We show that the US real exchange rate exhibits substantially different dynamics following news and contemporaneous TFP shocks. We show in the appendix that our main findings are robust to an alternative identification method, the sign restrictions approach.

We first check the exogeneity of our identified news and contemporaneous shocks by testing if they can be predicted by other variables like government spending, the relative price of investment and consumption goods, and oil prices.\(^\text{11}\) In these exercises, we regress the identify news and contemporaneous TFP shocks on the lagged changes in government spending, the lagged changes in the relative prices between investment and consumption goods and the lagged changes in oil prices. In general, we fail to reject the null that the coefficients are jointly zero, indicating that these lagged variables cannot predict our identified shocks. Details about these tests and results are reported in an appendix on the authors’ websites.

In Figure 1, the left and right panels display the estimated IRFs to favorable news and contemporaneous TFP shocks, respectively. 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.

\(^{10}\) 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. However, our results are robust to different numbers of lags and different filtering (e.g., in log differences rather than in log levels and in some cointegration relationships).

\(^{11}\) We thank a referee for the suggestion of this exercise and the results are available upon request.
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. In addition, we find that the increases of US-ROW relative variables are mainly driven by increases in US variables rather than decreases in ROW variables. 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.

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.

The most striking observation is that news and contemporaneous TFP shocks induce substan-

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12 In these exercises, we replace the US-ROW relative variables in our benchmark VAR system with the corresponding variables of the US and the ROW. For example, US-ROW relative GDP is replaced with US GDP and ROW GDP, and then in the resulting seven-variable system, the impulse response functions are estimated by employing Barsky and Sims’ identification scheme. The results are available upon request.

13 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. This is also confirmed in a robustness check using the sign restrictions approach.
tially 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.

Enders and Muller (2009) identify US labor productivity shocks using long-run restrictions as in Gali (1999). They document that following their identified positive labor productivity shock, the US real exchange rate displays a J-curve pattern, which is similar to that of our identified news TFP shock. In contrast, Enders, Muller, and Scholl (2011) document a hump-shaped pattern for the real exchange rate, which is similar to that of our identified contemporaneous TFP shock, when they identify US technology shocks with the sign restrictions approach. We argue that the discrepancy in these findings is because the long-run restrictions in Enders and Muller (2009) identify a shock similar to our news TFP shock, while the sign restrictions in Enders, Muller, and Scholl (2011) identify a shock closely related to our contemporaneous TFP shocks.

\(^{14}\)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. Our results are robust to this measure of the real exchange rate.
Figure 1 shows that the identified news TFP shocks have a very persistent long-run effect on US TFP. We will report later that news TFP shocks also account for a large share of long-run changes in TFP. Not surprisingly, Enders and Muller’s (2009) labor productivity shocks identified from long-run restrictions are closely related to our news TFP shocks. In contrast, the sign restrictions in Enders, Muller, and Scholl (2011) are consistent with contemporaneous TFP shocks as we show in the robustness check using the sign restrictions approach in the appendix.

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 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 2014), Enders and Muller (2009), and Enders, Muller, and Scholl (2011).

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 observed in the data. In Section 3, we will assess if a standard international macroeconomic model augmented with news TFP shocks can replicate our 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 and the underlying mechanisms that generate these dynamics 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. Unlike some previous studies, we find significant responses for both real exports and real imports following identified news and contemporaneous TFP shocks, which are consistent with the perception that productivity gains are main drivers of exports and imports.\textsuperscript{15} 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.\textsuperscript{16} The IRFs of 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

\textsuperscript{15}Corsetti, Dedola, and Leduc (2014) identify US manufacturing productivity shocks by employing sign restrictions, but do not find any significant response of US real exports to their identified productivity shock. This is likely due to the fact that they do not separate news and contemporaneous components of their productivity shocks in their exercises.

\textsuperscript{16}The reported IRF of the terms of trade is estimated in the seven-variable system with the terms of trade and the trade balance. Other seven-variable systems have similar results for the IRF of the terms of trade.
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 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.

Arezki et al. (2015) consider a special type of news shocks: giant oil discoveries. There is usually a delay of 4 to 6 years between a discovery and production. Arezki et al. (2015) show that the current account declines for the first 5 years after an oil discovery and then rises sharply. This pattern is similar to the J-curve that we document for the US trade balance follow a positive news TFP shock. However, the current account determination in Arezki et al. (2015) is more persistent since the delay between a oil discovery and production is longer than the delay between our news TFP shock and the actual increase in TFP.

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 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 matching the S-shaped (unconditional) CCF observed in the data. In Section 2.3.1, we documented 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 subsection, we therefore 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

15
TFP shocks, or both. We also compute the unconditional CCF in the actual data. 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) with real exports (EXt+k) or real imports (IMt+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 underlying 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

\[17\] 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.
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. 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 increase, which suggests a negative correlation between the current TOT and future real imports.

\[\text{In the data, the contemporaneous correlation between the TOT (TOT)}_t\text{ and real imports (IM)}_t\text{ is slightly negative but almost zero. The corresponding correlation conditional on news TFP shocks is strongly negative while the correlation conditional on contemporaneous TFP shocks is strongly positive. In particular, the CCF conditional on both TFP shocks in the bottom chart traces the unconditional CCF much better than the CCF conditional on either news or contemporaneous TFP shocks.}\]
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 that use 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. Using sign restrictions to identify US TFP shocks, 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. The difference between Juvenal’s (2011) results and ours is due to the fact that she imposes sign restrictions that are consistent with contemporaneous TFP shocks but not with news TFP shocks. In fact, our identified contemporaneous TFP shocks also explain only about 10% of the FEV of the US real exchange rate, which is in the same range as Juvenal’s (2011) results.

At horizons less than 4 quarters, news and contemporaneous TFP shocks explain only a small share (about 10% of the FEV) of US real exchange rate movements. This finding suggests that other

\[19\]

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 as we show in the appendix.
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 was 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. 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.

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20 When applying the band pass filter, the frequencies are set between 6 and 32 quarters.
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 the observed relative volatility in the data well. Conditioning on either news or contemporaneous TFP shocks, the median relative standard deviation of each variable is close to that in the data. 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%), which is 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 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.

