Understanding the Effect of Productivity Changes on International Relative Prices: The Role of News Shocks*

Deokwoo Nam† Hanyang University

Jian Wang‡ Chinese University of Hong Kong (Shenzhen)

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Abstract

The US real exchange rate and terms of trade have been found to appreciate when its labor productivity increases relative to the rest of the world. This finding is at odds with predictions from standard international macroeconomic models. In this paper, we find that incorporating news shocks to total factor productivity (TFP) in an otherwise standard open-economy sticky-price dynamic stochastic general equilibrium (DSGE) model with variable capital utilization can help the model replicate the above empirical finding. Labor productivity increases in our model after a positive news shock to TFP because of an increase in capital utilization. Under some plausible calibrations, the wealth effect of good news about future productivity can increase domestic demand strongly and induce an increase in home goods prices relative to foreign goods prices.

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†Email: deokwnam@hanyang.ac.kr Address: Department of Economics and Finance, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Republic of Korea

‡Email: jianwang@cuhk.edu.cn Address: School of Management and Economics, Chinese University of Hong Kong (Shenzhen), Shenzhen, China, 518172.

1 Introduction

Standard international macroeconomic models (e.g., Backus, Kehoe and Kydland, 1994) predict that a country's terms of trade deteriorate when its productivity increases relative to the rest of the world. However, it has been documented that the US real exchange rate and terms of trade appreciate rather than depreciate when its labor becomes more productive relative to other countries. In this paper, we find that incorporating news shocks to productivity in an otherwise standard open-economy sticky-price dynamic stochastic general equilibrium (DSGE) model can help the model replicate the above empirical finding.

International relative prices – measured by the terms of trade and the real exchange rate – are very important channels for international transmissions of country-specific shocks. Standard international macroeconomic models predict that a country's terms of trade deteriorate when its productivity of the tradable goods sector increases relative to the rest of the world. In this case, productivity gains in that country spill over positively to other countries through international price adjustment, automatically insuring cross-country productivity uncertainties. As a result, additional welfare gains from international risk sharing through financial markets and policy coordination may be quite limited. For instance, see Cole and Obstfeld (1991) and Obstfeld and Rogoff (2002). However, Corsetti, Dedola, and Leduc (2006, 2014), Enders and Muller (2009), and Enders, Muller, and Scholl (2011) document a robust appreciation of the terms of trade and the real exchange rate in US data after an increase in the US labor productivity.

Several recent studies try to reconcile standard international macroeconomic models with the above empirical findings. Corsetti, Dedola, and Leduc (2008) emphasize the wealth effect of productivity gains when international financial markets are incomplete. A positive productivity shock in the home country has two effects. First, it raises the home country's output. Meanwhile, it increases home country's wealth, and therefore its consumption, under incomplete international financial markets. If consumption is biased towards home goods, demand for home goods increases more than demand for foreign goods. When the increase in relative demand from the wealth effect is stronger than the increase in relative output from productivity gains, home goods prices increase relative to foreign goods prices. In particular, Corsetti, Dedola, and Leduc (2008) identify two cases in which the wealth effect dominates the supply effect: (1) when the trade elasticity is low, or (2) when the productivity shock is very persistent and the trade elasticity is sufficiently high. In both cases, the terms of trade and real exchange rate appreciate following an increase in labor productivity in their model. Enders and Muller (2009) find similar results to those in Corsetti, Dedola, and Leduc (2008). In addition, they emphasize the importance of incomplete financial markets in shaping the dynamics of the terms of trade and trade balance following a country-specific productivity shock.

The international transmission of productivity gains can also depend on the nature of the gains. Corsetti, Martin, and Pesenti (2007) consider two types of productivity gains and their effects on the terms of trade. They show in their model that the productivity gain that reduces the cost of producing existing goods will deteriorate the terms of trade while the productivity gain that reduces the cost of creating new firms and product varieties can improve the terms of trade. This is because newly created firms produce and export high-price product varieties, which increases the home country's export prices relative to its import prices.

This paper studies if news shocks to total factor productivity (TFP) can help to replicate the comovement of the real exchange rate and labor productivity as documented in the US data. Our study is motivated by two observations. First, the news shock to TFP has a similar wealth effect that is emphasized in Corsetti, Dedola, and Leduc (2008). It may help to induce an appreciation of the real exchange rate following a positive news shock to productivity. Second, news about future productivity is an important driver of asset prices, including exchange rates, in the data. Beaudry and Portier (2006) argue that asset prices are likely a good measure of market expectations about future economic conditions. They identify news shocks as innovations in stock prices, which are orthogonal to innovations in some measures of productivity. Their identified news shocks predict productivity several years into the future. Kurmann and Otrok (2013) find that movements in the slope of the term structure of interest rates mainly reflect the asset market's response to news about future productivity. In particular, Nam and Wang (2010) apply the identification strategy of Barsky and Sims (2011) to structural vector autoregression models and empirically document that anticipated TFP increases appreciate the US real exchange rate. They also find in the data that news shocks to TFP play a very important role in driving the US real exchange rate and terms of trade. In this paper, we show in theoretical models that news TFP shocks are likely to contribute to the appreciation of the US real exchange rate following an increase in its labor productivity, which is documented in the data.[1]

Using the data of the G7 countries and imposing long-run restrictions in SVAR Models, we first estimate the impulse response functions (IRFs) of the real exchange rate and the terms of trade with respect to a permanent increase in US labor productivity relative to the rest of the G7 countries. Our empirical results confirm that the terms of trade and the real exchange rate appreciate in the US when its labor productivity increases relative to the rest of the world. Next, we identify news shocks to productivity following shape restrictions in Barsky and Sims (2011). We find that the US real exchange rate and terms of trade appreciate following a positive news shock to US labor productivity. In addition, the IRF of the real exchange rate to the news shock closely follows the IRF to the productivity shock identified by imposing long-run restrictions.

[1] There has been a revived interest of studying the role of news shocks in explaining business cycles. For instance, see Cochrane (1994), Beaudry and Portier (2004, 2006, and 2007), Jaimovich and Rebelo (2009), Barsky and Sims (2011), and Schmitt-Grohe and Uribe (2012) among others.

This finding suggests that the news shock to labor productivity contributes to the empirical finding that the US real exchange rate appreciates following an increase in its labor productivity.

Then, in an open-economy version of a standard sticky-price DSGE model with news shocks to TFP, we investigate conditions that help the model to replicate the above empirical findings. Following a positive contemporaneous productivity shock in the home country, our model performs similarly to other standard models in predicting a depreciation of the terms of trade and the real exchange rate. Contemporaneous shocks have two effects on home goods prices. First, the wealth of the home country increases because of the increase in productivity. The wealth effect increases demand in the home country and therefore raises home goods prices relative to foreign goods prices when consumption is biased towards home goods. However, there is a second effect. The contemporaneous shock also increases home TFP immediately and therefore increases the supply of home goods, which tends to reduce home goods prices relative to the foreign. In standard international macro models, the second effect dominates the first one and home goods prices decline relative to foreign goods prices following a positive contemporaneous TFP shock in the home country.

News shocks to TFP have a similar wealth effect as contemporaneous shocks. In expecting higher productivity in the future, households increase consumption immediately though TFP remains constant. This effect increases home prices. To have an increase in labor productivity after a positive news shock, we introduce another crucial component in our model: the variable capital utilization rate. A common problem for models with news shocks is that good news about future productivity reduces current labor supply and therefore output because of the wealth effect of good news. Jaimovich and Rebelo (2009) find that incorporating variable capital utilization into the model can alleviate this problem. The capital utilization rate increases after a positive news shock to TFP. As a result, labor productivity increases immediately following the news shock though TFP remains the same. A higher capital utilization rate will also raise the supply of home goods and therefore depress their prices, which works against the wealth effect of news shocks. Under some reasonable calibrations, we find that the wealth effect will dominate and the model can simultaneously replicate increases in both home prices and labor productivity, as empirical evidence shows.

We inspect the theoretical impulse response functions of the terms of trade and the real exchange rate in response to news shocks in our model. In addition, we simulate our model and estimate the impulse response functions of model-simulated variables using long-run restrictions as in empirical studies. In both cases, we show that the terms of trade and the real exchange rate appreciate while labor productivity rises after a positive news shock in our model. Our results are robust under different model setups as well. Our benchmark model employs the utility function in Jaimovich and Rebelo (2009) which nests as special cases the preferences used by King, Plosser, and Rebelo (1988) and Greenwood, Hercowitz, and Huffman (1988).

As a robustness check, we try the class of utility functions used in Backus, Kehoe, and Kydland (1994). Different values for trade elasticities and different functional forms for capital adjustment costs are also employed as robust checks. Our results hold up qualitatively well in all of these cases.

Compared to empirical results, we acknowledge a shortcoming of our benchmark results in that the appreciation of the terms of trade and the real exchange rate following an increase in labor productivity is less persistent in our model than in the data. However, the appreciation becomes more persistent in our model when the productivity growth is more persistent or the anticipation horizon of news shocks is larger. For instance, when news about future productivity arrives 12 periods in advance, the appreciation of the terms of trade can be as persistent as in the data, though our model still underestimates the persistence of the real exchange rate. The persistence of the appreciation can also be substantially improved by increasing the trade elasticity. If the trade elasticity is set to 4, a value widely used in the trade literature, the appreciation of the terms of trade in our benchmark model can be as persistent as in the data. We acknowledge that labor productivity and international relative prices are also jointly driven by other shocks and the price of nontradables. We abstract away from these factors to highlight the mechanism through which news shocks affect productivity and international relative prices.

The remainder of the paper is organized as follows. Section 2 compares the impulse response functions of the terms of trade and the real exchange rate in two standard international macro models with those estimated from the data. Section 3.3 describes our theoretical benchmark model. Section 4 discusses the main results of our benchmark model and additional robustness checks. Section 5 concludes.

2 Predictions of Standard Models and Empirical Findings

This section first shows the impulse response functions of the terms of trade and the real exchange rate in two standard international macroeconomic models: an international real business cycle (IRBC) model and an open-economy version of a sticky-price DSGE (Sticky-Price) model. Then we present the impulse response functions estimated from the data.

We use exactly the structure of the bond-economy model in Heathcote and Perri (2002) as our standard IRBC model. This model has the same structure as the model of Backus, Kehoe and Kydland (1994), but limits the financial market to a real-bond market only. The Sticky-Price model is an extension of the IRBC model, which assumes monopolistic competition, trade in nominal bonds, Calvo-staggered price setting, and a monetary policy (Taylor) rule. This type of models is often used in the studies of monetary policy in open economies. The Sticky-Price model is calibrated closely to the IRBC model. For parameters that are not in the IRBC model, we choose some standard values in the literature. Since the model setups are very standard in the literature, we leave them in the online appendix.

The terms of trade and the real exchange rate in these two standard models are defined as the price of foreign goods relative to the price of home goods. The real exchange rate denoted by Q_t is defined as:

$$Q_t = \frac{S_t P_t^*}{P_t}, \tag{1}$$

where P_t and P_t^* are prices of final consumption goods in the home and foreign countries, respectively, and S_t is the nominal exchange rate measured by the home-currency price of a unit of foreign currency.[2] The terms of trade denoted by TOT_t is defined analogously:

$$TOT_t = \frac{S_t P_{Ft}^*}{P_{Ht}}, \tag{2}$$

where P_{Ht} and P_{Ft}^* are prices of home and foreign tradable goods, respectively.[3] Under these definitions, an increase in the international relative prices means a depreciation of the terms of trade and the real exchange rate in the home country. Figure 1 shows the impulse response functions of these two international relative prices with respect to a one-standard-deviation increase of productivity in the home country for two models. Under the standard calibration, both the terms of trade and the real exchange rate increase after the shock, which indicates a decline in home goods prices relative to foreign goods prices.[4]

Next, we estimate the impulse response functions of the terms of trade and the real exchange rate between the US and the rest of the world (ROW). ROW in our sample includes the rest of G7 countries (Canada, France, Germany, Italy, Japan and the UK). The US-ROW differences of the following variables are used in the SVAR exercises: labor productivity in the manufacturing sector, manufacturing output, consumption, and the real exchange rate (or the terms of trade). The ratio of manufacturing output to GDP in the US is also included in the VAR. Following Corsetti, Dedula, and Leduc (2006), we use the manufacturing sector as a proxy for the tradeable goods sector. In this way, our exercise can hopefully capture productivity shocks in the tradable goods sector. Focusing on the tradable goods sector in our empirical study is also consistent with our theoretical model because we do not model the nontradable goods sector. To facilitate comparison, the terms of trade and the real exchange rate are defined in the same way as in the above standard models:

[2] In our two theoretical models, P_t and P_t^* are prices of final good composites in the Home and Foreign countries, respectively.

