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

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Abstract

The terms of trade and the real exchange rate of the US appreciate when the US 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 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 prices relative to foreign prices.

JEL codes: E32, F3, F4

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1 Introduction

Standard international macroeconomic models (e.g. Backus, Kehoe, and Kydland 1992) 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 terms of trade and the real exchange rate of the US 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 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. A common view in the literature is that a country's terms of trade deteriorate when its productivity increases relative to the rest of the world. In this case, productivity gains in one country spill over positively to other countries through the international price adjustment. In other words, international price movements automatically insure 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, recent empirical findings with the US data are at odds with the standard models' prediction that the terms of trade deteriorate after an increase in productivity. Corsetti, Dedola, and Leduc (2006, 2009), Enders and Muller (2009), and Enders, Muller, and Scholl (2008) document a robust appreciation of the terms of trade and the real exchange rate in the US after an increase of its labor productivity. These findings imply a negative transmission of productivity gains across countries.

Corsetti, Dedola, and Leduc (2008) show that the direction of the international transmission of productivity shocks depends on a country's openness to trade, trade elasticities, and the persistence of the shocks. In particular, they find that if a country's consumption is biased towards domestic goods and the elasticity of substitution between home and foreign goods is low, the country's terms of trade will improve rather than deteriorate when its productivity increases relative to the rest of the world. They find that increasing the persistence of productivity shocks can also help models replicate the negative international transmission of productivity shocks when the elasticity of substitution between home and foreign goods is large. Enders and Muller (2009) find similar results as in Corsetti, Dedola, and Leduc (2008) and emphasize the role of incomplete international financial markets for the findings. The international transmission of productivity gains may 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.

In this paper, we explore a different avenue to replicate the comovement of international relative prices and labor productivity documented in the US data: news shocks to total factor productivity (TFP). News shocks consist of information about future economic fundamentals. It has long been recognized that changes in expectations about the future path of productivity may be an important source of economic fluctuations (e.g. Beveridge 1909, Pigou 1927, and Clark 1934). 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), and Schmitt-Grohe and Uribe (2009) among others. In a standard sticky-price DSGE model with news shocks to TFP, we show that after a favorable news shock to TFP, a country's terms of trade and real exchange rate appreciate while its labor productivity increases relative to the rest of the world.

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 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 prices relative to foreign 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 prices relative to the foreign. In standard international macro models, the second effect dominates the first one and home prices decline relative to foreign 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. 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.

Nam and Wang (2010) identify news and contemporaneous shocks to the US TFP following the identification strategy proposed in Barsky and Sims (2010). In that paper, we document that the US real exchange rate appreciates after a favorable news shock while it depreciates in response to a positive contemporaneous shock. These empirical findings are consistent with the theoretical predictions in this paper. We also find that the identified news TFP shocks play a much more important role than the identified contemporaneous TFP shocks in explaining US real exchange rate movements.

Using the long-run restriction method, we first estimate the impulse response functions of the real exchange rate and the terms of trade with respect to a permanent increase in labor productivity for the US and several other countries. Our results confirm recent findings that the terms of trade and the real exchange rate appreciate in the US when labor productivity increases. The terms of trade and the real exchange rate depreciate in most other countries in our sample after an increase in labor productivity. Then we show in a two-country DSGE model that incorporating news shocks to TFP and the variable capital utilization rate can help the model replicate the empirical findings in the US data. 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. Capital utilization and therefore labor productivity rise in response to a positive news shock. The increase of labor productivity can partially offset the decline of labor supply induced by the wealth effect.

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 empirical impulse response functions 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 (1992). Different values for trade elasticities and different functional forms for capital adjustment cost are also employed as robust checks. Our results hold up qualitatively well in all of these cases.

The terms of trade and the real exchange rate depreciate after an increase of labor productivity in several other countries, although they appreciate in the US. This heterogeneity could reflect the difference in the availability of news about future productivity across countries. Following Jaimovich and Rebelo (2009), we use the accuracy of survey forecasts (Consensus Forecasts) for output growth as a measure of the availability of news shocks. The output growth forecasts are more accurate (measured by the sum of percentage forecast errors in absolute values) for the US than other G7 countries at both one- and two-year forecast horizons. This finding suggests that the news shock may have played a more important role in driving economic fluctuations in the US than in other G7 countries. This is consistent with the finding that the terms of trade and the real exchange rate appreciate in the US but depreciate in other countries when labor productivity increases.

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 length of news shocks is larger. For instance, when the 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 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 using long-run restrictions. Section 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

In this section, we first show 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 a dynamic stochastic general equilibrium (DSGE) 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 Backus, Kehoe and Kydland's (1992) model, but limits the financial market to a real-bond market only. Baxter and Crucini (1995) compare this incomplete financial market model with the model with perfect risk-sharing and find that they behave very similarly if the productivity shock is not extremely persistent or the cross-country spillover of productivity shocks is high. The DSGE 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 DSGE 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 appendix.

The terms of trade and the real exchange rate in the standard models are defined as the price of foreign goods relative to the price of home goods. Therefore, 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 international relative prices with respect to a one-standard-deviation increase of productivity in the home country for these models. Under the standard calibration, both the terms of trade and the real exchange rate increase after the shock, which indicates a decline of home prices relative to foreign prices.[1]

Next, we estimate the impulse response functions of the terms of trade and the real exchange rate for the following countries: Australia, Japan, New Zealand, Norway, the UK, and the US. The choice of these countries is dictated by the data availability in the G10 dataset of Haver Analytics. We run structural VARs for each country using the long-run restriction method as in Gali (1999) to identify productivity shocks. The following variables in each country are included in the VAR exercise: labor productivity, GDP, consumption, net exports relative to GDP, the real exchange rate, and the terms of trade.[2] Labor productivity is measured by output per employed person. As a robustness check, we also use output per hour for the US. Our main findings for the US hold up in this case as well. Output per hour for other countries is not available in the G10 data set. To facilitate comparison, the terms of trade and the real exchange rate are defined in the same way as in the above standard models: foreign prices divided by home prices. Except for net exports, all variables are logged. We also take the first difference of all variables. Using the levels of the real exchange rate and the terms of trade instead of the first differences produces similar results. The sample period (from

[1] 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 DSGE 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's (2008) finding that home goods prices can increase relative to foreign goods prices after a positive productivity shock in the home country if the trade elasticity is low and consumption is biased towards home goods. The equilibrium of the IRBC and DSGE 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.

[2] We do not use cross-country differentials of these variables in our estimation. Symmetry across home country and the rest of the world is implicitly assumed when using cross-country differentials. The assumption of symmetry is unrealistic for most countries in our sample. Our empirical setup is also consistent with our theoretical model in the next section. In our model, home and foreign productivity is cointegrated, so there is no permanent change in the relative productivity.

1989Q1 to 2009Q1) is the same for all countries in our sample to facilitate cross-country comparison of our results.[3]

Figure 2 shows the impulse response functions with respect to a positive productivity shock in the US. In response to an increase in labor productivity, US output and consumption increase while trade balance declines. In particular, an increase in the labor productivity in the US induces an appreciation of the terms of trade and the real exchange rate, which is at odds with the predictions of standard international macroeconomic models that we have just shown. Similar findings are also documented in Corsetti, Dedola, and Leduc (2006), Enders, Muller, and Scholl (2008), and Enders and Muller (2009). Figure 3 shows the impulse response functions of the terms of trade and the real exchange rate for the rest of the countries in our sample. These impulse response functions are generally consistent with the standard theoretical prediction that a country's terms of trade or real exchange rate or both depreciate following an increase in labor productivity.