21 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.
3 Evaluation of Standard International Macroeconomic Models

In this section, we consider a standard international macroeconomic model that is augmented with news TFP shocks and shares many features with existing quantitative international business-cycle models (e.g., home bias in demand, sticky price in local currency pricing (LCP) or producer currency pricing (PCP) and Taylor-rule monetary policy). We evaluate the model’s ability to replicate the international transmission of news and contemporaneous TFP shocks, in particular, the dynamics of the real exchange rate. To this end, we estimate the model by matching the theoretical impulse response functions with those of our benchmark VAR model.

3.1 International Business Cycle Model and Estimation Results

Our two-country sticky-price dynamic stochastic general equilibrium (DSGE) model is similar to those widely used in the literature (e.g., Chari, Kehoe, and McGrattan, 2002, Kollmann, 2002, and Enders, Muller, and Scholl, 2011). 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:

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

where the functional form of the period utility function is:

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

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

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

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22Our results are robust to the utility function in Jamovich and Rebelo (2009).
where \( \bar{C}_t \) and \( \bar{L}_t \) 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.\(^{23}\)

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:

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

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

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

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:

\[
y_t(i) = A_t (u_t K_t(i))^\varphi (L_t(i))^{1-\varphi},
\]

where \( A_t \) is total factor productivity (TFP). Differentiated intermediate goods can be traded across countries and are aggregated into a CES composite:

\[
Y_{Ht} = \left( \int_0^1 y_t(i)^{\frac{\varphi - 1}{\varphi}} \, di \right)^{\frac{\varphi}{\varphi - 1}}.
\]

We introduce price stickiness for intermediate goods \textit{a lâ} Calvo (1983). In each period, an individual firm re-optimizes its price with probability \( 1 - \alpha \) by maximizing the expected discounted profits.\(^{24}\)

\(^{23}\)We introduce the endogenous discount factor to induce stationarity, since we assume that the international asset markets are incomplete.
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:

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

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:

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

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 \( GDP_f \) 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. \( \Theta_i, \Theta_\pi, \) and \( \Theta_y \) denote the interest rate smoothing, inflation targeting, and output gap coefficients, respectively.

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.

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:

\[ a_t = a_t^u - a_t^s, \]  

(1)
with
\[ a^u_t = \xi^u a^u_{t-1} + \varepsilon^u_t + \varepsilon^u_{t-p} \text{ and } a^s_t = \xi^s a^s_{t-1} + \varepsilon^s_{t-p}, \] (2)

where \( \xi^u > \xi^s \), and \( \varepsilon^u_{t-p} \) and \( \varepsilon^s_t \) are i.i.d. with zero means. First, \( \varepsilon^u_t \) only appears in the process of \( a^u_t \) and represents contemporaneous shocks to TFP, since it affects the current level of TFP (i.e., \( a_t \)) immediately through \( a^u_t \). Second, \( \varepsilon^n_{t-p} \) appears in the processes of both \( a^u_t \) and \( a^s_t \) and represents news shocks to TFP with an anticipation horizon of \( p \geq 0 \), since \( \varepsilon^n_{t-p} \) does not have any immediate impact on the current level of TFP. This is true even when \( p = 0 \). However, \( \varepsilon^n_{t-p} \) affects the future TFP level.

Under this setup, TFP follows an AR(1) process with its coefficient of \( \xi^u \) with respect to a contemporaneous shock, while TFP changes gradually in response to a news shock, depending on the sizes of \( \xi^u \) and \( \xi^s \).\(^{24}\) 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).

To estimate our model, 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, which are standard in the literature and the details are left to the appendix on the authors’ websites.

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 \( \zeta \) denote a vector of the parameters to estimate. Then the IRFME estimate of \( \zeta \) solves the following problem:

\[
\min_{\zeta} \left( \hat{M} - M(\zeta) \right)'W \left( \hat{M} - M(\zeta) \right),
\]

\(^{24}\)The parameter \( \xi^u \) defines the persistence of contemporaneous TFP shocks. The parameter \( \xi^s \) governs the degree of diffusion of news TFP shocks, given the size of \( \xi^u \).
where \( \hat{M} \) 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 Model Estimation Results

We consider three cases when implementing the IRFME. In our benchmark case, the impulse responses to both news and contemporaneous TFP shocks are included in \( \hat{M} \). In this case, we try to match the impulse responses to both TFP shocks. In the other two cases, \( \hat{M} \) contains the impulse responses to either news or contemporaneous TFP shocks. Thus, Table 4 reports three sets of estimation results.

The parameter estimates in Table 4 are generally in line with previous studies and thus we leave discussions of most of the parameter estimates to an appendix on the authors’ websites. A very interesting finding is on the estimate of the trade elasticity (\( \theta \)). In our benchmark case, where we try to match the IRFs to both news and contemporaneous TFP shocks, the estimated trade 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 estimated 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 estimated trade elasticity is much lower: 0.28. This is very similar to the case of low trade price elasticity discussed in Corsetti, Dedola, Dedola, 25

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 \( \varepsilon_{n-\tau}^{t} \)) 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.
and Leduc (2008) and Enders and Muller (2009). 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 also required if the model tends to match the observed appreciation of the real exchange rate in response to a positive news TFP shock.

However, the model requires a relatively high trade price elasticity to generate the depreciation of the real exchange rate following a positive contemporaneous TFP shock, which we documented in the data. 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 fails to generate the observed appreciation of the real exchange rate following the news shock. If we use a low trade elasticity (the green lines with squares in the left panel) by only matching the IRFs to the news shock, the real exchange rate in the model does appreciate on impact of the news shock, but the real exchange rate will also appreciate following a positive contemporaneous TFP shock, which is against our empirical finding. More importantly, the model still performs poorly in matching the horizontally J-shaped dynamics of the impulse response of the real exchange rate following a positive news TFP shock and the hump-shaped response following a positive contemporaneous TFP shock 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 worse for relative GDP and hours worked.\(^{26}\)

\(^{26}\)It is worthwhile to note that the estimation results for all three cases are robust to exclusion of the IRF of relative consumption.
3.3 Discussions

The above estimation results suggest that standard international business cycle models cannot replicate the opposite responses of the real exchange rate following news and contemporaneous TFP shocks unless we allow a low trade elasticity following news TFP shocks and a high trade elasticity following contemporaneous TFP shocks. But several challenges remain even for models with such a trade elasticity setup.