[3] In the two theoretical models, P_{Ht} and P_{Ft}^* are Home and Foreign intermediate good composites, respectively.

[4] When the elasticity of substitution between home and foreign goods (γ) is low (between 0.313 and 0.325 for the IRBC model and between 0.313 and 0.315 for the Sticky-Price model), the terms of trade and the real exchange rate appreciate when the home country becomes more productive relative to the foreign. This result is consistent with Corsetti, Dedola, and Leduc (2008). The equilibrium of the IRBC and Sticky-Price models is indeterminate when γ is less than 0.313. See Bodenstein (2010) for details about multiple equilibria in international macro models when the trade elasticity is low.

foreign prices divided by home prices. Our quarterly data are from 1975Q1 to 2007Q4.[5] Data sources and details on the aggregation of the ROW data can be found in the online appendix. All variables are logged, and a constant term and four lags are included in our SVARs.

We impose long-run restrictions as in Gali (1999) to identify productivity shocks. Figure 2 shows the estimated impulse response functions with respect to a positive US productivity shock relative to ROW. In response to an increase in relative labor productivity, US manufacturing output and consumption increase relative to ROW. In particular, an increase in the labor productivity of the US manufacturing sector induces an appreciation of the terms of trade and the real exchange rate, which is at odds with the predictions of standard international models that we have just shown in Figure 1.

Figure 3 shows the estimated impulse response functions following a positive news shock to US manufacturing productivity relative to ROW. The news shock is identified applying shape restrictions of Barsky and Sims (2011). This identification strategy imposes the restriction that a positive news shock results in a small impact effect on labor productivity followed by persistent growth over time. We also plot in this figure the point estimates of the impulse response functions following a positive productivity shock identified by imposing long-run restrictions. Following a positive news shock, the labor productivity does not increase significantly above zero until about 10 periods later. This is consistent with the definition that news shocks only affect productivity in the future. One interesting observation is that the impulse response functions of the real exchange rate under two identification strategies trace each other closely, although the impulse response functions of labor productivity and other variables differ significantly between Figure 2 and Figure 3. This similarity of the impulse response function of the real exchange rate between the two identification approaches suggests that news shocks to productivity contribute significantly to the empirical finding that the US real exchange rate appreciates following a positive productivity shock. The result for the terms of trade is similar, though its impulse response functions differ more under these two identified shocks.

3 Theoretical Model

In this section, we describe our benchmark theoretical model. The structure of our model is similar to Kollmann (2004) and Wang (2010). The world economy consists of two symmetric countries: Home and Foreign. There are two sectors of production in each country: the final goods sector and the intermediate goods sector. Final goods are internationally nontradable, and are produced from the internationally traded

[5] The sample ends in 2007 because we want to avoid the effect of the global financial crisis on the exchange rate. Engel and West (2010) document that during the recent global financial crisis, the US exchange rate is mainly driven by the risk premium, rather than economic fundamentals such as the labor productivity.

Home and Foreign intermediate good composites. The intermediate goods are produced using capital and labor in each country. Due to the symmetry between the two countries, we focus on the Home country when describing our model.

In the Home final goods sector, there is a continuum of differentiated final goods $Y_t(f)$ indexed by $f \in [0,1]$. The representative household of Home country uses them to form a final good composite Y_t according to equation (3) for consumption, investment, saving, and associated costs:

$$Y_t = \left[\int_0^1 Y_t(f)^{\frac{\theta_F - 1}{\theta_F}} df\right]^{\frac{\theta_F}{\theta_F - 1}}, \tag{3}$$

where θ_F is the elasticity of substitution among differentiated final goods. Each variety of final goods is produced from the Home and Foreign intermediate good composites Y_{Ht} and Y_{Ft} by a single final goods firm. The Home (Foreign) intermediate good composite is composed of differentiated Home (Foreign) intermediate goods $Y_{Ht}(i)$ ($Y_{Ft}(i)$). In the intermediate goods sector, each variety of Home (Foreign) intermediate goods is produced by a single firm with capital and labor in the Home (Foreign) country.

3.1 Firms

The final goods market is monopolistically competitive. In the Home country, each final goods firm produces a variety of final goods from the Home and Foreign intermediate good composites according to equation (4):

$$Y_t(f) = \left[\omega^{\frac{1}{\psi}} Y_{Ht}(f)^{\frac{\psi - 1}{\psi}} + (1-\omega)^{\frac{1}{\psi}} Y_{Ft}(f)^{\frac{\psi - 1}{\psi}}\right]^{\frac{\psi}{\psi - 1}}, \tag{4}$$

where $Y_{Ht}(f)$ ($Y_{Ft}(f)$) is the Home (Foreign) intermediate good composite demanded by final goods firm f, ω is the home bias in domestic intermediate good composite, and ψ is the elasticity of substitution between home and foreign good composites. From equation (3), we have the demand function of final good f:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t}\right)^{-\theta_F} Y_t, \tag{5}$$

where $P_t(f)$ is the price of final good f and $P_t = \left[\int_0^1 P_t(f)^{1-\theta_F} df\right]^{\frac{1}{1-\theta_F}}$ is the price of the final good composite.

For given demand for final goods in equation (5), technology in equation (4), and production factor prices, final goods firms choose prices to maximize their expected lifetime profits. We introduce staggered price setting *a lá* Calvo (1983). In each period, an individual firm will re-optimize its price with probability

$1-\alpha_F$. Otherwise, it will charge a price equal to last period's price multiplied by the long-run inflation rate denoted by $\bar{\Pi}$. When a final goods firm re-optimizes its price, it will choose its price $\tilde{P}_t(f)$ to maximize the expected lifetime real profit:

$$\max_{\tilde{P}_t(f)} \sum_{k=0}^{\infty} E_t \left\{ \alpha_F^k \Gamma_{t,t+k} P_{t+k}^{-1} \left[\left(\bar{\Pi}^k \tilde{P}_t(f) - mc_{t+k}(f) \right) \left(\frac{\bar{\Pi}^k \tilde{P}_t(f)}{P_{t+k}} \right)^{-\theta_F} Y_{t+k} \right] \right\},$$

where $\Gamma_{t,t+k}$ is the pricing kernel between period t and $t+k$ and $mc_t(f)$ is the marginal cost of firm f.

The Home intermediate good composite used by final goods producers is made from a continuum of differentiated intermediate goods indexed by $i \in [0,1]$ according to equation (6):

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}(i)^{\frac{\theta_I - 1}{\theta_I}} di \right]^{\frac{\theta_I}{\theta_I - 1}}, \tag{6}$$

where θ_I is the elasticity of substitution among differentiated intermediate goods. Following Devereux and Engel (2007) and Wang (2010), we assume that intermediate goods are priced in the producer's currency while final goods prices in each country are denominated in the consumer's currency. We also assume that law of one price (LOP) holds for intermediate goods.

The intermediate goods producers rent capital and labor from households. The technology takes a standard Cobb-Douglas form:

$$Y_{Ht}(i) = A_t^{1-\varphi} \left[\varrho_t K_t(i) \right]^{\varphi} L_t(i)^{1-\varphi}, \tag{7}$$

where A_t is the labor-augmented TFP, φ is the capital share in production, and ϱ_t is the capital utilization rate that is an endogenous variable chosen by the household optimally in each period. $K_t(i)$ and $L_t(i)$ are, respectively, capital and labor used by firm i. We follow the same staggered pricing scheme as in the final goods sector to introduce staggered prices of intermediate goods. $1-\alpha_I$ is the probability for intermediate goods firms to re-optimize their prices in each period. Following Jaimovich and Rebelo (2009) and Schmitt-Grohe and Uribe (2012), we consider news shocks to permanent changes in TFP. Schmitt-Grohe and Uribe (2012) find that anticipated shocks to permanent components of TFP explain a large fraction of the variance of output growth in the US. Considering news shocks to permanent changes in TFP allows us to confirm our theoretical findings with simulated data using long-run restrictions as in empirical studies. Note that our theoretical results do not depend on the nonstationarity of the TFP process. Our model can still replicate the comovement of international relative prices and labor productivity when TFP is stationary.

3.2 Household

The representative household maximizes expected lifetime utility:

$$E_0\left[\sum_{t=0}^{\infty}\beta^t U\left(C_t, L_t, X_t\right)\right], \tag{8}$$

where β is the subjective discount factor. The period utility is a function of consumption (C_t) and hours worked (L_t), and takes the form of:

$$U\left(C_t, L_t, X_t\right)=\frac{\left(C_t-\chi L_t^{\eta} X_t\right)^{1-\rho}}{1-\rho}, \text{ where } X_t=C_t^{\gamma} X_{t-1}^{1-\gamma}. \tag{9}$$

Note that ρ and η measure relative risk aversion and Frisch elasticity of labor supply, respectively, and χ is the labor wedge parameter. This preference specification is proposed by Jaimovich and Rebelo (2009). It nests as special cases the two classes of utility functions widely used in the literature. When the parameter γ is equal to 1, it reduces to the class of preferences discussed in King, Plosser, and Rebelo (1988), which we refer to as KPR. When γ is equal to 0, we obtain the preferences in Greenwood, Hercowitz, and Huffman (1988), which is referred to as GHH.

The representative household sells labor and rents capital to domestic intermediate goods firms in competitive markets. The law of motion for capital takes the form of:

$$K_{t+1}=(1-\delta(\varrho_t))K_t+S_1\left(\frac{I_t}{I_{t-1}}\right)I_t, \tag{10}$$

where the capital depreciation rate δ is a function of the capital utilization rate ϱ_t. Following Schmitt-Grohe and Uribe (2012), $\delta(\varrho)$ takes a quadratic functional form of:

$$\delta(\varrho)=\delta_0+\delta_1(\varrho-1)+\frac{\delta_2}{2}(\varrho-1)^2,$$

where the parameter δ_1 governs the steady state value of ϱ_t, which is set at a value consistent with a unit steady state value of ϱ_t, the parameter δ_0 corresponds to the steady state value of the depreciation rate of capital, and δ_3 defines the sensitivity of capacity utilization to variations in the rental rate of capital. The function $S_1(\cdot)$ represents investment adjustment costs following Christiano, Eichenbaum, and Evans (2005):

$$S_1(x)=1-\frac{\kappa}{2}(x-\bar{\mu}_I)^2,$$

where κ is the parameter for investment adjustment costs and $\bar{\mu}_I$ denotes the steady-state growth rate of investment.