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 Home and Foreign intermediate good composites. The intermediate goods are produced from 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 (1) for consumption, investment, saving, and associated costs:

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

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

[3] Some countries have data before 1989Q1. Including the observations in early periods does not change our results qualitatively.

(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 (2):

$$Y_t(f) = \left[\omega^{\frac{1}{\psi}} Y_{Ht}(f)^{\frac{\psi-1}{\psi}} + (1-\omega)^{\frac{1}{\psi}} Y_{Ft}(f)^{\frac{\psi-1}{\psi}}\right]^{\frac{\psi}{\psi-1}}, \tag{2}$$

where $Y_{Ht}(f)$ ($Y_{Ft}(f)$)is the Home (Foreign) intermediate good composite demanded by final goods firm f. From equation (1), we have the demand function of final good f:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t}\right)^{-\theta_F} Y_t, \tag{3}$$

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 (3), technology in equation (2), and production factor prices, final goods firms choose prices to maximize the expected lifetime profit. We introduce staggered price setting *a lá* Calvo (1983) and Yun (1996). 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 ($\bar{\Pi}$). When a final goods firm re-optimizes its price, it will choose a price $\tilde{P}_t(f)$ to maximize the expected lifetime real profit:

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

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 at time t.

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 (4):

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}(i)^{\frac{\theta_I - 1}{\theta_I}} di\right]^{\frac{\theta_I}{\theta_I - 1}}. \tag{4}$$

Following Devereux and Engel (2009) 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:

$$Y_{Ht}(i) = A_t^{1-\varphi} \left[\varrho_t K_t(i)\right]^{\varphi} L_t(i)^{1-\varphi}, \tag{5}$$

where ϱ_t is the capital utilization rate and A_t is the labor-augmented TFP. Capital utilization ϱ_t 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 method as in the final goods sector to introduce staggered prices. $1-\alpha_I$ 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 (2009), we consider news shocks to permanent changes in TFP. Schmitt-Grohe and Uribe (2009) 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 the long-run restriction method 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:

$$U = E_0 \left[\sum_{t=0}^{\infty} \beta^t u_t \left(C_t, L_t, X_t\right) \right]. \tag{6}$$

The period utility is a function of consumption (C_t) and hours worked (L_t), and takes the form of:

$$u_t \left(C_t, L_t, X_t\right) = \frac{\left(C_t - \chi L_t^{\eta} X_t\right)^{1-\rho}}{1-\rho}, \tag{7}$$

where $X_t = C_t^{\gamma} X_{t-1}^{1-\gamma}$. 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 $\gamma = 1$, it reduces to the class of preferences discussed in King, Plosser, and Rebelo (1988), which we refer to as KPR. When $\gamma = 0$, 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:

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

where the capital depreciation rate δ is a function of the capital utilization rate ϱ_t. Following Schmitt-Grohe and Uribe (2009), $\delta(\varrho)$ takes a quadratic functional form of:

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

The function $S_1(\cdot)$ represents investment adjustment costs following Christiano, Eichenbaum, and Evans (2005). It takes the following form in our model:

$$S_1(x) = 1 - \frac{\kappa}{2}(x - \bar{\mu}_I)^2, \tag{8}$$

where $\bar{\mu}_I$ 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:

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

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.[4] This cost is introduced to ensure stationarity of the model. By assigning very small values to ϕ_d and ϕ_a, the bond-holding cost has a negligible effect on model dynamics.[5]

The real exchange rate is defined as $Q_t = \frac{S_t P_t^*}{P_t}$, where P_t and P_t^* are prices of final good composites in the Home and Foreign countries, respectively. The terms of trade is defined analogously:

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

[4]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.

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

where P_{Ht} and P^*_{Ft} are prices of Home and Foreign intermediate good composites, respectively.

3.3 Monetary Policy Rule and Process of Shocks

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

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

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 optimal exchange rate stabilization parameter is very small if the central bank targets the CPI inflation rate optimally. Engel (forthcoming) shows in a modified version of Glarida, Gali, and Gertler's (2002) model that the interest 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 consider explicitly exchange rate targeting in the Taylor rule of our model.

The technology shocks are 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:

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

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

Similar VEC representation of the technology processes is also used in Rabanal, Rubio-Ramirez and Tuesta (2009). They show that the technology processes in the US and the "rest of the world" 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 (2007) and Schmitt-Grohe and Uribe (2009), we assume that $\epsilon_{A,t}$ and $\epsilon^*_{A,t}$ have both contemporaneous and anticipated news components:

$$\epsilon_{A,t} = \xi_{A,t} + \zeta_{A,t-p},$$

where $\xi_{A,t}$ is the contemporaneous component and $\zeta_{A,t-p}$ is the anticipated component of the technology shock. $p \geq 1$ is the length 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. $\xi_{A,t}$ and $\zeta_{A,t}$ are *i.i.d.* and have mean zero.

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 steady-state capital depreciation rate is 10% per annum ($\delta_0 = 10\%/4 = 0.025$). δ_1 is calibrated such that the capital utilization rate equals one in the steady state. Following Jaimovich and Rebelo (2009), δ_2 is calibrated such that the elasticity of $\delta'(\varrho)$ evaluated in the steady state ($\delta''(\varrho)\varrho/\delta'(\varrho)$) is 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.

The elasticity of substitution between home and foreign goods is set to 1.5 following Backus, Kehoe, and Kydland (1992). 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 are set at levels such that the profit margin is 20% for intermediate and final goods firms. Under our calibration of price stickiness parameters, 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 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 elasticity of labor supply is 2.5 and χ is calibrated to match the steady-state value of hours worked (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 (2009) 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 (2009) 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 (2009) choice of annual data follows the practice in the studies on long-run risks. He argues that annual data is not altered by any seasonal adjustment and also contains less noise related to the low-frequency component of productivity. Following Croce (2009), 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. So 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 (2009) estimate. The cointegrating coefficient ρ_R is set to 0.007 following Rabanal, Rubio-Ramirez, and Tuesta (2009). The length of news shocks (p) is calibrated to 8 periods in the benchmark model. We find that our results are sensitive to this parameter and various lengths 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 the data simulated with our benchmark model. All data are logged and HP filtered with a smooth parameter of 1600. The calibration of the relative size of news and contemporaneous shocks remain a highly debatable issue.[6] As a result, we show the statistics of our model under each shock separately. In general, 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 labor supply relative to the volatility of GDP. As in all other standard RBC 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. Similar finding is also reported in Matsumoto, Cova, Pisaniz, and Rebucci (2010). In Table 2, news shocks also help to improve the model's performance in matching the cross-country correlation of investment. News shocks are not helpful for solving the quantity puzzle (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.

Now consider a one-percent contemporaneous shock to the growth rate of Home country's TFP ($\mu_{A,t}$). Figure 4 shows the theoretical impulse response functions with KPR and GHH preferences. After a positive 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 shown in Section 2. Next we study the case with the news shock. Figure 5 displays the impulse response functions with respect to a one-percent news shock of length 8 in the Home country. On the impact of the news shock, the terms of trade and the real exchange rate appreciate while labor productivity rises for both KPR and GHH preferences.

To help us understand this difference, note 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

[6]For empirical studies on identifying contemporaneous and news TFP shocks, see Beaudry and Portier (2006), Beaudry, Dupaigne, and Portier (2008), Beaudry and Luke (2009), and Barsky and Sims (2010).

and Foreign bonds, we have:

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

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 exchange rate and $i_t = R_t - 1$ is the nominal interest rate. We can re-write 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:

$$q_t = E_t[q_{t+\infty}] - \sum_{j=0}^{\infty} E_t[r_{t+j} - r_{t+j}^*], \tag{9}$$

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, 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 of the prices in 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 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 Foreign country after the first few periods.