First, our estimated low trade elasticity of 0.28, which matches a real appreciation, is far below direct estimates of trade elasticities in the literature. The direct estimates from macro data are usually around 1 and estimates from micro data are substantially greater.\(^{27}\)

Nam and Wang (2010) show that the trade elasticity required to generate a real appreciation could be higher if we increase the anticipation horizon of news shocks or shock persistence.\(^{28}\) However, empirical support is very weak for any anticipation horizon of news shocks that is extended beyond 8 quarters. Moreover, the increase in the trade elasticity from using longer anticipation horizons and/or higher persistence of news shocks is limited. For instance, even when the anticipation horizon is increased to 12 quarters, the upper bound of the trade elasticity, which is required for our model to generate a real appreciation following a positive news shock, remains at around 0.35, still far below 1. In fact, the trade elasticity has to be low enough (below a threshold) for existing standard models to generate a real appreciation. The threshold is so low in our standard model that the improvement from extending the horizon of news shocks is only very limited.\(^{29}\)

Therefore, we may have to rely on some changes in model structures to raise the trade elasticity to a level close to its direct estimates (e.g., the inclusion of non-traded components for traded goods). But a second issue remains: it is not clear, on theoretical grounds, why the trade elasticity is low following news shocks but high following contemporaneous shocks. Indeed, the opposite case is more likely to be true based on previous studies. Ruhl (2004) argues that the trade elasticity is low following temporary shocks but high following permanent shocks. If firms face entry costs, annual.

\(^{27}\)See Ruhl (2004) for discussions on these estimates.
\(^{28}\)Given the size of \(\xi^s\) in equation (2), an increase in \(\xi^u\), the parameter defining the persistence of contemporaneous TFP shocks, also raises the persistence of news TFP shocks as well as the degree of diffusion for news TFP shocks.
\(^{29}\)See Corsetti et al. (2008) for more discussions on the threshold of trade elasticity below which the real exchange rate can appreciate, rather than depreciate, and on how the real exchange rate and other model variables perform within such a region.
the benefits of positive transitory shocks may not be large enough to cover the entry costs and have no or a very small effect on the firms’ decision to participate in the international trade. In contrast, permanent shocks encourage the entry of new firms to the international trade, which will increase the trade elasticity when more firms produce similar products. As in our paper and other empirical studies, news TFP shocks are found to have permanent effects on TFP, while the effect of contemporaneous TFP shocks is mainly transitory. These studies suggest that the trade elasticity following news TFP shocks should be higher, not lower, than that following contemporaneous TFP shocks.

In sum, it is not appealing for standard models to totally rely on the trade elasticity to replicate the opposite responses of the real exchange rate to news and contemporaneous TFP shocks. It leads us to think about our empirical findings under some less standard model environments. At first glance, it may seem surprising that standard models with a trade elasticity around 1 cannot replicate a real appreciation following a positive news TFP shock. Intuitively, news shocks sounds like demand shocks: consumption and investment increase following good news about future productivity while current productivity remains constant. As a result, home goods prices should increase with an appreciation of the real exchange rate as suggested by a demand shock (e.g., an exogenous shock to consumption in the utility function) in standard international macroeconomic models. However, there is a big difference between demand shocks and news TFP shocks: news shocks change TFP in the future while demand shocks do not. Agents know perfectly about this difference under the information structure of standard models, and thus they respond to news and demand shocks differently.

In what follows, we first discuss how demand and news shocks operate differently based on their effects on the real exchange rate. Then some conjectures are made on how it may help to replicate our empirical findings by adding some features of demand shocks to news shocks.

In most international macroeconomic models with incomplete asset markets (including ours), the on-impact response of the real exchange rate is determined by the dynamics of the relative real interest rate. In these models, uncovered interest-rate parity (UIP) in real terms approximately
holds:

\[ q_t = E_t [q_{t+1}] - [r_t - r^*_t], \]

where \( q_t \) is the real exchange rate and \( r_t \) is the real interest rate. \( r^*_t \) is the foreign real interest rate. Iterating this condition, we have:

\[ q_t = \bar{q} - \sum_{j=0}^{\infty} E_t [r_{t+j} - r^*_{t+j}]. \] (3)

Equation (3) says that the on-impact change of the real exchange rate is determined by the path of the relative real interest rate. Following a positive demand shock, the home real interest rate increases relative to the foreign one, since the demand shock reduces savings in the home country. As a result, \( \sum_{j=0}^{\infty} E_t [r_{t+j} - r^*_{t+j}] \) is positive and \( q_t \) drops (appreciates) below its long-run level following a positive demand shock.

In contrast, the IRF of the relative real interest rate displays a horizontally S-shaped pattern following a positive news TFP shock (e.g., Figure 5 in Nam and Wang 2010): it is initially positive like in the case of the demand shock, but gradually declines and becomes negative after some periods. The negative response of the relative real interest rate reflects an eventual increase in TFP of the home country when the good news about future productivity materializes. Under standard model calibrations, the negative part of the relative real interest rate dominates the positive part and \( \sum_{j=0}^{\infty} E_t [r_{t+j} - r^*_{t+j}] \) is negative, indicating a depreciation of the real exchange rate (an increase in \( q_t \)) on impact of a positive news shock.

If we can modify standard models to enhance the positive part of the impulse responses of the relative real interest rate following a news shock, it will help the models to generate a real appreciation following the shock. As we mentioned, an increase in either the anticipation horizon of news shocks or their persistence will enhance the wealth effect of news shocks, which increases the initial rise of the relative real interest rate and helps to generate a real appreciation. However, the quantitative effect is limited and the empirical support is weak for any news shock horizons beyond 8 quarters, as we discussed.
Information frictions such as information dispersion discussed in Lorenzoni (2009, 2010) and Angeletos and La’O (2011) might help to replicate our empirical findings. However, several difficulties remain in such models. For instance, our identified news shocks are perfectly anticipated and will eventually change TFP with a delay. The noise shocks in Lorenzoni (2009), in contrast, do not influence TFP in the future. Another problem is that SVARs may not recover news and noise shocks correctly in such a model, as discussed in Blanchard et al. (2013).