The international financial market is incomplete: households can only trade non-state-contingent Home and Foreign nominal bonds. There is a quadratic real cost of holding bonds:

$$BC_t = \frac{\phi_d}{2}\left(\frac{B_{H,t+1}}{P_t}\frac{1}{A_t}\right)^2 A_t + \frac{\phi_a}{2}\left(\frac{S_t B_{Ft+1}}{P_t}\frac{1}{A_t}\right) A_t, \tag{11}$$

where $B_{H,t+1}$ ($B_{F,t+1}$) is the Home (Foreign) bond held by the household in the Home country between period t and period $t+1$. All bonds are denominated in the issuing country's currency. S_t is the nominal exchange rate defined as the Home currency price of one unit of Foreign currency. ϕ_d and ϕ_a are cost parameters for holding domestic bonds and holding foreign bonds, respectively.[6] This cost is introduced to ensure model stationarity. By assigning very small values to ϕ_d and ϕ_a, the bond-holding cost has a negligible effect on model dynamics.[7]

3.3 Monetary Policy Rule and Process of Technology Shocks

In the Home country, the monetary authority follows a simple monetary policy (Taylor) rule:

$$log(R_t/\bar{R}) = \Theta_\pi log(\Pi_t/\bar{\Pi}) + \Theta_y log(GDP_t/\overline{GDP}), \tag{12}$$

where R_t is the gross nominal interest rate, Π_t is the consumer price index (CPI) inflation rate, and GDP_t is gross domestic product (GDP) at time t. Variables with a bar on top are steady-state levels of corresponding variables. The monetary authority in our model uses the nominal interest rate to stabilize the deviation of the inflation rate and GDP from their steady-state levels. The central bank may also include the exchange rate in the Taylor rule. For instance, Clarida, Gali, and Gertler (1998) find empirical evidence that the central bank of Germany targeted the real exchange rate when conducting monetary policy. However, the policy parameter in front of the exchange rate deviation is usually small. In Clarida, Gali, and Gertler's (1998) estimate, the German central bank raised the annual nominal interest rate by only 50 basis points for a 10% depreciation of its real exchange rate. In a model similar to ours, Wang (2010) finds that the optimal exchange rate stabilization parameter is very small if the central bank optimally targets the CPI inflation rate. Engel (2011) shows in a modified version of Clarida, Gali, and Gertler's (2002) model that the interest

[6] Note that in the Foreign country, ϕ_d is the cost parameter of holding Foreign bonds, and ϕ_a is the cost parameter of holding Home bonds.

[7] See Schmitt-Grohe and Uribe (2003) for more details.

rate reaction function may involve only the CPI inflation rate even if optimal monetary policy targets not only inflation and the output gap, but also the currency misalignment. As a result, we do not explicitly consider exchange rate targeting in the Taylor rule of our model.

Technology shocks are assumed to be nonstationary in our model. Let $\mu_{A,t} \equiv A_t/A_{t-1}$ and $\mu^*_{A,t} \equiv A^*_t/A^*_{t-1}$ denote the growth rate of Home and Foreign TFP shocks. The logarithms of $\mu_{A,t}$ and $\mu^*_{A,t}$ are assumed to follow the following vector error correction (VEC) processes:

$$log(\mu_{A,t}/\bar{\mu}_A) = \rho_A log(\mu_{A,t-1}/\bar{\mu}_A) - \rho_R log(A_{t-1}/A^*_{t-1}) + \epsilon_{A,t}, \tag{13}$$

$$log(\mu^*_{A,t}/\bar{\mu}^*_A) = \rho_A log(\mu^*_{A,t-1}/\bar{\mu}^*_A) + \rho_R log(A_{t-1}/A^*_{t-1}) + \epsilon^*_{A,t}. \tag{14}$$

A similar VEC representation of the technology processes is also used in Rabanal, Rubio-Ramirez and Tuesta (2011). They show that the technology processes in the US and the ROW are characterized by a VEC model. In addition, they find that adding cointegrated technology shocks to the standard international real business cycle model helps the model replicate the observed high real exchange rate volatility in the data.

Following Ravn, Schmitt-Grohe, and Uribe (2012) and Schmitt-Grohe and Uribe (2012), we assume that $\epsilon_{A,t}$ and $\epsilon^*_{A,t}$ have both contemporaneous and anticipated news components:

$$\epsilon_{A,t} = \xi_{A,t} + \zeta_{A,t-p} \text{ and } \epsilon^*_{A,t} = \xi^*_{A,t} + \zeta^*_{A,t-p}, \tag{15}$$

where $\xi_{A,t}(\xi^*_{A,t})$ is the contemporaneous component and $\zeta_{A,t-p}(\zeta^*_{A,t-p})$ is the anticipated (or news) component of the technology shock with $p \geq 1$ being the anticipation horizon of the news shock. $\zeta_{A,t-p}$ is in the information set of the economic agents since period $t-p$ though it affects the growth rate of technology only after period t. For instance, when $p = 4$, part of the technology shock is anticipated four periods in advance. $\xi_{A,t}$, $\zeta_{A,t}$, $\xi^*_{A,t}$, and $\zeta^*_{A,t}$ are *i.i.d.* and have mean zero.

Finally, the real exchange rate and terms of trade are defined as in equations (1) and (2) of Section 2.

4 Calibration and Model Performance

We calibrate our model to match quarterly data. Table 1 shows parameter values used in our calibration. The discount factor β is set to 0.9902, which implies an annual real interest rate of 4%. The relative risk aversion parameter ρ is set to 2. The parameter δ_0 is set equal to 0.025 so that the steady-state capital depreciation rate is 10% per annum. The parameter δ_1 is calibrated such that the capital utilization rate equals one in the steady state. Following Jaimovich and Rebelo (2009), the parameter δ_2 is calibrated such that the elasticity of $\delta'(\varrho)$ evaluated in the steady state is 0.15 (i.e., $(\delta''(\varrho)\varrho/\delta'(\varrho) = 0.15)$. The investment adjustment cost parameter κ is set to the same value as in Christiano, Eichenbaum, and Evans (2005). With this calibration of κ, the standard deviation of investment is about three times as large as the standard deviation of GDP in our model.

Following Backus, Kehoe, and Kydland (1994), the elasticity of substitution between home and foreign goods ψ is set to 1.5. The home bias parameter ω is set to match the fact that the ratio of import to GDP is around 15% in the US. The production share of capital is set to 0.36 following King, Plosser, and Rebelo (1988). The elasticities of substitution between differentiated intermediate and final goods (i.e., θ_F and θ_I) are set at levels such that the profit margin is 20% for intermediate and final goods firms. Under our calibration of price stickiness parameters (α_F and α_I), final and intermediate goods firms on average re-optimize their prices every four quarters. Following Kollmann (2004), the steady-state annual inflation rate is 4.2%. The inflation targeting parameter Θ_π is set to 3 and the output targeting parameter Θ_y is set to zero in the benchmark model. In a closed-economy model similar to ours, Schmitt-Grohe and Uribe (2007) find that these are optimal values for policy parameters. Similar results are also found in Wang (2010) in an open-economy DSGE model.

We consider two classes of preferences in our benchmark model. In the first case, γ is set to 0.001 following Jaimovich and Rebelo (2009). In this case, the preference is very close to the one proposed by Greenwood, Hercowitz, and Huffman (1988) and has a very weak wealth effect on the labor supply. η is set to 0.15 such that the Frisch elasticity of labor supply is 2.5 and χ is calibrated such that the steady-state value of hours worked is 0.2. These parameters take the same values as in Jaimovich and Rebelo (2009). When γ is set to one, our period utility function reduces to the class of preferences used in King, Plosser, and Rebelo (1988).

The estimate of the persistence of productivity growth (ρ_A) has a wide range in the literature. Baxter and Crucini (1995) estimate a vector error correction model for the Solow residuals of the US and Canada. The estimated AR(1) coefficient for the US is 0.113. Aguiar and Gopinath (2007) estimate a small-open-economy model with the data of Canada and Mexico. The AR(1) coefficient of the productivity growth rate is statistically insignificant from zero in their estimation. Schmitt-Grohe and Uribe (2012) estimate a closed-economy model with the US data using the Bayesian method. They find the mean of the posterior distribution for the AR(1) coefficient is 0.14. However, Croce (2014) finds that the productivity growth rate is very persistent when he estimates an ARMA(1,1) process with a direct measure of the annual productivity growth rate in the US. Croce's (2014) choice of annual data follows the practice in the studies on long-run risks. He argues that annual data are not altered by any seasonal adjustment and also contains less noise related to the low-frequency component of productivity. Following Croce (2014), we estimate an AR(1) process for the US multifactor productivity index from 1949 to 2008. The multifactor productivity data are provided by the Bureau of Labor Statistics and take into account capital accumulation. The data are only available at an annual frequency. The estimated AR(1) coefficient is 0.6, which implies a coefficient of about 0.85 at a quarterly frequency. Thus we set ρ_A to 0.85 in our benchmark model. A less persistent growth rate for productivity shocks is also considered in our robustness checks. In this case, we set ρ_A to 0.14 following Schmitt-Grohe and Uribe's (2012) estimate. The cointegrating coefficient ρ_R is set to 0.007 following Rabanal, Rubio-Ramirez, and Tuesta (2011). The anticipation horizon of news shocks (p) is set equal to 8 periods in the benchmark model. We find that our results are sensitive to this parameter and various horizons are also considered in robustness checks.

Following Schmitt-Grohe and Uribe (2003), the foreign bond holding cost parameter (ϕ_a) is set to 0.000742. The domestic bond holding cost parameter (ϕ_d) is set to zero. Changing bond holding cost has no qualitative effect on our results so long as the magnitude of the cost is not too large.

4.1 Theoretical Benchmark Results

We first report some business cycle statistics of our model and then show that our model can replicate the appreciation of the real exchange rate and the terms of trade following an increase in labor productivity as documented in the US data. Table 2 displays some business cycle statistics of simulated variables with our benchmark model and compares them with those observed in the data.[8] The calibration of the relative size of news and contemporaneous shocks remains a highly debatable issue.[9] For this reason, we show the statistics of the model variables simulated under each of contemporaneous and news shocks. In general, the results show that our model performs similarly under these two shocks and can replicate some real business cycle statistics that are commonly studied in the literature. For instance, our model can replicate the volatility of consumption, investment, and hours relative to the volatility of GDP. As in all other standard international macroeconomic models, the real exchange rate is less volatile in our model than in the data. However, we find that the relative volatility of the real exchange rate in the case with news shocks is about twice as large as in the case with contemporaneous shocks. Matsumoto, Cova, Pisaniz, and Rebucci (2013) find that introducing news shocks to standard DSGE models can help to increase the volatility of asset prices in these models. Our simulation results on the exchange rate is consistent with this finding. In Table 2, news shocks also help to improve the model's performance in matching the cross-country correlation of investment. News

[8] All variables are logged and HP filtered with a smoothing parameter of 1600.

[9] For empirical studies on identifying contemporaneous and news TFP shocks, see Beaudry and Portier (2006), Beaudry, Dupaigne, and Portier (2011), Beaudry and Luke (2009), and Barsky and Sims (2011).

shocks, however, are not helpful for solving the quantity puzzle (see Chari, Kehoe and McGrattan, 2002): consumption is more correlated across countries than output in our model under both contemporaneous and news shocks while the opposite is true in the data.

We now turn to the impulse response functions (IRFs) from the benchmark model. The IRF results are similar for KPR and GHH preferences. To save space, we only report the IRF results of KPR preference and leave the IRF results of GHH preference to the online appendix. Figure 4 shows the theoretical IRFs to a one-percent increase in a contemporaneous or news shock to the home TFP growth. Figure 4(a) shows the IRFs following a contemporaneous shock. After a positive TFP growth shock in the Home country, its labor productivity, output and consumption rise. The terms of trade and the real exchange rate depreciate following the shock. These predictions are consistent with the standard models, as shown in Figure 1. Figure 4(b) displays the IRFs to a one-percent increase in the news shock with its anticipation horizon of 8. On the impact of the news shock in the Home country, the terms of trade and the real exchange rate appreciate while labor productivity rises.