Similar tradeoffs exist in the case of news shocks. The Home household increases consumption immediately after the good news, which tends to increase the price of Home goods relative to Foreign goods when consumption is home-biased. Labor productivity also increases right after the news shock although 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 and 5. 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 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 (9), 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, Figure 6 shows the impulse response functions with respect to a news shock with and without variable capital utilization. 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 (Figure 6(b)) 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. Figure 5(b) shows the theoretical impulse response functions when we use the GHH utility function. Consistent with Jaimovich and Rebelo (2009), output increases in response to a positive news shock.[7] Our finding that the terms of trade and the real exchange rate appreciate while labor productivity rises holds up well in this case.

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

Figure 7 shows how the impulse response functions of the terms of trade and the real exchange rate vary with the length of news shocks and the persistence of productivity shocks. In the two subfigures of the upper panel, the AR(1) coefficient of the productivity shocks is fixed at zero. When we change the length of news shocks from 4 to 12, the persistence of the appreciation in the terms of trade and the real exchange rate increases. In the two subfigures of the lower panel, the length 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

[7] Hours worked also increases in our model as in Jaimovich and Rebelo (2009). Results are available upon request.

liberation can be as high as 15. These findings present what is called the trade elasticity puzzle. See Ruhl (2005) and Engel and Wang (forthcoming) 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 8 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. Figures 8(a) and 8(b) show the cases with KPR and GHH preferences, respectively. In both cases, 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 length 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 length of the news shock is as short as four. As in our benchmark model, the persistence of the appreciation increases with the length of the news shock. When the length 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 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 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 the foreign. Devereux and Hnatkovska (2010) 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 section, we simulate our model and estimate the impulse response functions with the simulated data using the long-run restriction method 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. We want to confirm that the method with 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 from the simulated data. The labor productivity is measured by output (Y_{Ht}) divided by labor input L_t in the simulated data. Figure 9 shows the median and 16% and 84% quantiles of 500 impulse response functions estimations, as well as the theoretical impulse response functions of our model. In these plots, the period utility function is calibrated to the KPR one. 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 few periods following the shock. Similar results are also found in Figure 10 when the period utility function is calibrated to the GHH one. Figures 11 and 12 display the estimations of impulse response functions from the simulated data when the trade elasticity is set to 4. The length of the appreciation in the terms of trade and the real exchange rate following a positive news shock can be more than 10 periods in this case.

Next, we show that our results are robust under other model setups. First, we consider another class of utility functions that are widely used in the literature (e.g. Backus, Kehoe, and Kydland, 1992):

$$u_t = \frac{\left[C_t^{\eta}(1-L_t)^{1-\eta}\right]^{1-\rho}}{1-\rho}. \tag{10}$$

We follow Backus, Kehoe, and Kydland (1992) in calibrating the preference parameters in equation (10) 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 introduces the capital adjustment cost and takes the form of:

$$S_2(x) = x - \frac{1}{2\kappa_2\overline{\mu}_{I/K}}\left(x - \overline{\mu}_{I/K}\right)^2, \tag{11}$$

where $\overline{\mu}_{I/K}$ is the steady-state investment-to-capital ratio. κ_2 is the elasticity of the investment-to-capital ratio with respect to Tobin's "q" ($\kappa_2 = -(S_2'/S_2'')/(I/K)$). 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 (10) and the capital adjustment cost function in equation (11). Figure 13 shows the impulse response functions of the terms of trade and the real exchange rate to a favorable news shock to TFP. We consider the impulse response functions under three utility functions: KPR, GHH, and BKK.[8] In all cases, the terms of trade and the real exchange rate appreciate on impact of the news shock.

Opazo (2006) finds that public signals about future innovations to TFP can help an otherwise standard international macro model replicate the negative correlation between the real exchange rate and relative consumption across countries (the Backus-Smith puzzle). Our model generates similar results as in Opazo (2006). In Figure 14, consumption increases in the home country relative to the foreign while the real exchange rate appreciates after a positive news shock. However, the labor productivity also increases in our model because of the increase in the capital utilization rate. The simultaneous increase in labor productivity and the real appreciation is a unique feature in the US data while the negative correlation between the real

[8]The case with BKK preference and benchmark capital adjustment cost function generates similar results, which are available upon request.

exchange rate and relative consumption is a general phenomena for most countries. As a result, the news shock to TFP may have played a limited role in explaining the Backus-Smith puzzle.

4.4 News Shocks and Survey Data

Although the terms of trade and the real exchange rate appreciate in the US when its labor productivity increases, they usually depreciate in other countries. Two potential explanations are consistent with our news shock story. First, anticipated technology shocks may have played a more important role in driving the economy in the US than in other countries. Second, the length of news shocks may be longer in the US than in other countries, meaning that technology improvement can be predicted at a longer horizon in the US than in other countries. These differences may be caused by the leading position of the US in information technology. The better availability of data and the ability to process these data make it easier to forecast the future productivity. Jaimovich and Rebelo (2009) argue that the increasing availability of news may have played a role in the reduction of output volatility after 1980s in the US and other industrial countries.

Following Jaimovich and Rebelo (2009), we use the accuracy of survey forecasts as an indicator of the availability of news shocks. Consensus Forecasts, released by Consensus Economics, provide GDP growth forecasts at one- and two-year horizons for several countries. From 1992 to 2008, GDP growth forecasts are available for G7 countries: Canada, France, Germany, Italy, Japan, the UK, and the US. We compare the accuracy of GDP growth forecasts between the US and the rest of G7 countries. Forecast errors are measured by

$$e_i = \frac{1}{T} \sum_{t=1}^{T} \frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}, \tag{12}$$

where $g_{i,t}^f$ is Consensus Forecasts of the GDP growth rate in year t for country i. $g_{i,t}$ is the actual GDP growth rate of country i during the same period. That is, we use the sum of percentage forecast errors (in absolute values) in each period as a measure of forecast accuracy. Actual GDP growth rate data are obtained from OECD national accounts.

Table 3 shows the ratio of forecast errors in other G7 countries to that in the US. All entries are greater than one, which indicates the GDP forecast errors in these countries are bigger than that in the US. We notice that there are outliers in some countries for $\frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}$, which occurs when a country's growth rate is close to zero in a given year. All countries have at the most two outliers in our sample. To eliminate the effect of outliers, we exclude observations that $\frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}$ is more than two standard deviations away from its sample mean in each country. Forecast errors of the US remain smaller than those in other G7 countries even after excluding these outliers.

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 cause appreciation in the terms of trade and the real exchange rate.

To generate an immediate increase of 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 will rise 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. However, under various reasonable calibrations, 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 length 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.

Unlike in the US, the terms of trade and the real exchange rate in most other countries depreciate when their labor productivity rises. The news shocks in these countries may have played a less important role in driving economic fluctuations than in the US. Following Jaimovich and Rebelo (2009), we use the accuracy of survey forecasts as an indicator of the availability of news shocks. We find some evidence that the Consensus Forecasts of GDP growth is more accurate for the US than for other G7 countries. We acknowledge that other factors such as difference in the availability of credit to finance the increase in consumption after a positive news shock may have also played important roles in the cross-country heterogeneity in the correlation between labor productivity and international relative prices.