We believe that theoretical explorations of the sources of empirically identified news shocks might be helpful to reconcile theoretical models with our empirical results. Bacchetta and van Wincoop (2013) develop a two-country model in which a self-fulfilling shock to expectations induces synchronized deep recessions in both countries, similar to the Great Recession in 2008. Besides sentiment shocks through international financial markets, intangible assets could be another channel for the international transmission of news shocks. For example, a decline in ROW output may lead to the shifting of intangible resources to the US, which does not immediately impact US TFP but instead does so down the road. Jinnai (2013) proposes a structural model with a research and development (R&D) sector and shows that the news shocks identified from Barsky and Sims’ strategy may reflect the surprise shocks to the productivity in the R&D sector.

Another promising avenue is to incorporate a financial channel of the exchange rate determination into standard international macroeconomic models. A more careful description of financial markets may help to break the UIP condition in standard models and provide an alternative channel to replicate the real appreciation following a positive news shock. Intuitively, expected improvements in US technology lead to an increase in the demand for US financial assets, which should cause an appreciation of the dollar with everything else constant. This channel is consistent with the facts that most trade in US dollars is for the purpose of financial investment rather than international trade and UIP does not hold in the data.

Our estimation results also indicate that existing standard international business cycle models...

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30 See Lorenzoni (2011) for an excellent review.

31 Although TFP does not move on impact of a positive R&D shock in Jinnai’s (2013) model, it increases quickly after the impact. Future studies may want to investigate how to generate more delayed response of TFP in such a model.
fail to replicate the documented delayed overshooting of the real exchange rate following news and contemporaneous TFP shocks.\footnote{Several other recent studies also find a horizontally J-shaped or hump-shaped impulse response of the real exchange rate to their identified productivity shocks. See Eichenbaum and Evans (1995), Faust and Rogers (2003), and Cheung and Lai (2000) for earlier empirical studies on this topic.} Steinsson (2008) argues that the non-monotonic response of the real exchange rate is critical for theoretical international macroeconomic models to replicate exchange rate persistence (the persistence anomaly discussed in Chari et al., 2002). He shows in his model that real shocks (productivity, labor supply, etc.) are more promising than nominal shocks to replicate the delayed overshooting of the real exchange rate and its persistence. However, Steinsson’s (2008) theoretical results depend on several over-simplifications such as a log utility function with only consumption in the function.\footnote{Iversen and Soderstrom (2014) show that Steinsson’s (2008) results are also weakened under alternative parameter calibrations such as home bias level in consumption and the cross-country correlation of productivity shocks.} Our empirical findings show that news TFP shocks play an important role in exchange rate dynamics and thus future theoretical studies on this topic may want to focus more attention on this shock.

4 Conclusion

The cross-border transmission of country-specific TFP changes 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. 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.

We find that news and contemporaneous US TFP shocks induce substantially different dynamics for international relative prices and international trade. Our findings 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 driv-
ing exchange rates: omitting news shocks to TFP may generate incomplete and sometimes self-contradictory results. Our study reconciles some puzzling results in the related literature and thus leads to a better understanding of these topics.

Furthermore, our paper evaluates a standard international business cycle model and finds that existing standard international macroeconomic models cannot generate the observed dynamics of the real exchange rate following both news and contemporaneous TFP shocks. We discuss the reasons for the discrepancies between standard models and our empirical results and potential mechanisms that may bring these models closer to the data.
References


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2284.


537-557.


37
Figure 1: Impulse Response Functions to News and Contemporaneous TFP Shocks

Impulse Responses to a Positive News TFP Shock

IRFs to a Positive News TFP Shock

IRFs 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

IRFs to a Positive News TFP Shock

<table>
<thead>
<tr>
<th>USTFP</th>
<th>Relative Consumption</th>
<th>Relative Investment</th>
<th>Relative GDP</th>
<th>Relative Hours</th>
<th>Real Exchange Rate</th>
</tr>
</thead>
</table>

Impulse Responses to a Positive Contemporaneous TFP Shock

IRFs to a Positive Contemporaneous TFP Shock

<table>
<thead>
<tr>
<th>USTFP</th>
<th>Relative Consumption</th>
<th>Relative Investment</th>
<th>Relative GDP</th>
<th>Relative Hours</th>
<th>Real Exchange Rate</th>
</tr>
</thead>
</table>

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.
### Table 1: Forecast Error Variance Decomposition

<table>
<thead>
<tr>
<th></th>
<th>Share of FEV Attributable to New TFP Shocks</th>
<th>Share of FEV Attributable to Contemporaneous TFP Shocks</th>
<th>Sum of Two Shares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(h=0)</td>
<td>(h=4)</td>
<td>(h=8)</td>
</tr>
<tr>
<td>US TFP</td>
<td>0.00</td>
<td>0.02</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>([0.00, 0.01, 0.04, 0.27, 0.37, 0.40, 0.00, 0.08, 0.24, 0.54, 0.67, 0.73])</td>
<td>([1.00, 0.80, 0.63, 0.37, 0.25, 0.16, 1.00, 0.92, 0.83, 0.64, 0.53, 0.46])</td>
<td>([1.00, 0.86, 0.81, 0.85, 0.87, 0.80, 1.00, 0.95, 0.94, 0.95, 0.96, 0.94])</td>
</tr>
<tr>
<td>Relative Consumption</td>
<td>0.70</td>
<td>0.75</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>([0.49, 0.55, 0.56, 0.54, 0.53, 0.47, 0.85, 0.87, 0.88, 0.87, 0.84])</td>
<td>([0.01, 0.01, 0.01, 0.01, 0.01, 0.02, 0.53, 0.60, 0.63, 0.65, 0.64, 0.60])</td>
<td>([0.89, 0.90, 0.92, 0.92, 0.92, 0.91])</td>
</tr>
<tr>
<td>Relative Investment</td>
<td>0.05</td>
<td>0.21</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>([0.00, 0.05, 0.08, 0.10, 0.11, 0.12, 0.06, 0.02, 0.02, 0.02, 0.03, 0.03, 0.10, 0.09, 0.14, 0.20, 0.22, 0.23])</td>
<td>([0.15, 0.17, 0.16, 0.16, 0.16, 0.16, 0.31, 0.52, 0.62, 0.66, 0.66, 0.66])</td>
<td>([0.26, 0.30, 0.34, 0.31, 0.30, 0.22, 0.18, 0.16, 0.16, 0.16, 0.16, 0.16])</td>
</tr>
<tr>
<td>Relative GDP</td>
<td>0.07</td>
<td>0.30</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>([0.01, 0.11, 0.21, 0.29, 0.33, 0.34, 0.21, 0.50, 0.63, 0.71, 0.74, 0.76])</td>
<td>([0.08, 0.04, 0.03, 0.03, 0.03, 0.03, 0.02, 0.13, 0.12, 0.12, 0.12, 0.12])</td>
<td>([0.35, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38, 0.38])</td>
</tr>
<tr>
<td>Relative Hours</td>
<td>0.06</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>([0.01, 0.04, 0.05, 0.05, 0.05, 0.06, 0.00, 0.00, 0.01, 0.04, 0.04, 0.04, 0.01, 0.05, 0.08, 0.17, 0.20, 0.20])</td>
<td>([0.01, 0.02, 0.03, 0.07, 0.22, 0.26, 0.26, 0.23, 0.49, 0.55, 0.59, 0.57, 0.54])</td>
<td>([0.01, 0.01, 0.02, 0.02, 0.03, 0.03, 0.11, 0.16, 0.20, 0.20, 0.22, 0.22, 0.22, 0.22, 0.22, 0.22, 0.22, 0.22])</td>
</tr>
<tr>
<td>Real Exchange Rate</td>
<td>0.10</td>
<td>0.27</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>([0.00, 0.09, 0.11, 0.11, 0.11, 0.12, 0.00, 0.01, 0.02, 0.02, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03])</td>
<td>([0.05, 0.04, 0.10, 0.15, 0.16, 0.17, 0.26, 0.60, 0.61, 0.60, 0.60])</td>
<td>([0.01, 0.01, 0.02, 0.02, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03])</td>
</tr>
</tbody>
</table>