To help us understand this difference, it is worth noting that the direction of the real exchange rate movement in our model is determined by the dynamics of the real interest rate differentials. Uncovered interest rate parity (UIP) approximately holds in our model. From the Home country's first order conditions of holding Home and Foreign bonds, we have:

$$1 + \phi_d \left(\frac{B_{H,t+1}}{A_t} \right) = E_t \left[\Gamma_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right] \text{ and } 1 + \phi_a \left(\frac{B_{F,t+1} S_t P_t^*}{A_t P_t} \right) = E_t \left[\Gamma_{t,t+1} \frac{R_t^*}{\Pi_{t+1} S_t / S_{t+1}} \right].$$

The bond holding cost parameters ϕ_d and ϕ_a are very small and we set them to zero in our following approximation. Up to a first-order approximation, we have the standard UIP condition:

$$s_t \approx E_t[s_{t+1}] - (i_t - i_t^*),$$

where s_t is the log nominal exchange rate and $i_t = R_t - 1$ is the nominal interest rate. We can rewrite the UIP condition in terms of the log real exchange rate and the real interest rate:

$$q_t = E_t q_{t+1} - \left[i_t - E_t \pi_{t+1} - (i_t^* - E_t \pi_{t+1}^*) \right].$$

By iterating this condition forward, we obtain:

$$q_t = E_t[q_{t+\infty}] - \sum_{j=0}^{\infty} E_t[r_{t+j} - r^*_{t+j}], \tag{16}$$

where $r_t \equiv i_t - E_t\pi_{t+1}$ is the expected real interest rate at time t. In the above equation, the real exchange rate at time t, q_t, is determined by two parts: the steady-state value of the real exchange rate, $E_t[q_{t+\infty}]$, and the infinite sum of the expected Home and Foreign real interest rate differentials. The real exchange rate is stationary in our model, so the steady-state value of the real exchange rate is a constant. As a result, the initial response of the real exchange rate to a shock depends on the infinite sum of the expected real interest rate differentials.

In Figure 4(a), the Home country has a lower real interest rate than the Foreign country in most periods following a positive contemporaneous TFP shock, although its real interest rate is higher than the foreign country in the first few periods due to the strong wealth effect. The sum of the expected real interest rate differentials turns out to be negative in this case. As a result, the real exchange rate at time t will jump above its steady state, indicating a decrease in the prices of the Home country. The CPI inflation rate in the Home country is higher than that in the Foreign country in the first few periods following the contemporaneous shock. This is mainly caused by the strong wealth effect from a persistent TFP growth shock. Expecting higher income in the future, households increase current consumption more than the increase in output. Because of inflation-targeting monetary policy, the Home country has both higher nominal and real interest rates than the Foreign country during this period. However, the increased TFP and capital stock raise the supply of Home goods and push down their prices in the following periods. As a result, the inflation rate and the nominal interest rate in the Home country become lower than in the Foreign country after the first few periods.

Similar tradeoffs exist in the case of news shocks. The Home household increases consumption immediately after good news about future TFP, which tends to increase the price of Home goods relative to Foreign goods when consumption is home-biased. Labor productivity also increases immediately after the news shock though TFP remains constant. This is because the capital utilization rate rises after the shock due to the wealth effect of the good news about future productivity. The increase in the capital utilization rate raises the supply of Home goods, which tends to reduce the price of Home goods relative to Foreign goods. However, the wealth effect after a news shock is strong enough to offset the effect of higher capital utilization and induces an appreciation of the terms of trade and the real exchange rate in our model.

We can see the above tradeoff by comparing the dynamics of real interest rate differentials in cases with contemporaneous and news shocks in Figures 4(a) and 4(b). The wealth effect discourages savings in the Home country. Because the wealth effect dominates in the case of the news shock, the real interest rate differential between the Home and Foreign countries is much higher in this case than in the case with the contemporaneous shock. Compared to the case of the contemporaneous shock, the real interest rate differential remains positive for more periods following a news shock. As a result, the infinite sum of expected real interest rate differentials becomes positive in this case. From equation (16), we know that the real exchange rate jumps below its steady state in this case, indicating an increase in Home prices.

To confirm this intuition, we consider a case in which variable capital utilization is turned off.[10] After we shut down variable capital utilization in our model, the terms of trade and the real exchange rate experience even stronger appreciation for a given news shock because in this case, households cannot increase the supply of Home goods by raising the capital utilization rate. However, labor productivity does not change after a positive news shock when we shut down the capital utilization rate because TFP remains constant after a news shock. It confirms that the increase of labor productivity after a news shock in our model is mainly due to the increase in the capital utilization rate.

One discrepancy between our model with KPR preference and the data is the decline of output and labor supply after a positive news shock about future productivity. It is well-understood that standard business cycle models have difficulties in generating a boom in response to good news about future productivity. For instance, see Cochrane (1994), Danthine, Donaldson, and Johnsen (1998), and Beaudry and Portier (2004, 2007). Jaimovich and Rebelo (2009) find that a model with variable capital utilization, adjustment costs to investment, and a preference with weak short-run wealth effects on the labor supply can generate an increase of hours in response to a positive news shock. The impulse response functions of our model with GHH utility function are consistent with Jaimovich and Rebelo's (2009) findings: output and hours increase in response to a positive news shock.[11] Our finding that the terms of trade and the real exchange rate appreciate while labor productivity rises holds up well in this case.[12]

4.2 Improving Model Performance

Although the terms of trade and the real exchange rate appreciate on impact of the news shock in our model, they begin to depreciate shortly after the shock. The appreciation of the terms of trade and the real exchange rate is more persistent in the data than in our benchmark model. As we have discussed, our model

[10] To save space, the impulse response functions to a positive news shock in the cases with and without variable capital utilization are reported in the online appendix.

[11] The results are available upon request.

[12] The results for the GHH utility specification are reported in the online appendix.

generates an appreciation after a positive news shock through the wealth effect. The model performance will improve if we can enhance the wealth effect in our model.

Figure 5(a) shows how the impulse response functions of the terms of trade and the real exchange rate vary with the anticipation horizon of news shocks and the persistence of productivity shocks. In the two subfigures of the first row, the AR(1) coefficient of the productivity shocks (ρ_A) is fixed at zero. When we change the anticipation horizon of news shocks (p) from 4 to 12, the persistence of the appreciation in the terms of trade and the real exchange rate increases. This result is consistent with the empirical finding in Fujiwara, Hirose, and Shintani (2011). They estimate a DSGE model with news shocks to TFP using Bayesian methods for the US and Japan. They find that a news shock with a longer forecast horizon has larger effects on nominal variables. In the two subfigures of the second row, the anticipation horizon of news shocks is fixed at 8 and the AR(1) coefficient of the productivity shock increases from 0 to 0.8. Increasing the persistence of productivity shocks also helps our model replicate the persistent appreciation of the terms of trade and the real exchange following an increase in labor productivity. The stronger wealth effect in the case with more persistent shocks helps to increase consumption in the Home country, and therefore the appreciation of the terms of trade and the real exchange rate.

The appreciation of the terms of trade and the real exchange rate also becomes more persistent when home and foreign goods are more substitutable in our model. The empirical estimates of the elasticity of substitution between home and foreign goods have a wide range. When matching the moments of macroeconomic variables at the business cycle frequency, the elasticity of substitution is found to be around unity. For instance, see Heathcote and Perri (2002). However, estimates from disaggregated data are higher, usually above 4. For instance, Bernard, Eaton, Jensen, and Kortum's (2003) estimate of the elasticity equals 4, and in Head and Ries (2001), the trade elasticity is estimated to be about 8. Estimates from the studies of trade liberation can be as high as 15. These findings present what is called the trade elasticity puzzle – see Ruhl (2005) and Engel and Wang (2011) for discussions about recent studies on this puzzle. Ruhl (2005) finds that the elasticity of substitution with respect to a permanent shock, such as tariff reduction, can be much higher than one due to the entry of new exporters. Since our paper studies the dynamics of the real exchange rate and the terms of trade after a permanent shock, rather than matching business-cycle statistics, it may be more appropriate to use a higher elasticity of substitution. If we increase the trade elasticity to 4, a moderate level in the trade literature, the appreciation of the terms of trade and the real exchange rate becomes almost as persistent as in the data.

Figure 5(b) shows the impulse response functions of the terms of trade and the real exchange rate with respect to contemporaneous and news shocks when the elasticity of substitution between home and foreign goods is set to 4. The terms of trade and the real exchange rate depreciate with respect to a positive contemporaneous shock. However, they appreciate for several periods following a positive news shock. The terms of trade and the real exchange rate appreciate at an even shorter anticipation horizon of the news shock than in our benchmark model. For instance, the terms of trade and the real exchange rate appreciate on impact of the news shock for both preference functions when the anticipation horizon of the news shock is as short as four. As in our benchmark model, the persistence of the appreciation increases with the anticipation horizon of the news shock. When the horizon of news shocks is 8, the terms of trade remain in the appreciative territory for about 8 periods following a positive news shock. This is about the same number of periods of appreciation found in our empirical study. The appreciation of the real exchange rate in our model is still less persistent than in the data. The persistency of the real exchange rate in the data may also be driven by other factors such as the relative price between tradable and nontradable goods, which are missing in our model.

High elasticity of substitution helps to generate persistent appreciation of the terms of trade and the real exchange rate in our model because it reduces the spillover of the wealth effect across countries. When the good news about Home country's productivity is realized in the future, Home goods prices decline relative to Foreign goods prices. The decline in the relative price is smaller with higher elasticity of substitution between Home and Foreign goods. As a result, the spillover of wealth from the Home country to the Foreign country is smaller in the case of higher elasticity of substitution. Corsetti, Dedola, and Leduc (2008) find that in the case of a highly persistent contemporaneous shock, a relatively high trade elasticity is crucial to obtain the appreciation of the terms of trade and the real exchange rate. Otherwise, the increase in the supply of Home goods after a positive productivity shock would generate a substantial drop in their prices, which could even reduce Home country's wealth. Baxter and Crucini (1995) find similar results in a model with perfectly substitutable home and foreign goods and highly persistent shocks. Shocks in our model are less persistent than the ones in these studies. As a result, the terms of trade and the real exchange rate depreciate after a positive contemporaneous shock as predicted by the standard models.

Price stickiness is another factor that affects the terms of trade movements when home TFP changes relative to foreign TFP. Devereux and Hnatkovska (2011) show analytically in a simple New Keynesian open economy model that the response of the terms of trade to a productivity shock is negatively correlated with the price stickiness. As a result, sticky prices in our model are helpful for our results because price stickiness reduces the terms of trade movements and therefore the cross-country spillover of the wealth effect when news shocks to TFP are realized in the future. When prices are fully flexible in our model, the real exchange rate and the terms of trade barely appreciate following a favorable news shock.

4.3 Simulated Impulse Response Functions and Robustness Checks

In this subsection, we simulate our model and estimate the impulse response functions by using the simulated data and imposing long-run restrictions as in Section 2. The theoretical impulse response functions show that our model can simultaneously generate an increase in the labor productivity and an appreciation of the terms of trade and the real exchange rate after a positive news shock in the Home country. We want to confirm that long-run restrictions can detect this pattern in the simulated data. We also consider several alternative setups of the model in this subsection to check the robustness of our results.

We use the same set of variables as in Section 2 when estimating the impulse response functions of the simulated data with long-run restrictions.[13] The labor productivity is measured by output (Y_{Ht}) divided by labor input (L_t) in the simulated data. Figure 6 shows the median and 16% and 84% quantiles of 500 impulse response function estimations, as well as the theoretical impulse response functions of our model. The median of the impulse response functions estimated from the simulated data trace the theoretical impulse response fairly well. Similar to what we found in the US data, when labor productivity rises, GDP and consumption increase while the trade balance deteriorates. Both the terms of trade and the real exchange rate appreciate in the first 10 periods following the shock.