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Figure 1: Impulse Response Functions in Standard Models

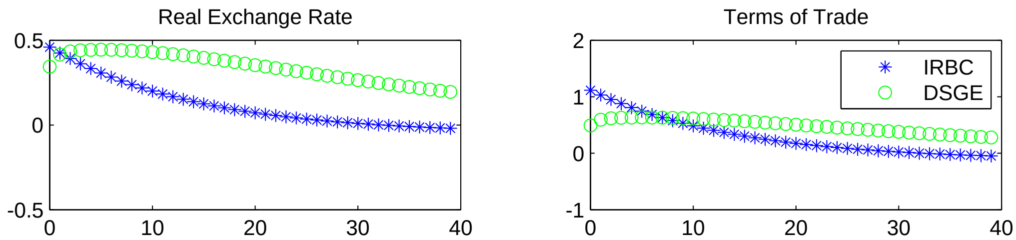


Figure 2: Impulse Response Functions Estimated with Long-run Restrictions: US

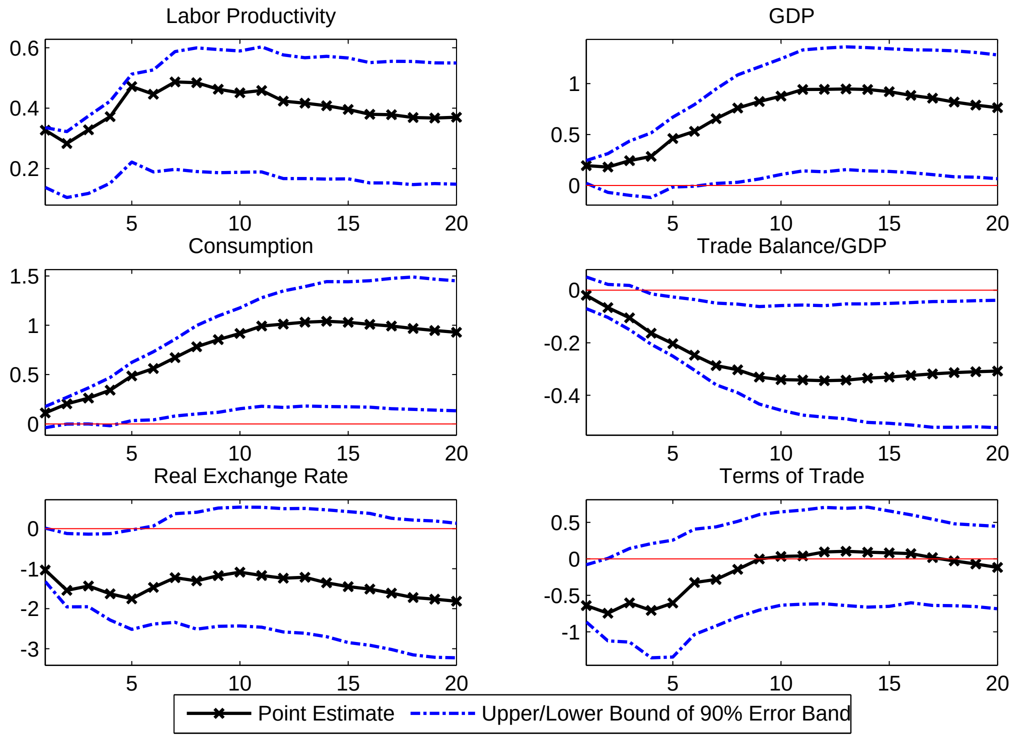


Figure 3: Impulse Response Functions Estimated with Long-run Restrictions: Other Countries

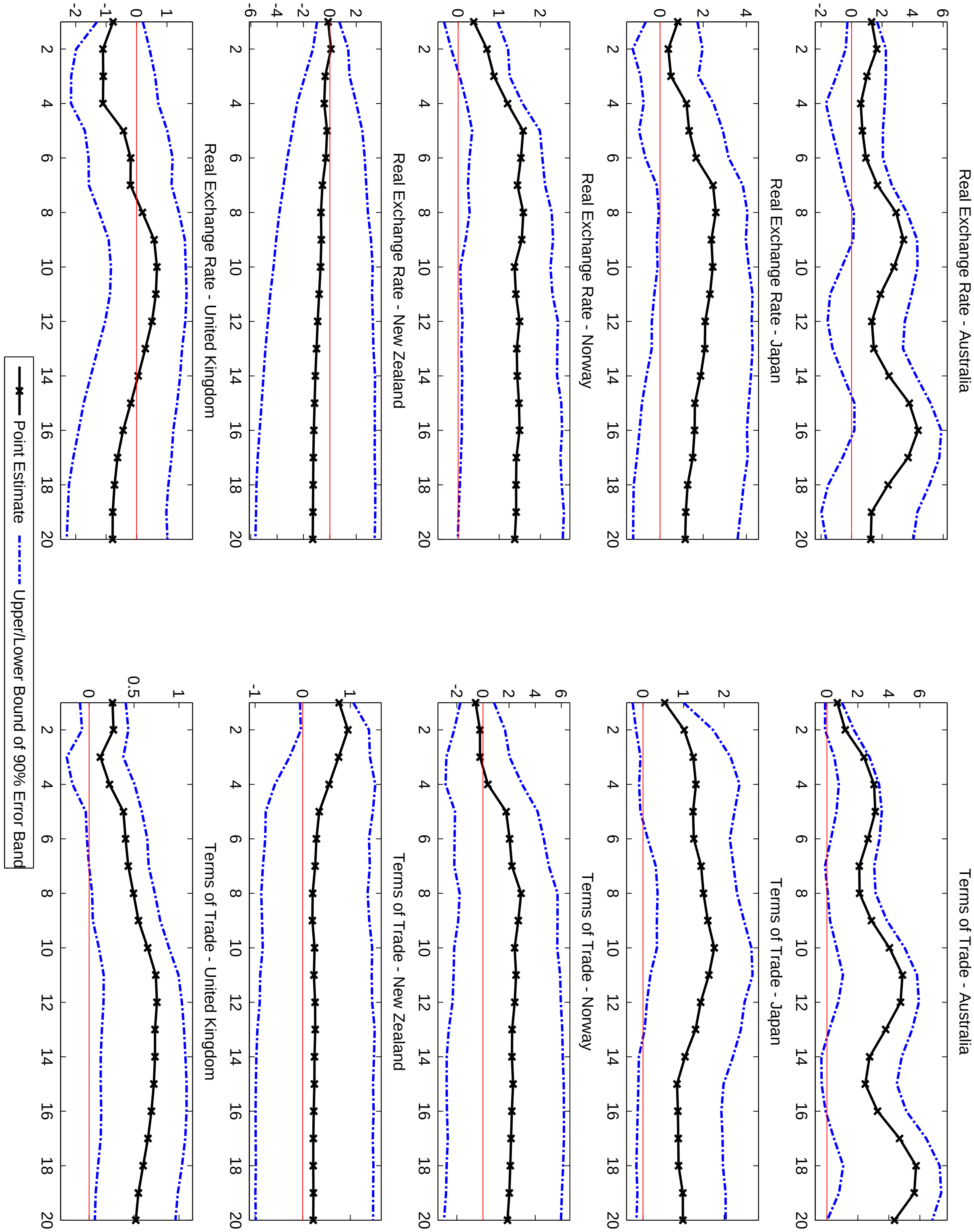
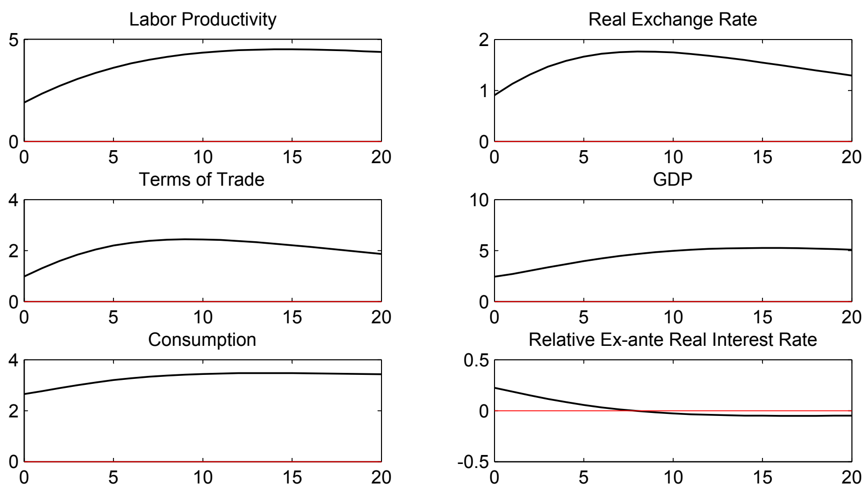
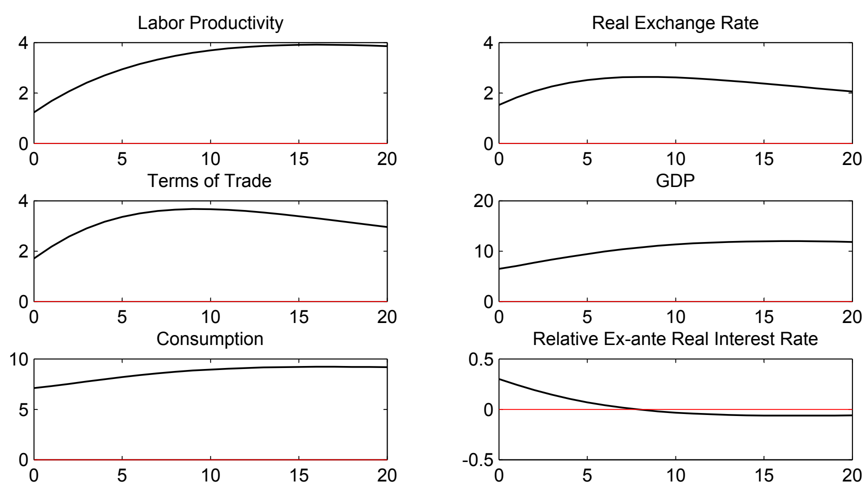