Note: This table reports the shares of the forecast error variances (FEVs) of variables in the benchmark six-variable system attributable to the identified new (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

<table>
<thead>
<tr>
<th></th>
<th>A. Business Cycle Variance Decomposition</th>
<th>B. Relative Standard Deviation</th>
<th>C. Correlation with Real Exchange Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variance Contribution of News TFP Shocks</td>
<td>Variance Contribution of Cont. TFP Shocks</td>
<td>Data Counterfactual Data Conditional on News TFP Shocks</td>
</tr>
<tr>
<td>Relative Consumption</td>
<td>0.71 [0.48, 0.95]</td>
<td>0.10 [0.04, 0.23]</td>
<td>0.64 [0.75, 1.23]</td>
</tr>
<tr>
<td>Relative Investment</td>
<td>0.35 [0.12, 0.76]</td>
<td>0.13 [0.05, 0.31]</td>
<td>5.79 [4.55, 7.84]</td>
</tr>
<tr>
<td>Relative GDP</td>
<td>0.32 [0.17, 0.53]</td>
<td>0.10 [0.05, 0.18]</td>
<td>1.01 [0.87, 1.70]</td>
</tr>
<tr>
<td>Relative Hours</td>
<td>0.31 [0.09, 0.72]</td>
<td>0.17 [0.06, 0.39]</td>
<td>1.31 [0.87, 1.70]</td>
</tr>
<tr>
<td>Real Exchange Rate</td>
<td>0.30 [0.11, 0.59]</td>
<td>0.11 [0.04, 0.26]</td>
<td>5.15 [2.78, 8.35]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>Risk aversion</td>
<td>2</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Consumption weight in utility</td>
<td>Chosen such that hours worked is one third in the steady state.</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Parameter that determines the steady state discount factor</td>
<td>Calibrated to have the discount factor of 0.99 in the steady state.</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>Steady state capital depreciation rate</td>
<td>0.025</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>Parameter that governs the steady state capital utilization rate</td>
<td>Chosen to ensure that the capital utilization rate equals 1 in the steady state.</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Home bias</td>
<td>0.88</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Capital share</td>
<td>0.36</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Elasticity of substitution between differentiated intermediate goods</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 4: Estimated Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Matching IRFs to Both TFP Shocks</th>
<th>Matching IRFs to News TFP Shocks</th>
<th>Matching IRFs to Cont. TFP Shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Estimate (S.E.)</td>
<td>Estimate (S.E.)</td>
<td>Estimate (S.E.)</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Investment adjustment costs</td>
<td>5.77 (1.66)</td>
<td>1.60 (1.36)</td>
<td>5.13 (1.69)</td>
</tr>
<tr>
<td>$\delta_2/\delta_1$</td>
<td>Elasticity of capital utilization to the rental rate of capital in the steady state</td>
<td>0.55 (0.38)</td>
<td>1.03 (0.65)</td>
<td>0.25 (0.25)</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Trade price elasticity</td>
<td>1.19 (0.24)</td>
<td>0.28 (0.03)</td>
<td>1.23 (0.30)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Calvo parameter</td>
<td>0.76 (0.06)</td>
<td>0.72 (0.11)</td>
<td>0.71 (0.08)</td>
</tr>
<tr>
<td>$\Theta_i$</td>
<td>Interest smoothing coefficient</td>
<td>0.72 (0.09)</td>
<td>0.68 (0.23)</td>
<td>0.86 (0.12)</td>
</tr>
<tr>
<td>$\Theta_\pi$</td>
<td>Inflation targeting coefficient</td>
<td>1.54 (0.28)</td>
<td>1.55 (0.31)</td>
<td>2.19 (0.67)</td>
</tr>
<tr>
<td>$\Theta_y$</td>
<td>Output gap coefficient</td>
<td>0.24 (0.09)</td>
<td>0.01 (0.15)</td>
<td>0.24 (0.25)</td>
</tr>
<tr>
<td>$\xi^u$</td>
<td>Persistence of contemporaneous TFP shocks</td>
<td>0.91 (0.01)</td>
<td>0.89 (0.01)</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\xi}^c$</td>
<td>Standard deviation of contemporaneous TFP shocks</td>
<td>0.67 (0.05)</td>
<td>0.56 (0.02)</td>
<td></td>
</tr>
<tr>
<td>$\xi^s$</td>
<td>Degree of diffusion of news TFP shocks</td>
<td>0.56 (0.02)</td>
<td>0.76 (0.04)</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\xi}^n$</td>
<td>Standard deviation of news TFP shocks</td>
<td>0.89 (0.10)</td>
<td>0.99 (0.16)</td>
<td></td>
</tr>
</tbody>
</table>

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 $\xi^u$ 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.
Appendix A  Robustness Check Using Sign Restrictions Approach

Our benchmark results are robust under an alternative identification strategy via sign restrictions. In implementing sign restrictions, we add two new variables, relative inflation and the relative nominal interest rate, to our benchmark VAR model. These newly added variables can help to better identify news and contemporaneous TFP shocks (and other shocks like demand and monetary policy shocks). Our sign restrictions rely on appealing narratives of the effects of these shocks on aggregate economic variables and are also consistent with the predictions by a large class of models.