We now show that our results are robust under other model setups. We first consider another class of utility functions that are widely used in the literature (e.g., Backus, Kehoe and Kydland, 1994):

$$U(C_t, 1 - L_t) = \frac{\left[C_t^{\eta}(1 - L_t)^{1-\eta}\right]^{1-\rho}}{1 - \rho}. \tag{17}$$

We follow Backus, Kehoe, and Kydland (1992) in calibrating the preference parameters in equation (17) and refer to this preference function as BKK in the rest of the paper. We also consider a different functional form for capital adjustment cost. Under this setup of capital adjustment cost, the law of motion for capital takes the form of:

$$K_{t+1} = (1 - \delta(\varrho_t))K_t + S_2\left(\frac{I_t}{K_t}\right)K_t.$$

The function $S_2(\cdot)$ introduces the capital adjustment cost and takes the form of:

$$S_2(x) = x - \frac{1}{2\kappa_2\overline{\mu}_{I/K}}\left(x - \overline{\mu}_{I/K}\right)^2, \tag{18}$$

[13] When our model is simulated, the trade elasticity of substitution is set equal to 4. The results of alternative model specifications and calibrations are reported in the online appendix.

where $\overline{\mu}_{I/K}$ is the steady-state investment-to-capital ratio and κ_2 is the elasticity of the investment-to-capital ratio with respect to Tobin's q (i.e., $\kappa_2 = -(S_2'/S_2'')/(I/K)$). This type of investment adjustment cost functions assumes that it is costly to change the investment-to-capital ratio and is also widely used in the literature. For instance, see Baxter and Crucini (1995) among others.

The appreciation of the terms of trade and the real exchange rate after a positive news shock holds up well under the preference in equation (17) and the capital adjustment cost function in equation (18). In all cases, the terms of trade and the real exchange rate appreciate on impact of the news shock. To save space, we only report the impulse response functions in the online appendix.

5 Conclusion

Several recent studies find that in the US, the terms of trade and the real exchange rate appreciate when its labor productivity rises relative to the rest of the world. In this paper, we study how news shocks to TFP help to replicate this finding in a standard open-economy macro model. The news shock to TFP to some extent resembles a demand shock: the demand for consumption increases right after the news shock because of the wealth effect, although TFP does not increase immediately. This effect tends to increase home goods prices relative to the foreign and causes appreciation in the terms of trade and the real exchange rate.

To generate an immediate increase in labor productivity after the news shock, we introduce variable capital utilization into the model. Although TFP remains constant following the news shock, the capital utilization rate rises because of the good news about future productivity. As a result, labor productivity increases immediately. The increase in the capital utilization rate raises the supply of home goods and therefore tends to decrease home goods prices. This will dampen some of the wealth effect on home goods prices. Under various reasonable calibrations, however, our model can successfully replicate the increase of labor productivity and the appreciation of the terms of trade and the real exchange rate simultaneously.

The appreciation of the real exchange rate and the terms of trade in our model following an increase in labor productivity is not as persistent as in the data. We find that increasing the persistence of TFP shocks, the anticipation horizon of news shocks, and the elasticity of substitution between home and foreign goods can strengthen the wealth effect and therefore help our model come closer to replicating a persistent appreciation of home prices when its labor productivity increases.

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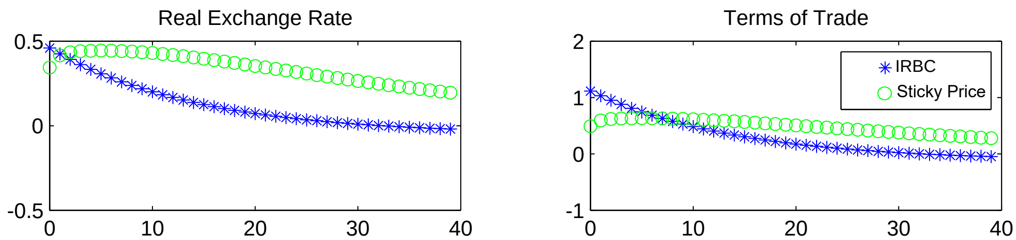
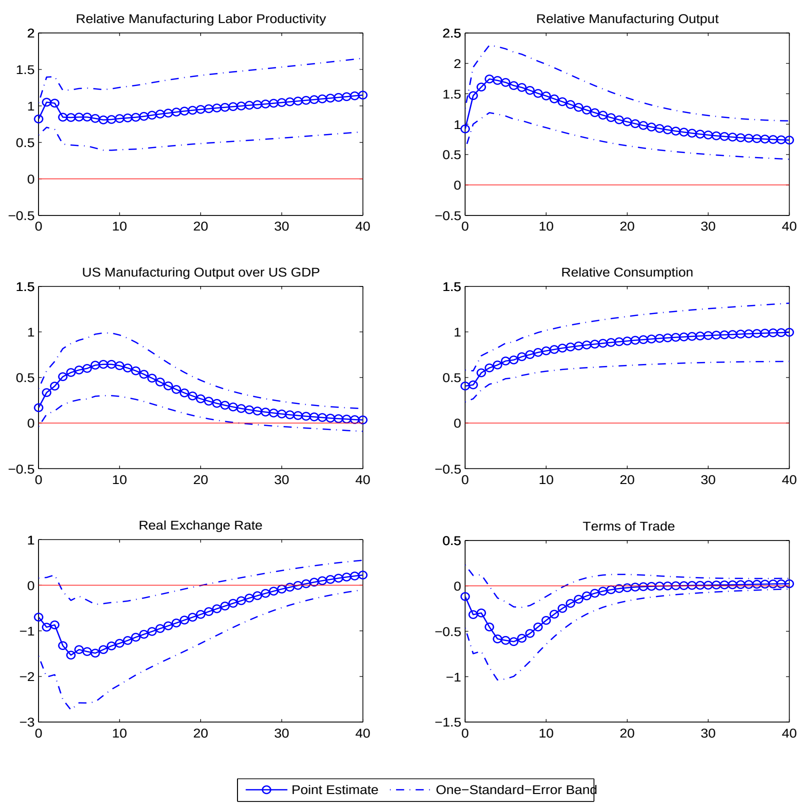
Figure 1: Impulse Response Functions of Real Exchange Rate and Terms of Trade in Standard International Macroeconomic Models



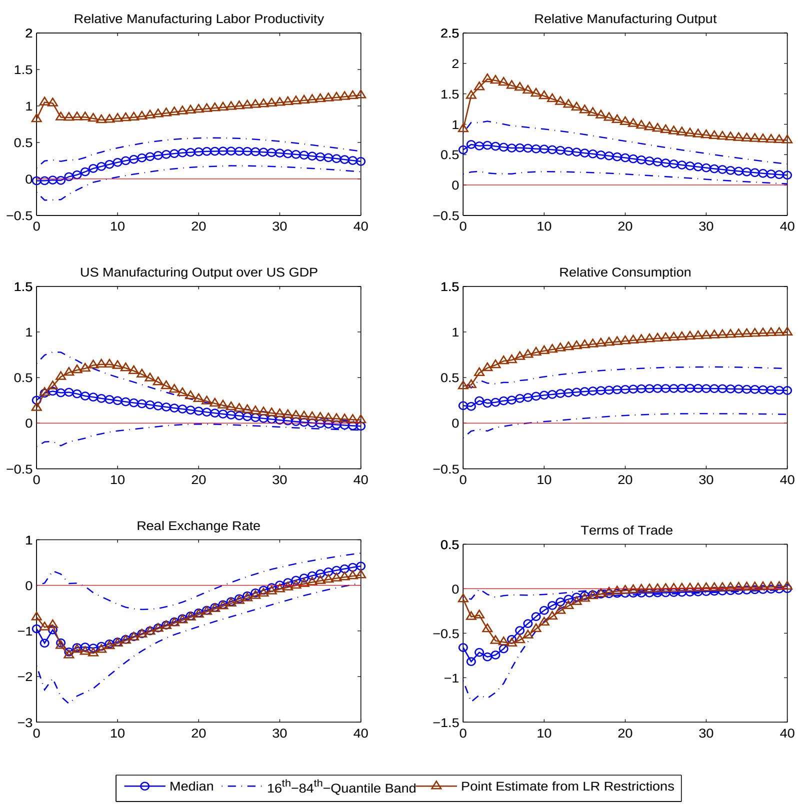
Note: This figure displays the impulse response functions of the real exchange rate and the terms of trade to a positive technology shock of the home country in two standard international macroeconomic models: an international real business cycle (IRBC) model and an open-economy version of a sticky-price DSGE (Sticky-Price) model. These models are described in the online appendix.

Figure 2: Empirical Impulse Response Functions from Long-Run Restrictions



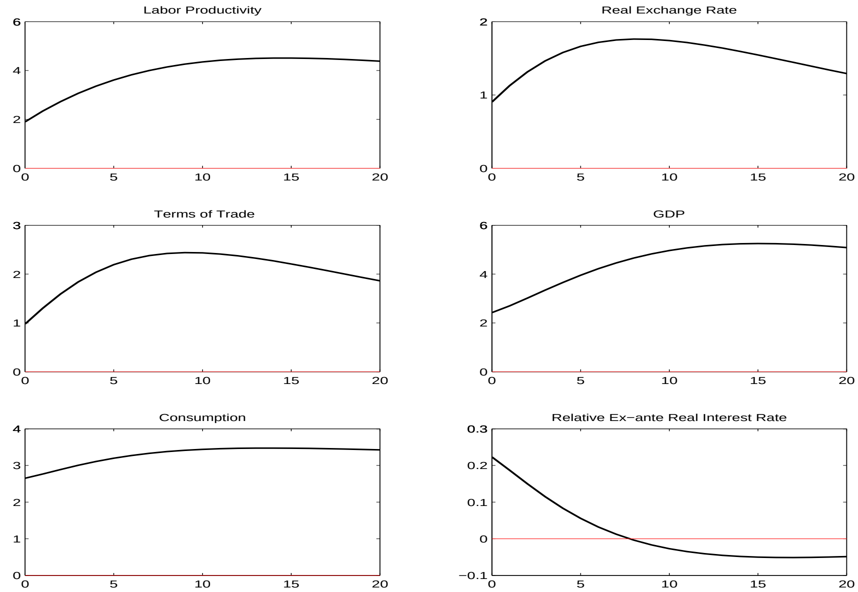
Note: This figure displays the estimated impulse response functions to a positive technology shock with the US-ROW data. The technology shock is identified by imposing long-run restrictions.

Figure 3: Empirical Impulse Response Functions from Shape Restrictions

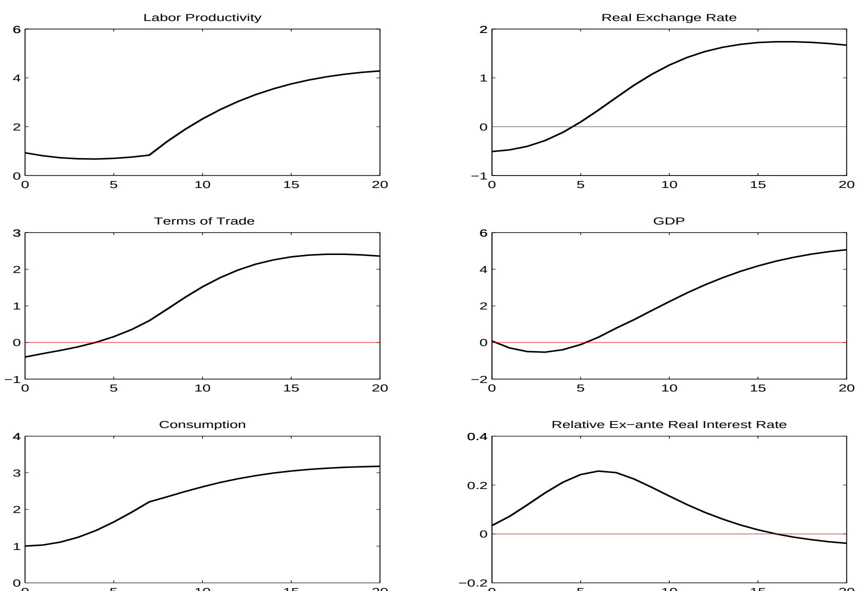


Note: This figure displays the estimated impulse response functions to a positive news shock with the US-ROW data. The news shock is identified by imposing shape restrictions. For comparison, the point estimates of the impulse response functions from long-run (LR) restrictions, which are shown in Figure 2, are also plotted.