Figure 4: Impulse Response Functions to Contemporaneous Shock: Benchmark Model

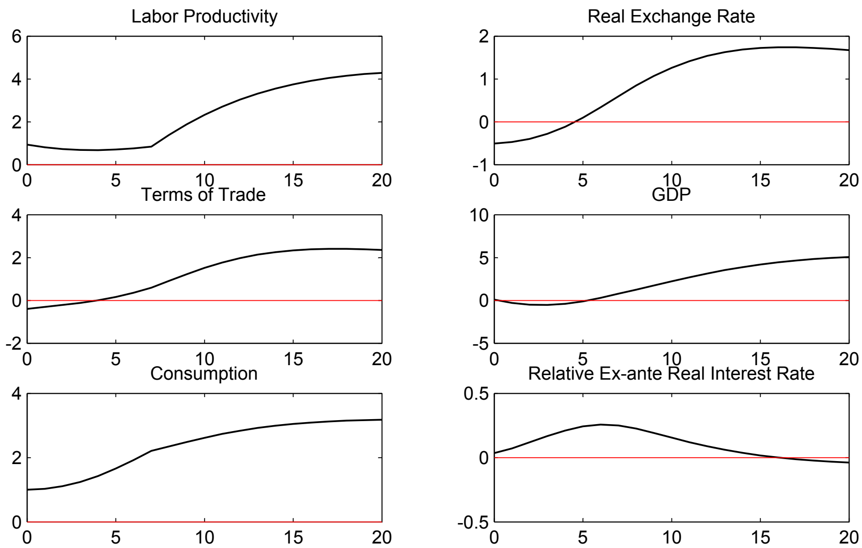


(a) KPR Preference

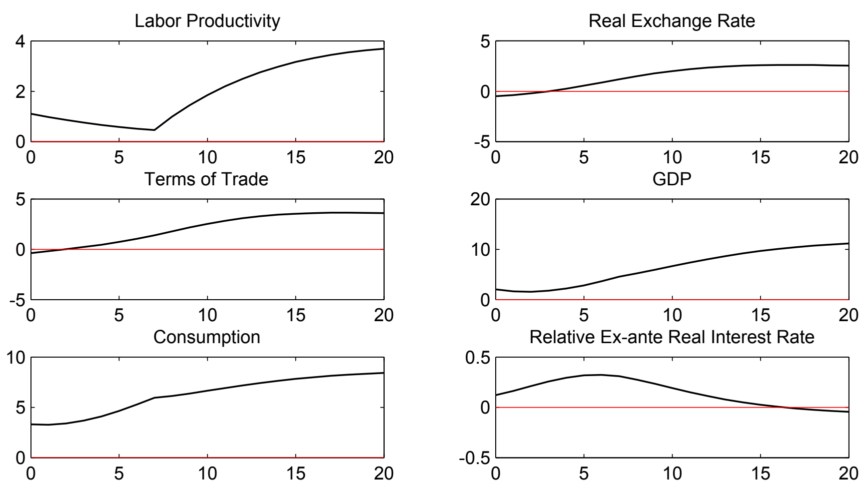


(b) GHH Preference

Figure 5: Impulse Response Functions to News Shock: Benchmark Model

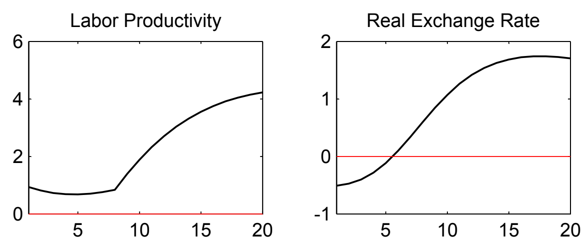


(a) KPR Preference

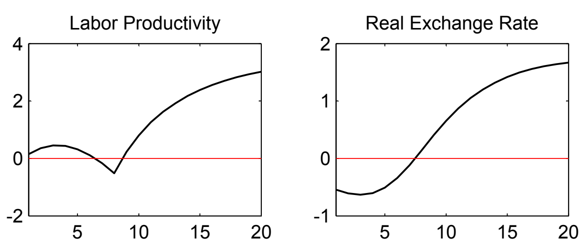


(b) GHH Preference

Figure 6: Impulse Response Functions with/without Capital Utilization (KPR)