To save space, the sign restrictions and the results are reported in an appendix on the authors’ websites. We will only highlight a few interesting findings here.

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.

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. A negative restriction on the relative interest rate is usually imposed in the literature to identify a positive productivity shock (e.g., Enders, Juller, and Scholl, 2011 and Juvenal, 2011), these studies likely exclude news TFP shocks from their identify productivity shocks.

Third, positive news TFP shocks are not associated with US inflation relative to the ROW: that is, relative inflation decreases in the first several quarters following the news shock. This finding is 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.

Our results from the sign restrictions approach are also robust under different sign restrictions. 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

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34 We take the penalty-function approach in Uhlig (2005) and Mountford and Uhlig (2009).
(and contemporaneous) TFP shocks could contain both global and US-specific components. However, our results are robust even when we only impose restrictions on US-ROW relative variables, indicating that we are likely to pick up a US-specific news component of TFP. Our results from the sign restrictions approach are also robust under different sign restrictions. 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. However, our results are robust even when we only impose restrictions on US-ROW relative variables, indicating that we are likely to pick up a US-specific news component of TFP.
APPENDIX (not for publication)

A.1 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 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.

A.2 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 \( \Sigma_u \). The relationship between the reduced-form innovations \( u_t \) and the structural shocks \( \epsilon_t \) 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 \( \tilde{A}_0 \) denote an arbitrary orthogonalization of \( \Sigma_u \), that is, \( \tilde{A}_0 \tilde{A}'_0 = \Sigma_u \) (e.g., \( \tilde{A}_0 \) is the Cholesky decomposition of \( \Sigma_u \)) and \( Q \) denote an orthonormal matrix of conformable size, that is, \( DD' = I_N \). Then, the matrix \( \tilde{A}_0 Q \) spans the space of possible orthogonalizations of \( \Sigma_u \):

\[
    u_t = \tilde{A}_0 \epsilon_t = \tilde{A}_0 Q \epsilon_t.
\]

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

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

where \( B_\tau \tilde{A}_0 Q \) is the coefficient matrix of the structural moving average representation at horizon \( \tau \). 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:

\[
    \Omega_i^{(j)}(h) = \left( \sum_{\tau=0}^{h} (B_{i,\tau} \tilde{A}_0 q^{(j)}) (B_{i,\tau} \tilde{A}_0 q^{(j)})' \right) / \left( \sum_{\tau=0}^{h} B_{i,\tau} \Sigma_u B'_{i,\tau} \right) = q^{(j)} F_i(h) q^{(j)'},
\]

where \( B_{i,\tau} \) is the \( i^{th} \) row of \( B_\tau \) and \( q^{(j)} \) is the \( j^{th} \) 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:

$$q^* = \arg \max_{q^{(2)}} \sum_{h=0}^{H} \Omega^{(2)}_1(h) = q^{(2)} F_1(h) q^{(2)'}$$

s.t. (1) $q^{(2)'} q^{(2)} = 1$; (2) $q^{(2)}_1 = 0$,

where $q^{(2)}_1$ represents the first element of an orthonormal vector $q^{(2)}$ and the constraint $q^{(2)}_1 = 0$ means that news TFP shocks have no immediate impact on TFP. The objective function in the above maximization problem can be expressed as:

$$q^{(2)} F_1(H) q^{(2)'}$$

with $F_1(H) = \sum_{h=0}^{H} F_1(h)$ is an $N \times N$ symmetric matrix,

and the corresponding Lagrangian can be expressed as $\mathcal{L}(q) = q F_1(H) q' - (q' q - 1)$, where the superscript of $q^{(2)}$ is dropped. Since $q_1 = 0$, this Lagrangian implies that $q^* = (0, q^*_2)'$, where $q^*_2$ is the eigenvector corresponding to the largest eigenvalue of the $(N-1) \times (N-1)$ sub-matrix of $F_1(H)$ (i.e., the one obtained from eliminating the first row and the first column of $F_1(H)$).

### A.3 Exogeneity Tests

In this section, we provide evidence that other variables (e.g., government spending, the relative price of investment and consumption goods, and oil prices) cannot predict our identified shocks. We run the following regression:

$$e_t = c + \sum_{p=1}^{n} (\alpha_{1p} \Delta g_{t-p} + \alpha_{2p} \Delta r p_{t-p} + \alpha_{3p} \Delta o p_{t-p}) + \varepsilon_t,$$ (1)
where $e_t$ is our identified news or contemporaneous shocks to US TFP from our benchmark six-variable VAR system, $\Delta g_{t-p}$ is the change in government spending, $\Delta r_{p_{t-p}}$ is the change in the relative price between consumption and investment goods, and $\Delta o_{p_{t-p}}$ is the change in oil prices. Note that government spending and the relative price of investment goods are measured in both US-ROW and US terms, where we construct the “US-ROW” relative price of investment goods by following Mandelman, Rabanal, Rubio-Ramirez, and Vilan (2011). In addition, we have analyzed the sensitivity of our regression results by using the ratio of consumption-goods deflation to equipment/software deflator or Fernald’s (2010) relative price of investment goods series as a measure of the “US” relative price of investment goods. Various lags ($n = 1, 2, 3, 4$) are considered.