Figure 4: Theoretical Impulse Response Functions: Benchmark Model



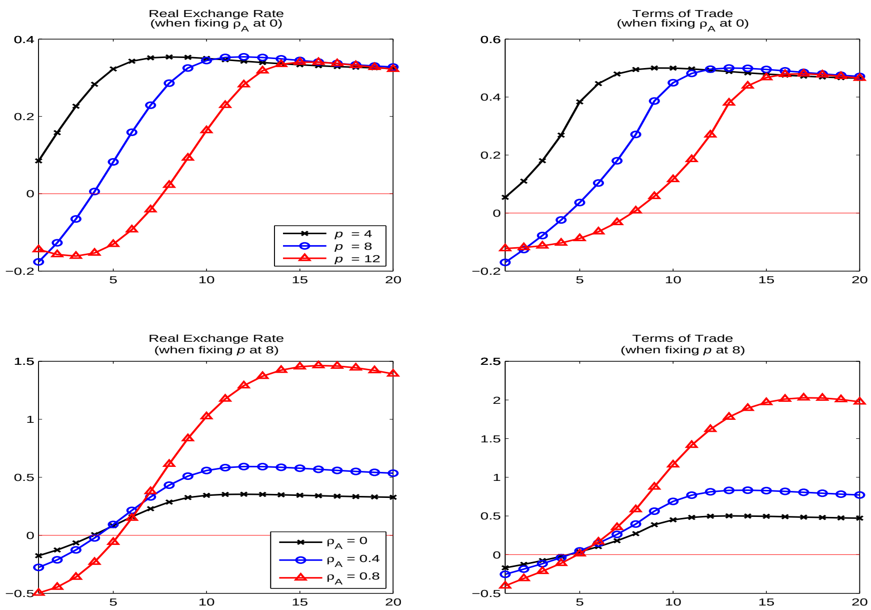
(a) Contemporaneous Shocks



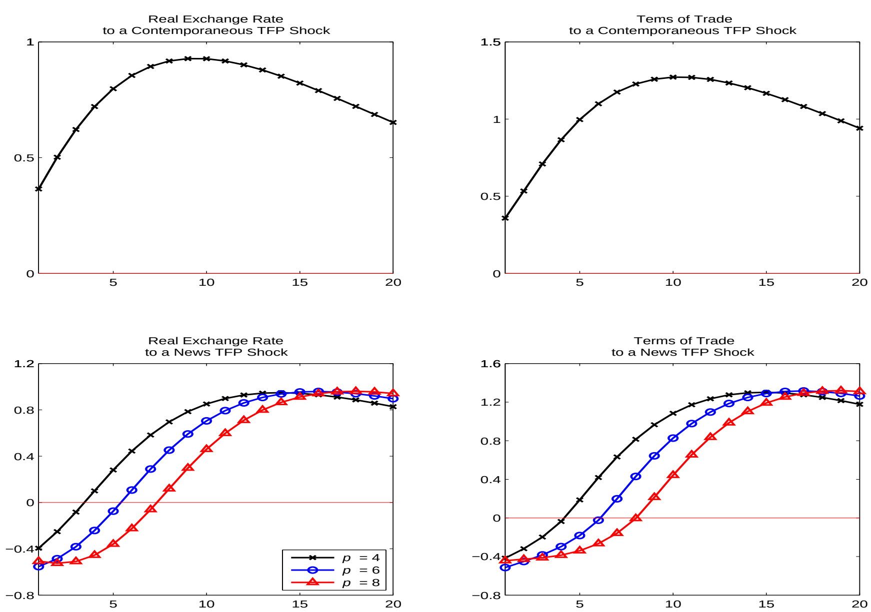
(b) News Shocks

Note: This figure shows the theoretical impulse response functions to a one-percent increase in contemporaneous (Panel (a)) and news shocks (Panel (b)) to the TFP growth rate of the Home country. These impulse response functions are generated based on the parameter values described in Table 1.

Figure 5: Effects of Anticipation Horizon and Persistence of News Shocks, and High Trade Elasticity on Appreciation of Real Exchange Rate and Terms of Trade



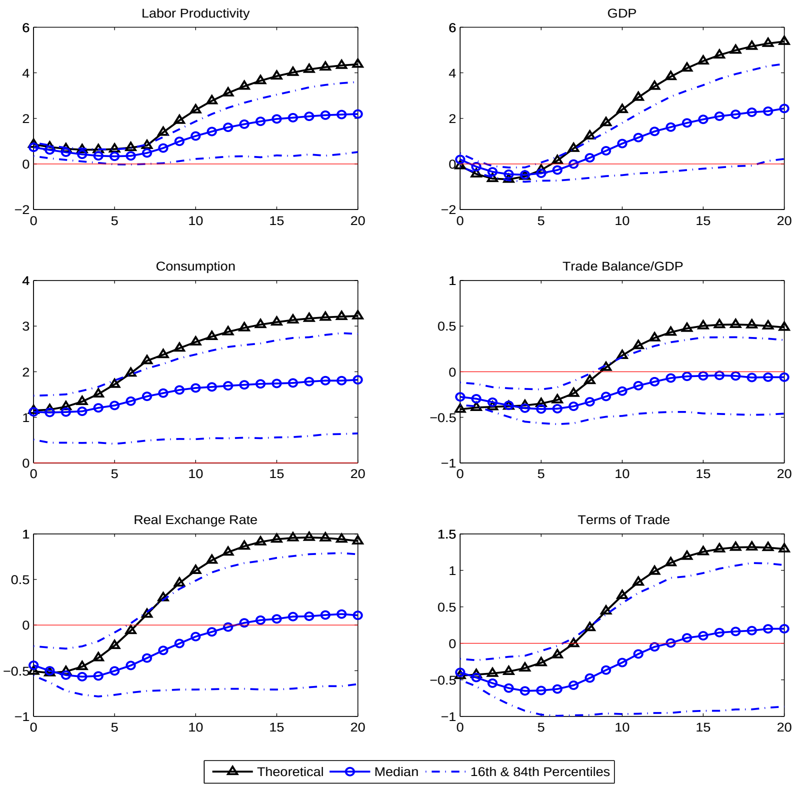
(a) Anticipation Horizon and Persistence of News shocks



(b) High Trade Elasticity

Note: This figure has two panels. Panel (a) shows the theoretical impulse response functions of the real exchange rate and the terms of trade to a positive news shock for various values of the anticipation horizon (p) of news shocks and the AR(1) coefficient (ρ_A) of the VECM process of TFP shocks. Panel (b) shows the theoretical impulse response functions to contemporaneous and news shocks when the trade elasticity is set equal to 4. In particular, various values of the anticipation horizon (p) of news shocks are considered for the impulse response functions to a news shock.

Figure 6: Estimated Impulse Response Functions with the Simulated Data



Note: This figure displays the estimated impulse response functions from the simulated data with long-run restrictions. When simulating our theoretical model, the trade elasticity of substitution is set equal to 4. For each of 500 simulations, the impulse response functions are estimated by imposing long-run restrictions. The median and the 16th-and-84th quantile band are plotted. For comparison, the theoretical impulse response functions of the model are also plotted.

Table 1: Calibration of the Benchmark Model

Parameter	Value	Description
β	0.9902	Subjective discount factor
ρ	2	Relative risk aversion
δ_0	0.0250	Steady-state capital depreciation rate
δ_1	0.0349	Calibrated such that steady-state capital utilization equals one
δ_2	0.0052	Calibrated such that $\delta(\varrho)''\varrho/\delta(\varrho)'$ equals 0.15
κ	2.79	Investment adjustment cost parameter
ψ	1.50	Elasticity of substitution between home and foreign goods
ω	0.85	Home bias in domestic goods
φ	0.36	Capital share in production
θ_F	6	Elasticity of substitution between differentiated final goods
θ_I	6	Elasticity of substitution between differentiated intermediate goods
α_F	0.75	Price stickiness parameter for final goods
α_I	0.75	Price stickiness parameter for intermediate goods
$\overline{\Pi}$	1.0103	Steady-state inflation rate
Θ_π	3	Inflation targeting parameter
Θ_y	0	Output targeting parameter
γ	1	When KPR utility is considered
γ	0.001	When GHH utility is considered
η	0.150	Calibrated such that the Frisch elasticity of labor supply is 2.5
χ	3.554	Calibrated such that the steady-state labor supply is 0.2
ρ_A	0.850	AR(1) coefficient of VECM of technology shocks
ρ_R	0.007	Cointegrating coefficient of VECM of technology shocks
p	8	Anticipation horizon of of news shocks
ϕ_a	0.000742	Cost parameter of holding foreign bonds
ϕ_d	0	Cost parameter of holding domestic bonds

Table 2: Business Cycle Statistics of the Benchmark Model

	SD Relative to SD of GDP				Cross-country Correlation			
	C	I	L	Q	GDP	C	I	L
Data†	0.83	2.78	0.67	4.36	0.60	0.38	0.33	0.39
	KPR Preference							
Contemporaneous shock	1.01	2.98	0.26	0.61	-0.11	0.81	-0.59	-0.16
News shock	0.75	2.97	0.71	1.28	-0.59	0.54	0.43	0.16
	GHH Preference							
Contemporaneous shock	1.08	2.97	0.73	0.35	0.29	0.86	-0.54	0.44
News shock	1.21	2.97	0.78	0.69	0.04	0.81	0.29	0.00

Note: (1) SD is the abbreviation of standard deviation; (3) C is consumption, I is investment, L is hours worked, and Q is the real exchange rate; (3) Statistics of the Data† come from Chari, Kehoe, and McGrattan (2002).

APPENDIX (not for publication)

A.1 Standard International Macroeconomic Models

In this section, we describe two standard international macroeconomic models that are used in Section 2: an international real business cycle (IRBC) model and an open-economy version of a sticky-price DSGE model.

A.1.1 IRBC Model

The standard IRBC model in Section 2 is the bond-economy model of Heathcote and Perri (2002). There are two symmetric countries, Home and Foreign. In each country, there are two sectors, intermediate goods sector and final goods sector. Due to symmetry, we focus only on the Home country in describing our model. The intermediate goods are produced from capital and labor with the standard Cobb-Douglas technology:

$$Y_{Ht}^{H} + Y_{Ft}^{H} = A_{Ht} K_{Ht}^{\theta} L_{Ht}^{1-\theta}, \tag{A.1.1}$$

where Y_{Ht}^{H} is Home intermediate goods used in the Home country and Y_{Ft}^{H} is Home intermediate goods used in the Foreign country. A_{Ht} is the TFP shock, K_{Ht} is capital and L_{Ht} is labor supply. Capital follows the standard law of motion:

$$K_{Ht+1} = (1-\delta) K_{Ht} + I_{Ht}. \tag{A.1.2}$$

The final goods are produced using Home and Foreign intermediate goods:

$$Y_{Ht} = \left[\alpha^{\frac{1}{\gamma}} (Y_{Ht}^{H})^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} (Y_{Ht}^{F})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}. \tag{A.1.3}$$

All prices and wages are flexible. The representative household maximizes the expected lifetime utility given those prices:

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t U(C_{Ht}, 1 - L_{Ht}) \right], \tag{A.1.4}$$

where the period utility function takes the form of:

$$U(C_{Ht}, 1-L_{Ht}) = \frac{1}{1-\sigma} \left[C_{Ht}^{\mu} (1-L_{Ht})^{1-\mu} \right]^{1-\sigma}. \tag{A.1.5}$$

As for the international financial market, the Home and Foreign countries can trade real bonds in terms of Home country's intermediate goods. To make the model stationary, we assume a small bond holding cost as in Heathcote and Perri (2002). We calibrate the model with the same parameter values as Heathcote and Perri (2002) and our simulation results are very close to those reported in their paper.