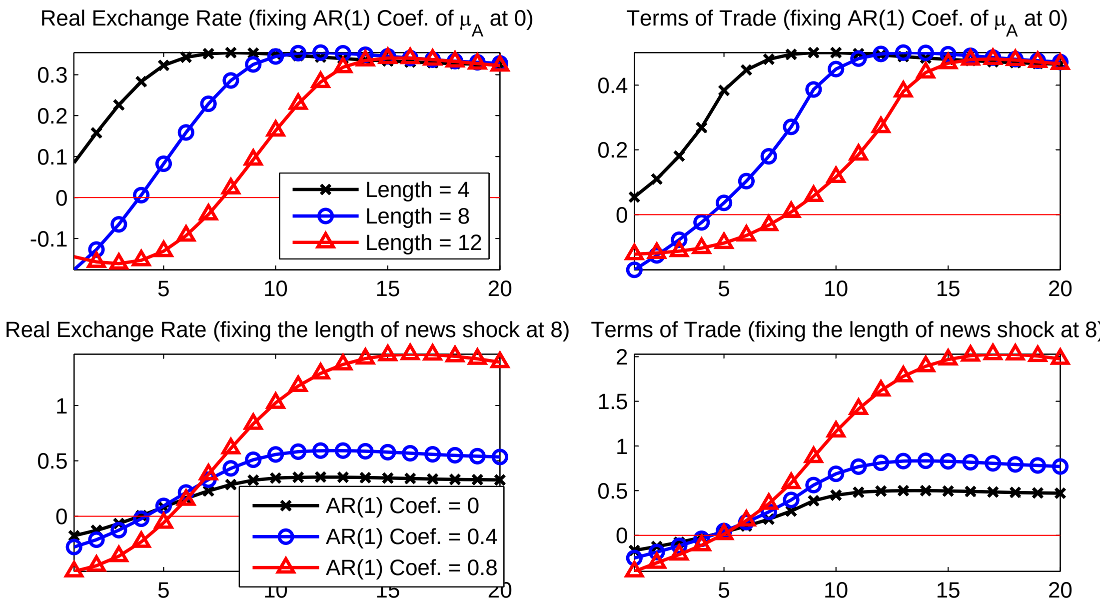


(a) With Capital Utilization

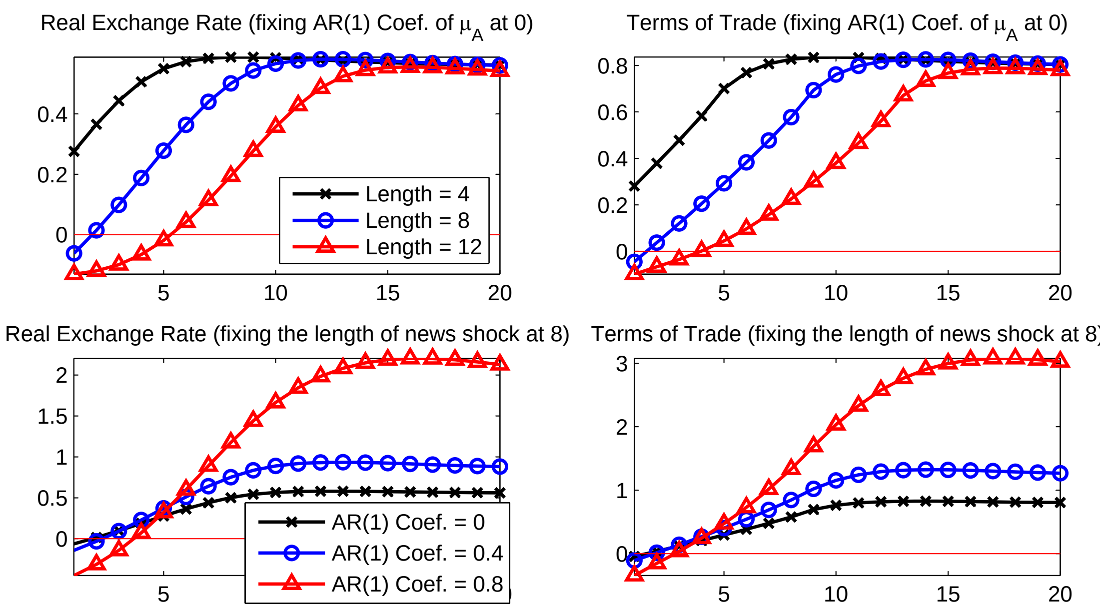


(b) Without Capital Utilization

Figure 7: Impulse Response Functions to News Shock: Various Lengths and Shock Persistence

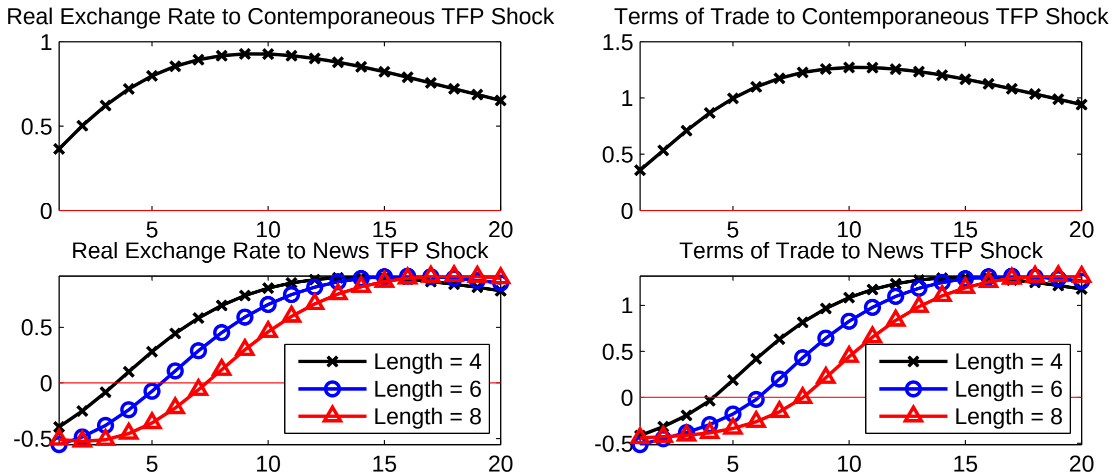


(a) KPR Preference

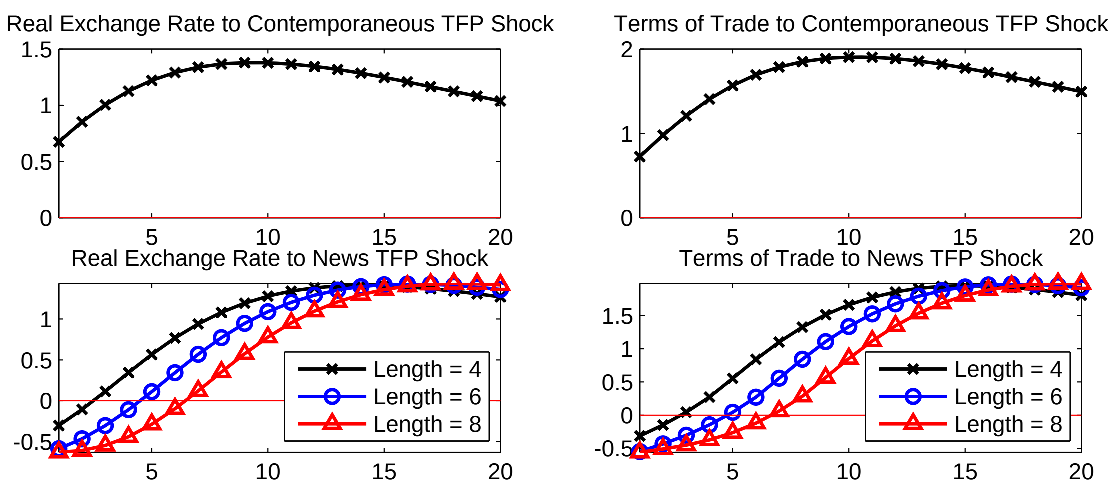


(b) GHH Preference

Figure 8: Impulse Response Functions with High Trade Elasticity



(a) KPR Preference



(b) GHH Preference

Figure 9: Estimated Impulse Response Functions with Simulated Data: KPR Preference