Tables 1.1 and 1.2 report the regression results when government spending and the relative price of investment goods are measured in US-ROW terms and in US terms, respectively. Based on F-statistic, we fail to reject the null that the coefficients are jointly zero except for one case, indicating that these lagged variables cannot predict our identified shocks.
### Table 1.1: Regression Results for Exogeneity Tests – US-ROW Measures

<table>
<thead>
<tr>
<th></th>
<th>Reg. 1</th>
<th>Reg. 2</th>
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<th>Reg. 1</th>
<th>Reg. 2</th>
<th>Reg. 3</th>
<th>Reg. 4</th>
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<td><strong>DEPENDENT VARIABLE: NEWS SHOCKS</strong></td>
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<td><strong>DGOV_REL(-1)</strong></td>
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<td>-14.12*</td>
<td>-14.19*</td>
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<td>4.43</td>
<td>4.05</td>
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<td><strong>DRELPRICEINV_REL(-1)</strong></td>
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<td><strong>DGOV_REL(-2)</strong></td>
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<td>2.40</td>
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<td>-18.17***</td>
<td>-18.87***</td>
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<td><strong>DRELPRICEINV_REL(-2)</strong></td>
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<td><strong>DGOV_REL(-4)</strong></td>
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<tr>
<td><strong>F-statistic</strong></td>
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<td>1.03</td>
<td>0.91</td>
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<td>0.28</td>
<td>0.06</td>
<td>0.17</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*: significant at 10%; **: significant at 5%; ***: significant at 1%

DGOV: growth rate of government spending; DRELPRICEINV: growth rate of the relative price of investment goods; DOILPRICE: growth rate of oil prices, where government spending and relative price of investment goods are measured in US-ROW relative terms.

### Table 1.2: Regression Results for Exogeneity Tests – US Measures

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<tr>
<th></th>
<th>Reg. 1</th>
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<tr>
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<tr>
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<tr>
<td><strong>DGOV_US(-1)</strong></td>
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<td><strong>DRELPRICEINV_US(-1)</strong></td>
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<td><strong>DOILPRICE(-1)</strong></td>
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<td>0.19</td>
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<td>-0.65</td>
<td>-0.75*</td>
<td>-0.77*</td>
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<td><strong>DGOV_US(-2)</strong></td>
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<td>-16.71*</td>
<td>-17.70**</td>
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<tr>
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<tr>
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<tr>
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<td><strong>Prob(F-statistic)</strong></td>
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<td>0.19</td>
<td>0.12</td>
<td>0.16</td>
<td>0.21</td>
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</tbody>
</table>

*: significant at 10%; **: significant at 5%; ***: significant at 1%

DGOV: growth rate of government spending; DRELPRICEINV: growth rate of the relative price of investment goods; DOILPRICE: growth rate of oil prices, where government spending and relative price of investment goods are measured in US terms.
A.4 Sign Restrictions Method

The sign restrictions approach 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. Our sign restrictions rely on appealing narratives of the effects of these shocks on aggregate economic variables and are also consistent with the predictions by a large class of models.\(^{35}\) Panel A of Table A.1 summarizes the sign restrictions that are imposed 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 unrestricted. These restrictions are consistent with the idea that good news about future TFP induces a broad economic boom with consumption leading investment and output (e.g., see Beaudry and Portier (2006)). The horizons of sign restrictions are taken from the standard theoretical model described in an appendix on the authors’ websites. Alternative horizons are also considered in sensitivity analysis.\(^{36}\)

The first restriction requires that the economic boom is not caused by a contemporaneous increase in TFP. Restriction 5 excludes an expansionary monetary shock being our identified shock. We will see shortly that the identified shock is not a demand shock either since it is associated with an eventual increase in US TFP and a short-run decrease in relative inflation rather than an increase, which is implied by a positive demand shock. We could impose positive restrictions on future TFP or a negative impact restriction on relative inflation to explicitly distinguish our identified shocks from conventional demand shocks. However, these restrictions will be so close to the estimated IRFs obtained from the identification approach of Barsky and Sims that they may undermine the usefulness of our robustness check.

\(^{35}\)In a similar way to Enders, Muller, and Scholl (2011), we generate the model-implied sign restrictions from a standard international business cycle model that encompasses many of the features emphasized in the literature. These model-implied sign restrictions are described in an appendix on the authors’ websites.

\(^{36}\)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.
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 unrestricted.\textsuperscript{37}

Figure A.1 shows the IRFs in the eight-variable VAR model, following positive news and contemporaneous TFP shocks that are identified by the sign restrictions in Panel A of Table A.1. Figure A.2 displays the IRFs of the terms of trade and three trade variables in the nine-variable VAR models.\textsuperscript{38} 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.

Figures A.1 and A.2 show that our results on the international transmission of news and contemporaneous TFP shocks in Section 2 are robust to our sign restrictions strategy.

Our results from the sign restrictions approach are also robust under different sign restrictions. We consider three alternative cases by removing the restrictions on 1) TFP; 2) the relative nominal interest rate; 3) both TFP and the relative nominal interest rate. These three alternative sign restrictions schemes are summarized in Panel B of Table A.1. Our main results for news TFP shocks hold well under these alternative identification schemes.

Figure A.3 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 A.1). First, it is interesting to note that US TFP tends to increase with a delay even if we do not impose the zero impact restriction on US

\textsuperscript{37}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.

\textsuperscript{38}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 A.2 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 A.1.
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 A.3 show that our results are robust even when we only impose restrictions on US-ROW relative variables, 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.

A.5 Calibration and Model Estimation

The risk aversion parameter ($\sigma$) is set equal to 2. The parameter for consumption weight in the period utility ($\gamma$) is calibrated such that the steady state value of hours worked is one-third and the parameter that determines the steady state discount factor ($\psi$) is chosen to have the discount factor of 0.99 in the steady state. The steady state value of the capital depreciation rate ($\delta_0$) 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 ($\delta_1$) is calibrated to ensure that it equals one in the steady state. The home bias parameter ($\omega$) 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 ($\phi$) is 0.36. The elasticity of substitution between differentiated intermediate goods ($\phi$) is set equal to 6, implying a profit margin of 20%.

We discuss some of our parameter estimates reported in Table 4. They are consistent with the values estimated by previous studies. Our estimate of the investment adjustment cost parameter ($\kappa$) 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 ($\delta_2/\delta_1$) 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 ($\alpha$) 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 ($\Theta_i$) between 0.68 and 0.86. The central bank strongly targets the inflation rate with the estimate of the inflation targeting parameter ($\Theta_\pi$) between 1.54 and 2.19, and puts some weight on the output gap with its coefficient estimate ($\Theta_y$) 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 ($\xi_u$) 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 ($\xi^*$) 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).