A.1.2 Sticky-Price DSGE Model

The DSGE model in Section 2 is a two-country symmetric model. We will focus on the Home country in describing our model. There is a continuum of differentiated intermediate goods indexed by $i \in [0,1]$. The Home intermediate good i ($Y_H(i)$) is produced by a single firm with capital $K_t(i)$ and labor $L_t(i)$ in the Home country. Capital and labor are not internationally mobile. Intermediate goods are aggregated into an intermediate-good composite according to a standard CES function:

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}^{\frac{\phi-1}{\phi}}(i)di\right]^{\frac{\phi}{\phi-1}}. \tag{A.1.6}$$

The intermediate goods market is monopolistically competitive. The intermediate goods firms choose prices to maximize expected profit. We follow Calvo staggered price setting in this sticky-price model. In each period, the firm has a probability of $1-\lambda$ to change its price. When $\lambda = 0$, the model reduces to the flexible price setup.

Final goods are produced from Home and Foreign intermediate good composites according to the CES function:

$$Y_t = \left[\alpha^{\frac{1}{\gamma}} Y_{Ht}^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} Y_{Ft}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}, \tag{A.1.7}$$

where α is the percentage of Home goods in final goods and γ is the elasticity of substitution between Home and Foreign goods. The final goods market is competitive with flexible prices.

The representative household chooses sequences of consumption C_t, capital accumulation I_t, labor supply L_t, and Home and Foreign nominal bonds (B_{Ht+1} and B_{Ft+1}) to maximize the expected lifetime utility:

$$E_0\left[\sum_{t=0}^{\infty} \beta^t U(C_t, 1-L_t)\right], \tag{A.1.8}$$

where $U(C_t, 1-L_t) = \frac{\left[C_t^{\mu}(1-L_t)^{1-\mu}\right]^{1-\sigma}}{1-\sigma}$, subject to the budget constraint:

$$\begin{aligned} C_t + \frac{B_{Ht+1}}{(1+i_t)P_t} + \frac{S_t B_{Ft+1}}{(1+i_t^*)P_t} + I_t + \frac{1}{2}\Phi\left(\frac{I_t}{K_t} - \delta\right)^2 K_t + \frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2 + \frac{1}{2}\phi_f\left(\frac{S_t B_{Ft+1}}{P_t}\right)^2 \\ \leq \frac{W_t L_t}{P_t} + \frac{R_t K_t}{P_t} + \frac{B_{Ht}}{P_t} + \frac{B_{Ft} S_t}{P_t} + \frac{\Pi_t}{P_t}, \end{aligned} \tag{A.1.9}$$

where $\frac{1}{2}\Phi\left(\frac{I_t}{K_t} - \delta\right)^2 K_t$ is capital adjustment cost, $\frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2$ and $\frac{1}{2}\phi_f\left(\frac{S_t B_{Ft+1}}{P_t}\right)^2$ are bond holding costs for the Home and Foreign nominal bonds. Π_t is the profit of intermediate goods firms. The nominal interest rate follows the monetary policy (Taylor) rule:

$$i_t = i + \Xi_\pi log(\pi_t/\pi) + \Xi_y log(gdp_t/gdp), \tag{A.1.10}$$

where π_t is the CPI inflation rate at time t.

The values that we use to calibrate the DSGE model are listed in Table A.1.1. Most parameter values are from Heathcote and Perri (2002) in order for us to compare the IRBC and DSGE models. Parameters that are not in Heathcote and Perri (2002) are calibrated to standard values used in the literature such as in Kollmann (2004) and Wang (2010).

Table A.1.1: Calibration of the Sticky-Price DSGE Model

Parameter	Value	Description
Intermediate Goods Sector		
ψ	0.36	Capital Share in Production
ϕ	6	Elasticity of Substitution between Differentiated Tradable Goods
λ	0.75	Probability of Not Changing Price
δ	0.025	Depreciation Rate of Capital
Final Goods Sector		
α	0.85	Share of Home Goods in Final Good
γ	0.9	Elasticity of Substitution between Home and Foreign Goods
Household		
β	0.99	Subjective Discount Factor
Φ	3.20	Investment Adjustment Cost (Calibrated to have investment 3 times volatile as output.)
ϕ_d	0.0001	Domestic Bond Holding Cost
ϕ_f	0.0003	Foreign Bond Holding Cost
σ	2	Preference Parameter
μ	0.36	Preference Parameter (Calibrated to have 1/3 labor supply)
Exogenous Shocks		
$\xi_{11} = \xi_{22}$	0.970	Technology shock AR(1) coefficient
$\xi_{12} = \xi_{21}$	0.025	Technology spillovers
σ_ε	0.0073	Standard Deviation of Productivity Shock

A.2 Data Description

This section describes the US-ROW data used in section 2. All data series are seasonally adjusted, except where noted. The following series are used:

- Manufacturing labor productivity
- Manufacturing output
- Manufacturing output/Real GDP
- Consumption
- The real exchange rate
- The terms of trade

For each variable, the data for the US is compared to a rest-of-world aggregate of Japan, Germany, UK, Italy, France and Canada (except where noted). Weights are calculated by country GDP as a share of aggregate GDP, excluding the US. After 1980, weights are obtained from the IMF. From 1973-1979, weights are calculated from the real GDP of each country obtained from the OECD Economic Outlook dataset:

- United States: Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- Japan: Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- Germany (West Germany): Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- UK: Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- Italy: Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- France: Gross Domestic Product, 2005 PPP (Mil.2005.US$);
- Canada: Gross Domestic Product, 2005 PPP (Mil.2005.US$);

Data sources are:

Manufacturing Output

United States: Industrial Production: Manufacturing, SA, 2005=100; OECD Main Economic Indicators;

Japan: Industrial Production: Manufacturing, SA, 2005=100; OECD Main Economic Indicators;

Germany: Industrial Production: Manufacturing, SA, 2005=100; OECD Main Economic Indicators;

UK: Industrial Production: Manufacturing, SA, 2005=100; OECD Main Economic Indicators;

Italy: Industrial Production: Manufacturing, SA/WDA, 2005=100; G10

France: Industrial Production: Manufacturing, SA, 2005=100; OECD Main Economic Indicators;

Canada: Real Domestic Product: Manufacturing (SA, 2005=100); OECD Main Economic Indicators;

Real GDP

United States: Gross Domestic Product (SAAR, Bil.Chn.2005$); G10

Japan: Japan: Gross Domestic Product (SAAR, Bil.Yen); OECD

Germany: From 1991:Q1 to 2011:Q1, the series used is Germany: Gross Domestic Product (SA/WDA, Bil.Chn.2000.Euros) (G10). Nominal GDP (OECDMEI) deflated to 2000 values was used to get a base value for 1991:Q1, then extended back to 1973:Q1 using real GDP growth rates.

UK: Gross Domestic Product (SA, Mil.Chained.2006.Pounds); G10

Italy: Gross Domestic Product (SA/WDA, Mil.Chn.2000.Euros); G10

France: Real Gross Domestic Product (SA/WDA, Bil.Chn.2000.Euros); OECDMEI

Canada: Gross Domestic Product (SAAR, Mil.Chn.2002.C$); G10

Consumption

United States: Private Final Consumption Expenditure (SA, Bil.US$); OECDMEI

Japan: Private Final Consumption Expenditure (SA, Trillions.Yen); OECDMEI

Germany: Private Final Consumption Expenditure (SA/WDA, Bil.Euros); OECDMEI

UK: Private Final Consumption Expenditure (SA, Bil.Pounds); OECDMEI

Italy: Private Final Consumption Expenditure (SA/WDA, Bil.Euros); OECDMEI

France: Private Final Consumption Expenditure (SA/WDA, Bil.Euros); OECDMEI

Canada: Private Final Consumption Expenditure (SA, Bil.C$); OECDMEI

Labor productivity in the manufacturing sector is obtained from:

United States

Output per man-hour in manufacturing index created by merging two series from BIS Data Bank using quarterly growth rates and indexing to 2005=100.

OUTPUT PER MAN-HOUR IN MANUFACTURING INDEX SA; :UQNB: US: 01 OUTPUT PER MAN-HOUR IN MANUFACTURING INDEX SA-DISC; :UQNB:US:91

Japan

Ratio of monthly hours worked in manufacturing index to manufacturing output index, indexed to 2005=100.

Monthly Hours Worked: Manufacturing (SA, 2005=100); OECDMEI IP: Manufacturing; OECDMEI)

Germany

Monthly data from 01/1991-01/2011 obtained from BIS Data Bank:

Output per man-hour in mining and manufacturing, SA/WDA; :UQMB:DE:01

Data from 1973:Q1-1992:Q4 obtained by applying West Germany quarterly real GDP growth rates to 1991-2011 series. The entire series is indexed to 2005=100.

UK

Quarterly data from 1973-1005 taken from BIS Data Bank:

Output per man-hour in manufacturing, SA; :UQNB:GB:91

1995-2010 data is ratio of output person in manufacturing to hours worked per person in manufacturing, indexed to 2005=100.

Out per person in manufacturing, SA; :Q:UQNB:GB:11 Hours Worked: Manufacturing (NSA, 2005=100) - Seasonal Adjustment, All; SA(N1126CEUDATA))

Italy

1973-2010:Q4 data taken from two BIS Data Bank series and joined together using legacy lira/euro exchange rates, indexed to 2005=100.

PRODUCTIVITY IN MANUF., (ESA95-2000)-BASIC PR CH LK 2000 EURO, WDA SA; :UQNB:IT:11 PRODUCTIVITY IN MANUF, (ESA95)-BASIC PR CONSTANT 1995 ITL WDA SA-DISC; UQNB:IT:95)

France

1973-1994Q2 data taken from BIS Data Bank:

PRODUCTIVITY PER MAN HOUR IN MANUFACTURING SA-DISC.; :UQBB:FR:95

1995-2010Q4 calculated from hours worked index in manufacturing (HAVER), IP: manufacturing (HAVER), and total manufacturing employment data (BIS) and indexed to 2005=100.

Hours Worked: Manufacturing (SWDA, 2005=100); S1326CEUDATA IP: manufacturing (Industrial Production: Manufacturing (SA, 2005=100); S132QCEUDATA EMPLOYM. IN MANUF., EMPLOYEES (ECB PROXY)(ESA 95)-IN TSD PERS,Q-AVG SA; :UGNB:FR:04)

Canada

Ratio of output per employed person in manufacturing (BIS) to weekly hours worked in manufacturing (HAVER), indexed to 2005=100. Output per employed were joined together using CPI data (HAVER). OUTPUT PER EMPLOYED PERSON IN MANUFACTURING (NAICS DEF.)- 2002 CAD NSA (M:UQNA:CA:11) OUTPUT PER EMPLOYED PERSON IN MANUFACTURING (SIC 80), NSA -DISC. (:M:UQNA:CA:92) Weekly Hours Worked: Manufacturing (NSA, Hours);

sa(INDEX(C156HWMNOECDMEI,2005=100)) Consumer Price Index (NSA, 2005=100)2002=100; INDEX(C156CZNOECDMEI,2002=100)

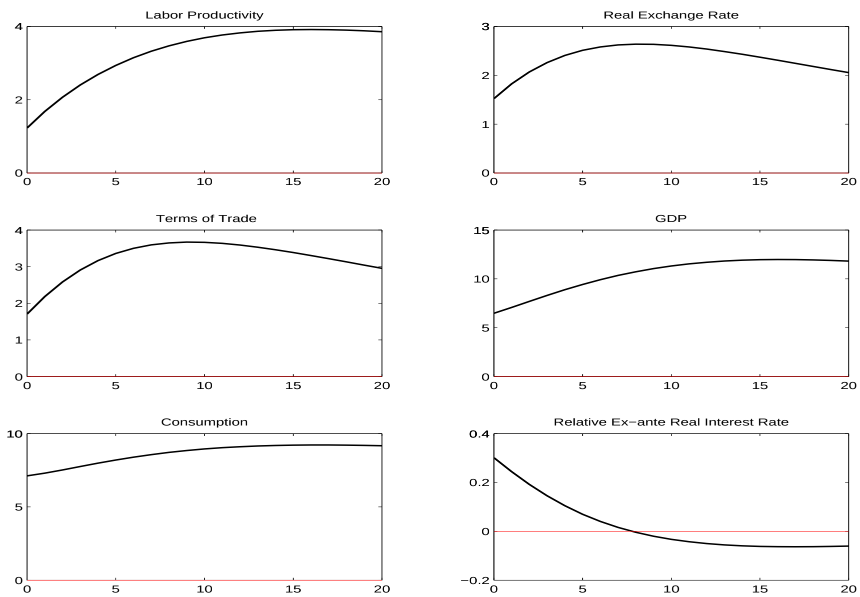
A.3 Additional Results

This section presents the results that are not reported in the main text. First, we report the results when preferences take the form of GHH specification. Figures A.3.1, A.3.2, and A.3.3 correspond to Figures 4, 5, and 6 in case of KPR preference in the main text, respectively.