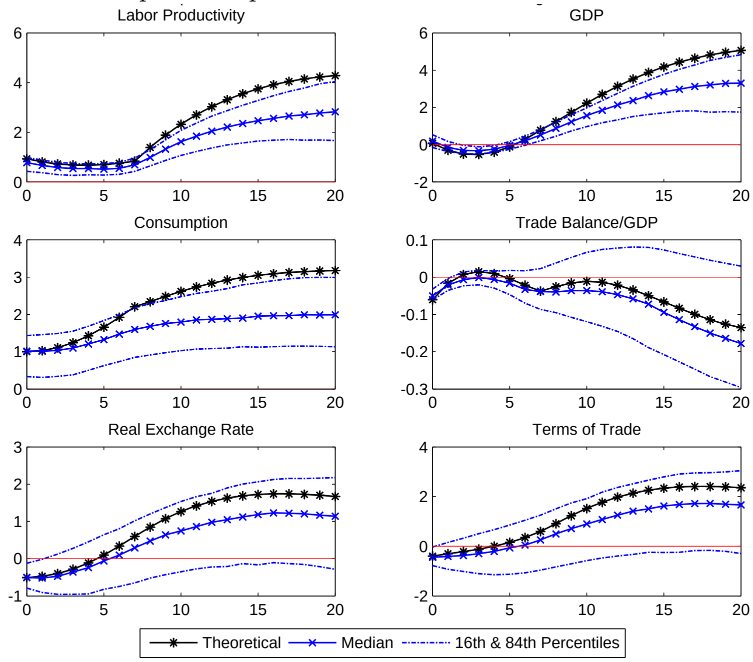


Figure 10: Estimated Impulse Response Functions with Simulated Data: GHH Preference

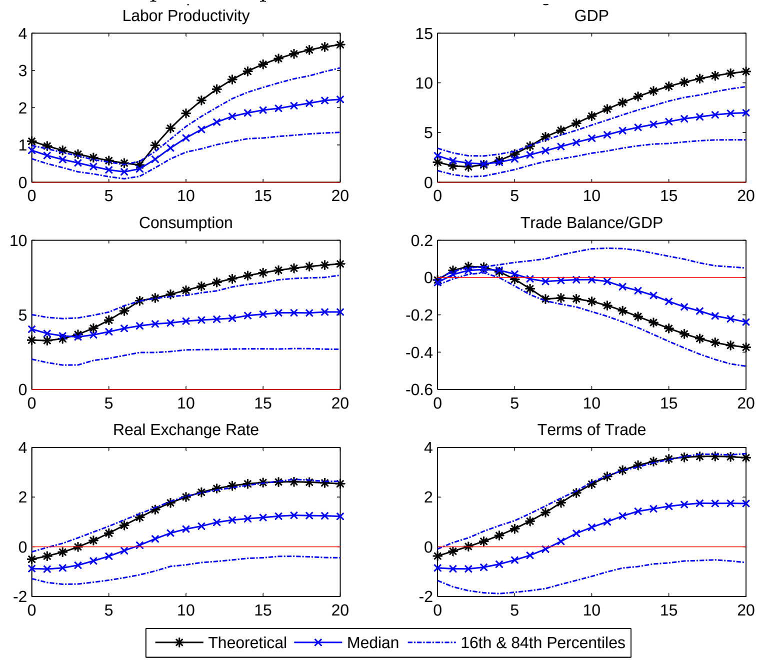


Figure 11: Estimated Impulse Response Functions with Simulate Data: High Trade Elasticity and KPR Preference

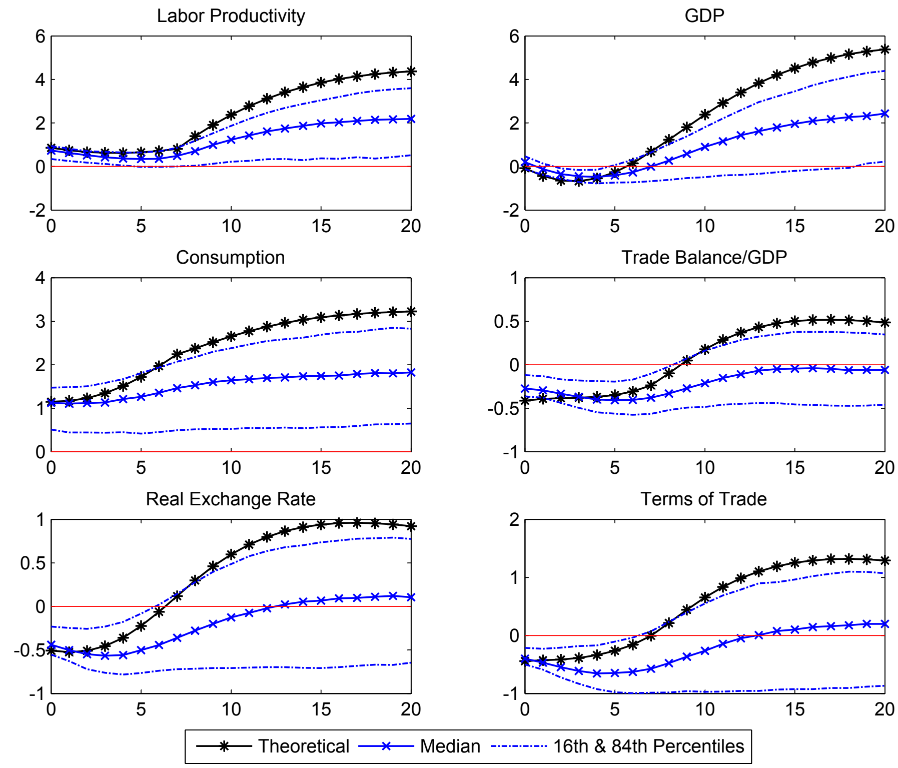


Figure 12: Estimated Impulse Response Functions with Simulated Data: High Trade Elasticity and GHH Preference