### A.6 Model-implied Sign Restrictions

In this appendix, we show that our sign restrictions imposed to identify news and contemporaneous TFP shocks, which are summarized in Table A.1, are also grounded in economic theory. To this end, we use our international business cycle model, which is considered in Section 3 and described in Appendix 3.1, so as to derive the model-implied sign restrictions. Our model encompasses many of the features emphasized in the literature and the model impulse responses to news and contemporaneous TFP shocks are drawn for a large number of parameter configurations. Thus, our model-implied sign restrictions are likely to be fairly uncontroversial to identify 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 A.2, 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.

Figure A.4 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 A.5 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 A.4 and A.5, 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). 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 A.4 and A.5 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

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39 TFP is obviously one variable that helps distinguish the effects of news and contemporaneous TFP shocks.
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.40

The two right panels of Figures A.4 and A.5 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.

In Table A.1, Panel A summarizes our sign restrictions to identify positive news and contemporaneous 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

40In simulation, we set the anticipation horizon of news TFP shocks equal to 3, based on our model estimation exercises in Section 3.
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.
Table A.1: Sign Restrictions for Identifying News and Contemporaneous TFP Shocks

<table>
<thead>
<tr>
<th></th>
<th>US TFP</th>
<th>Relative Consumption</th>
<th>Relative Investment</th>
<th>Relative GDP</th>
<th>Relative Inflation</th>
<th>Relative Interest Rate</th>
<th>Other Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Sign Restrictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>News TFP Shocks</td>
<td>0</td>
<td>[0, 0]</td>
<td>[0, 7]</td>
<td>[8, 15]</td>
<td>[4, 11]</td>
<td>[0, 3]</td>
<td></td>
</tr>
<tr>
<td>Contemporaneous TFP Shocks</td>
<td>+</td>
<td>[0, 27]</td>
<td>[1, 8]</td>
<td>[0, 7]</td>
<td>[0, 7]</td>
<td>[0, 2]</td>
<td>[0, 5]</td>
</tr>
<tr>
<td>B. Alternative Sign Restrictions for Identifying News TFP Shocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification III</td>
<td>0</td>
<td>[0, 0]</td>
<td>[0, 7]</td>
<td>[8, 15]</td>
<td>[4, 11]</td>
<td>[0, 3]</td>
<td></td>
</tr>
</tbody>
</table>

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 III, respectively.
Table A.2: Model Parameter Value Ranges used in Simulation for Confidence Bounds of Theoretical Model Impulse Responses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>Risk aversion</td>
<td>[1, 10]</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Consumption weight in utility</td>
<td>[0.02, 0.89]</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Steady state discount factor</td>
<td>[0.982, 0.99]</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Investment adjustment costs</td>
<td>[2.05, 2.91]</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>Steady state capital depreciation rate</td>
<td>[0.0038, 0.0602]</td>
</tr>
<tr>
<td>$\delta_2/\delta_1$</td>
<td>Elasticity of capital utilization to the rental rate of capital in the steady state</td>
<td>[0.1, 1]</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Home bias</td>
<td>[0.84, 0.92]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Trade price elasticity</td>
<td>Low: [0.1, 0.33] or High: [1, 4]</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Capital share</td>
<td>[0.15, 0.39]</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Elasticity of substitution between differentiated intermediate goods</td>
<td>[3.5, 15]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Calvo parameter</td>
<td>[0.55, 0.77]</td>
</tr>
<tr>
<td>$\Theta_I$</td>
<td>Interest smoothing coefficient</td>
<td>[0.65, 0.9]</td>
</tr>
<tr>
<td>$\Theta_y$</td>
<td>Inflation targeting coefficient</td>
<td>[1.5, 2.5]</td>
</tr>
<tr>
<td>$\zeta^u$</td>
<td>Output gap coefficient</td>
<td>[0.5, 1]</td>
</tr>
<tr>
<td>$\zeta^s$</td>
<td>Persistence of contemporaneous TFP shocks</td>
<td>[0.89, 98]</td>
</tr>
<tr>
<td>$\zeta^w$</td>
<td>Degree of diffusion of news TFP shocks</td>
<td>[0.5, $\zeta^u$]</td>
</tr>
</tbody>
</table>

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 $\beta$ determines the value of the parameter $\psi$, and the parameter $\delta_1$ is chosen to ensure that the capital utilization rate equals one in the steady state.
Figure A.1: Sign Restrictions Strategy: Impulse Response Functions to News and Contemporaneous TFP Shocks

Impulse Responses to a Positive News TFP Shock

IRFs to a News TFP Shock Identified by Sign Restrictions

IRFs to a Contemporaneous TFP Shock Identified by Sign Restrictions

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 A.1 and the vertical gray area represents the period on which the sign restrictions are imposed.
Figure A.2: Sign Restrictions Strategy: Impulse Responses Functions of Terms of Trade and Three Trade Variables

Impulse Responses to a Positive Contemporaneous TFP Shock

IRFs to a Contemporaneous TFP Shock identified by Sign Restrictions

Terms of Trade

0 10 20 30 40
−3 −2.5 −2 −1.5 −1 −0.5 0 0.5 1

Trade Balance

0 10 20 30 40
−0.3 −0.25 −0.2 −0.15 −0.1 −0.05 0 0.05 0.1 0.1

Real Exports

0 10 20 30 40
−1.5 −1 −0.5 0 0.5 1 1.5 2 2.5 3 3.5

Real Imports

0 10 20 30 40
−1 −0.5 0 0.5 1 1.5 2 2.5 3

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 A.1 and the vertical gray area represents the period on which the sign restrictions are imposed.
Figure A.3: Alternative Sign Restrictions: Impulse Response Functions to a News TFP Shock

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 A.1. The vertical gray area represents the period on which the sign restrictions are imposed.
Figure A.4: Confidence Bounds of Theoretical Model Impulse Responses: PCP Model

Confidence Bounds of IRFs to a News TFP Shock

Confidence Bounds of Theoretical Model IRFs to a News Shock to Home TFP (PCP Model)

Confidence Bounds of IRFs to a Contemporaneous TFP Shock

Confidence Bounds of Theoretical Model IRFs to a Contemporaneous Shock to Home TFP (PCP Model)

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 A.5: 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 A.4.