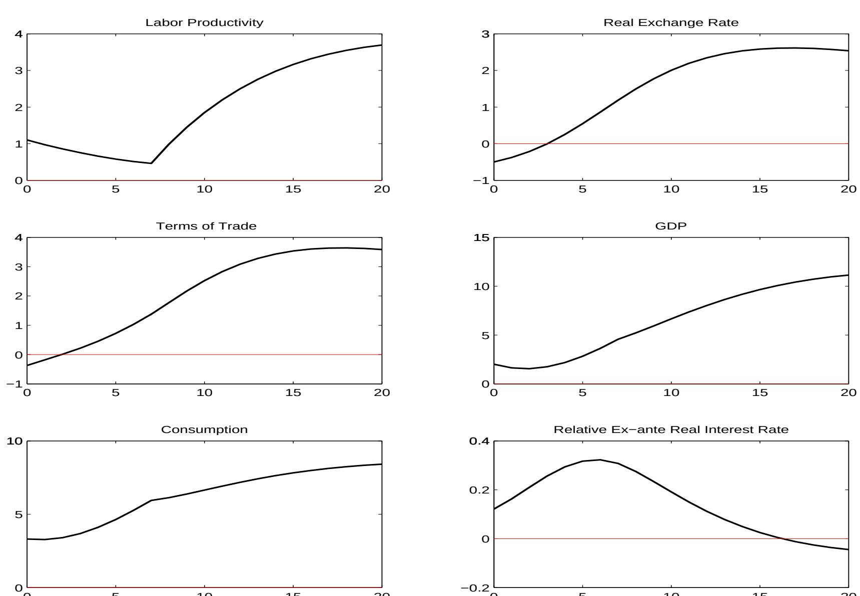
Second, Figure A.3.4 reports the results when capital utilization is shut down. As explained in Section 4.1 in the text, the figure indicates that variable capital utilization helps labor productivity increase following a news shock.

Finally, we report the results from robustness checks in Section 4.3. Our results about appreciation of the real exchange rate and terms of trade hold up well under a different functional form of capital adjustment costs and another type of preferences (BKK preference). Figure A.3.5 the impulse response functions of the real exchange rate and terms of trade to a news shock in the model with capital adjustment costs described in 4.3 for three different specifications of preferences including BKK one.

Figure A.3.1: GHH Preference: Theoretical Impulse Response Functions: Benchmark Model

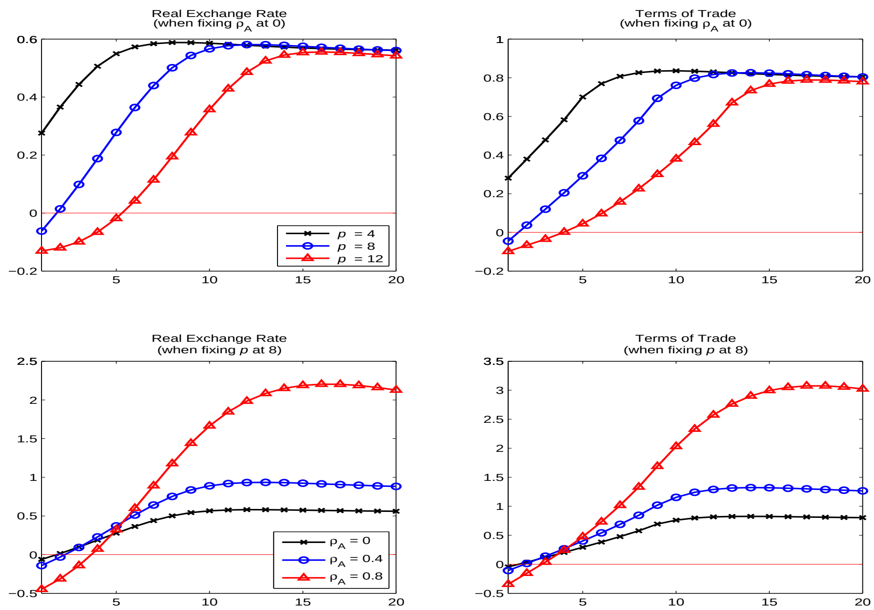


(a) Contemporaneous Shocks

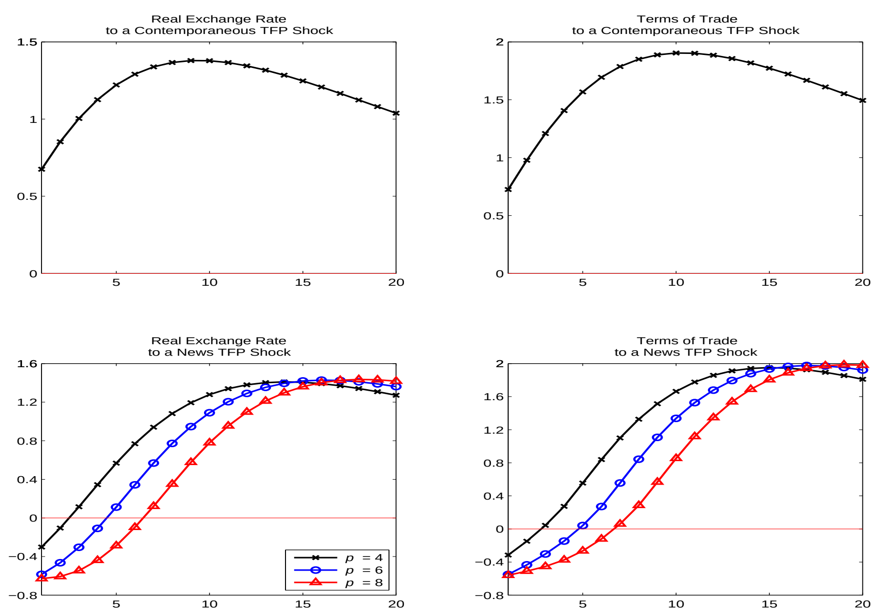


(b) News Shocks

Figure A.3.2: GHH Preference: Effects of Anticipation Horizon and Persistence of News Shocks, and High Trade Elasticity on Appreciation of Real Exchange Rate and Terms of Trade



(a) Anticipation Horizon and Persistence of News shocks



(b) High Trade Elasticity

Figure A.3.3: GHH Preference: Estimated Impulse Response Functions with the Simulated Data

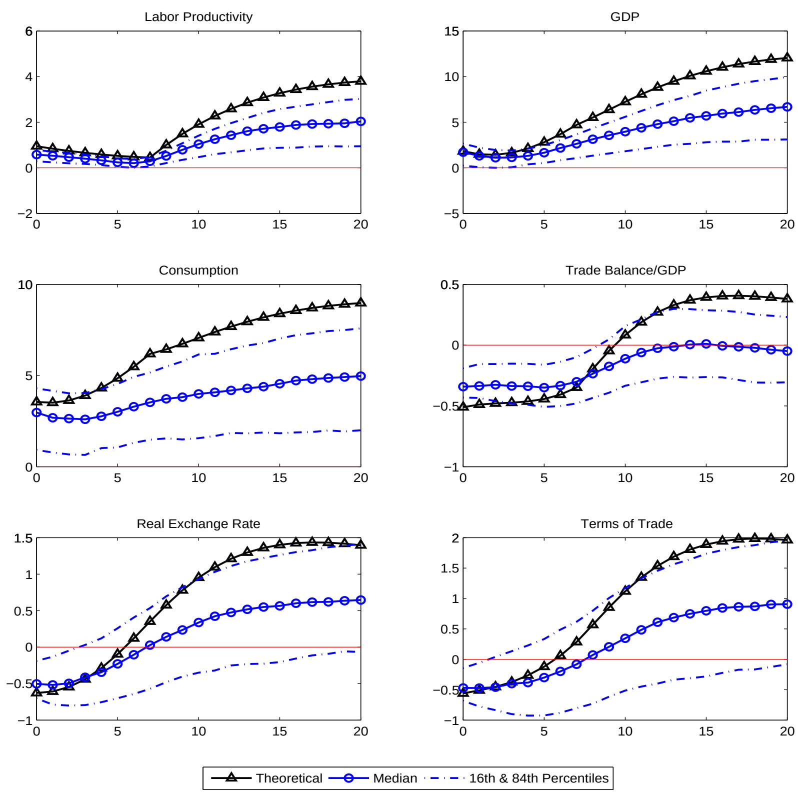
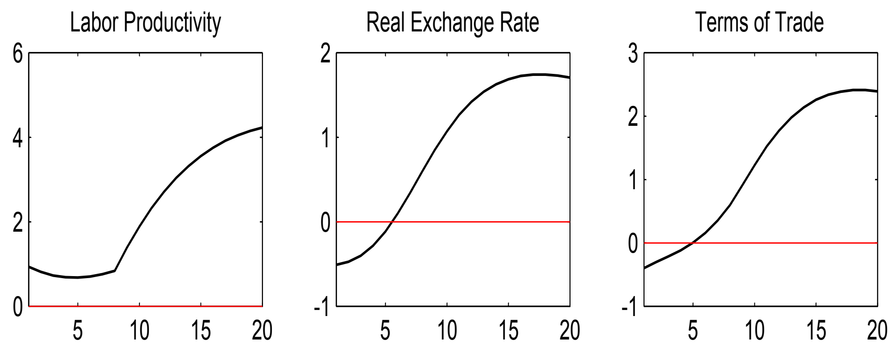
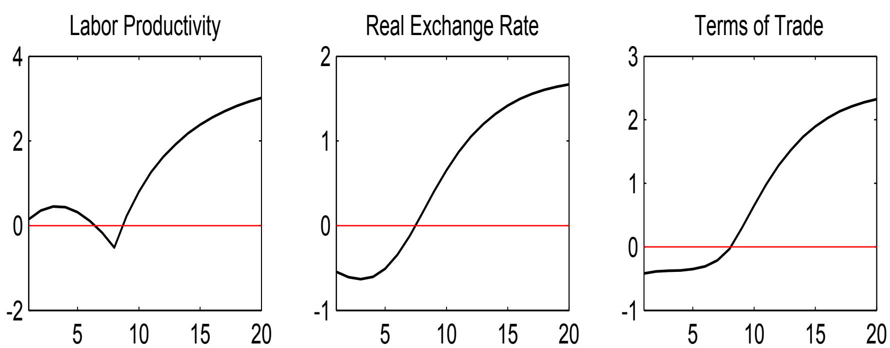


Figure A.3.4: Impulse Response Functions with/without Capital Utilization (KPR Preference)



(a) With Capital Utilization



(b) Without Capital Utilization

Figure A.3.5: Robustness Checks with Different Capital Adjustment Cost Function and Utility Function