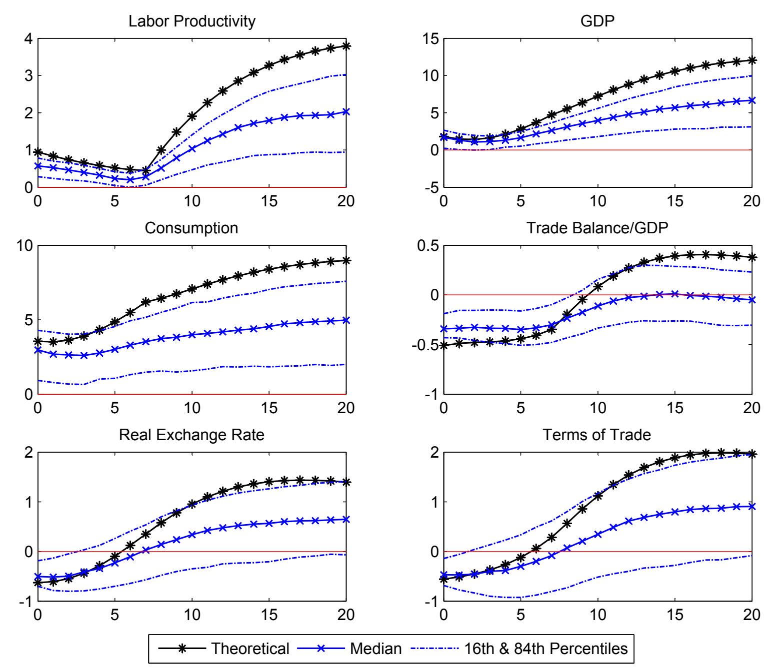


Figure 13: Robustness Check with a Different Capital Adjustment Cost Function

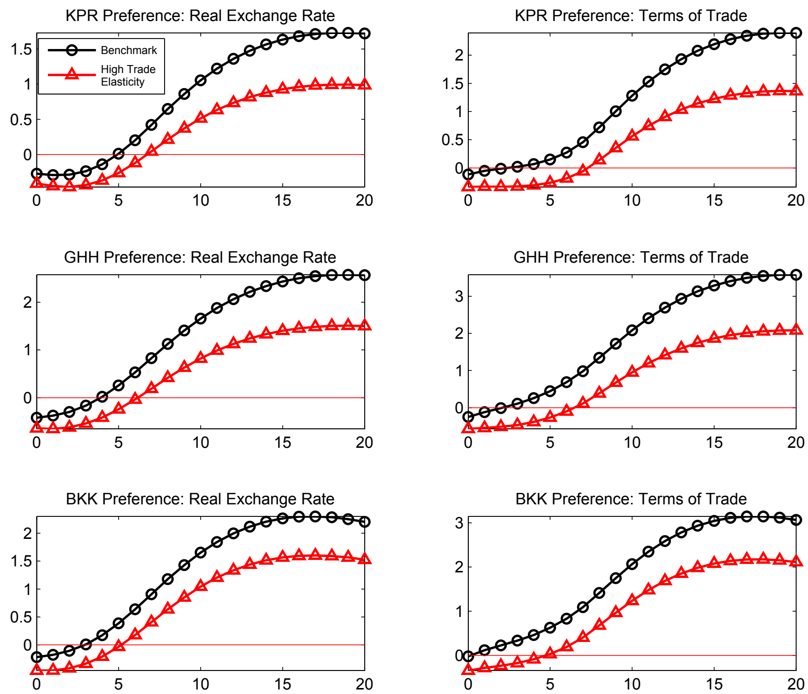


Figure 14: Impulse Response Functions to News Shock

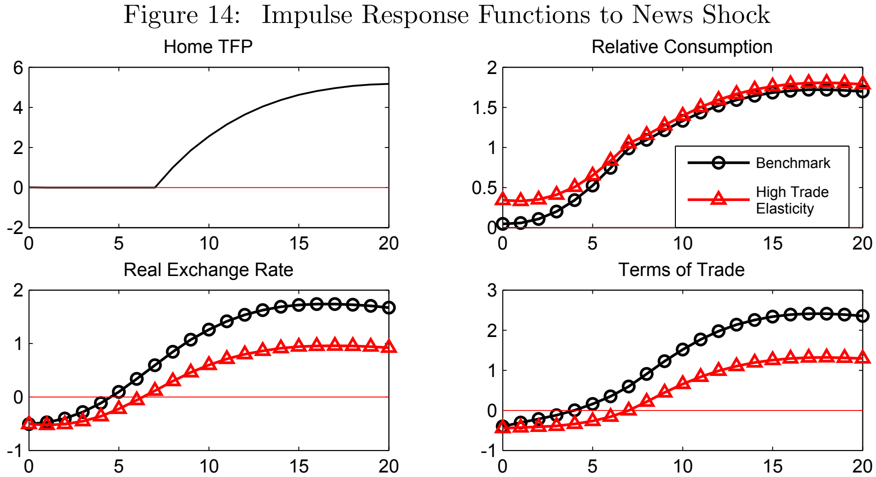


Table 1: Calibration of Benchmark Model

Parameter	Value	Description
β	0.9902	Subjective discount factor
ρ	2	Relative risk aversion parameter
δ_0	0.025	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 $\delta(\varrho)''\varrho/\delta(\varrho)' = 0.15$
κ	2.79	Investment adjustment cost parameter
ψ	1.5	Elasticity of substitution between home and foreign goods
ω	0.85	Home bias in consumption
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	0.001	GHH utility
γ	1	KPR utility
η	0.15	Calibrated such that the elasticity of labor supply is 2.5
χ	3.5540	Calibrated such that the steady-state labor supply is 0.2
ρ_A	0.85	AR(1) coefficient of technology growth rate
ρ_R	0.007	Cointegrating coefficient of technology shocks
p	8	Length of news shock
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 That of GDP				Cross-country Correlation			
	C	I	L	REX	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:

–SD is the abbreviation of standard deviation. C is consumption, I is investment, L is labor input (hours worked), and REX is the real exchange rate.

†–Statistics of the data are from Chari, Kehoe, and McGrattan (2002).

Table 3: GDP Growth Forecast Errors in Other G7 Countries Relative to the US

	One-year-ahead Forecast		Two-year-ahead Forecast	
	Full Sample	Exclude Outliers	Full Sample	Exclude Outliers
Canada	1.57	1.13	1.37	1.36
France	2.18	1.82	1.74	2.13
Germany	9.29	2.62	23.81	2.47
Italy	5.31	2.68	6.91	3.64
Japan	6.05	8.92	11.59	5.20
UK	1.95	1.20	1.92	1.08
Average	4.39	3.06	7.89	2.65

Note:

–Entries are GDP growth forecast errors calculated from Consensus Forecasts in other G7 countries relative to the forecast error in the US.

–Sample period is from 1992 to 2008 and the forecast error in each country is defined as $e_i = \frac{1}{T}\sum_{t=1}^{T} \frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}$, where $g_{i,t}^f$ is Consensus Forecasts of the GDP growth rate in year t for country i. $g_{i,t}$ is the actual GDP growth rate of country i in year t.

–In the columns of "Exclude Outliers", we exclude the observations of $\frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}$ that are larger than two standard deviations of the sample when calculating e_i.

APPENDIX (not for publication)

A.1 Standard Models

In this section, we describe the standard models used in Section 2.

A.1.1 IRBC Model

The standard IRBC model in Section 2 is the bond-economy model in 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 from 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:

$$E_t \sum_{j=0}^{\infty} \beta^j u_{Ht},$$

where the period utility function u_{Ht} takes the form of:

$$u_{Ht} = \frac{1}{1-\sigma} \left[C_{Ht}^{\mu} (1-L_{Ht})^{1-\mu}\right]^{1-\sigma}. \tag{A.1.4}$$

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 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

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}^{\frac{\phi-1}{\phi}}(i)di \right]^{\frac{\phi}{\phi-1}}. \tag{A.1.5}$$

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

$$Y_t = \left[\alpha^{\frac{1}{\gamma}} Y_{Ht}^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} Y_{Ft}^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}, \tag{A.1.6}$$

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

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t u_t(C_t, 1 - L_t) \right], \tag{A.1.7}$$

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

$$C_t + \frac{B_{Ht+1}}{(1+i_t)P_t} + \frac{S_t B_{Ft+1}}{(1+i_t^*)P_t} + I_t + \frac{1}{2}\Phi\left(\frac{I_t}{K_t} - \delta\right)^2 K_t + \frac{1}{2}\phi_d\left(\frac{B_{Ht+1}}{P_t}\right)^2 + \frac{1}{2}\phi_f\left(\frac{S_t B_{Ft+1}}{P_t}\right)^2 \leq \frac{W_t L_t}{P_t} + \frac{R_t K_t}{P_t} + \frac{B_{Ht}}{P_t} + \frac{B_{Ft} S_t}{P_t} + \frac{\Pi_t}{P_t}, \quad (A.1.8)$$

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:

$$i_t = i + \Xi_\pi log(\pi_t/\pi) + \Xi_y log(gdp_t/gdp), \quad (A.1.9)$$

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 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	3.2	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		
$\xi_{11} = \xi_{22}$	0.97	Technology shock AR(1) coefficient
$\xi_{12} = \xi_{21}$	0.025	Technology spillovers
σ_ε	0.0073	Standard Deviation of Productivity Shock