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 sticky prices, inflation targeting monetary authorities and variable capital utilization can help the model replicate the above empirical finding. The labor productivity increases in our model after a positive news shock to TFP because of the increase of capital utilization. Due to the wealth effect of good news about future productivity, demand and therefore inflation increase. Under inflation targeting monetary policy, the interest rate increases and the nominal exchange rate tends to appreciate. However, there is a second effect. The inflation rate and the interest rate are expected to decrease in the future when the expected increase in TFP realizes. This effect tends to depreciate the current exchange rate. Under some plausible calibrations, we find that the first effect can dominate the second and induce an appreciation of the nominal exchange rate after a positive news shock. Because of price stickiness, the terms of trade and the real exchange rate appreciate in this case.

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1 Introduction

Standard international macroeconomic models 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 the rest of the world. In this paper, we find that incorporating news shocks 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 transmission of country-specific shocks. A common view in the literature is that a country's terms of trade fall when its productivity increases relative to the rest of the world. As a result, productivity gains in one country spill over positively to other countries through the wealth effect. In this case, international price movements insure productivity risks across countries and 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 are at odds with the standard models' prediction that the terms of trade deteriorate after an increase of 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, though different sample periods and identification schemes are employed in these studies. These findings imply a negative transmission of productivity gains cross countries. Corsetti, Dedola, and Leduc (2008) show that the international transmission of productivity shocks may depend on a country's openness and trade elasticities, as well as the degree of shock persistence. 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 level increases relative to the rest of the world. They find that increasing the degree of shock persistence can also help models replicate the negative international transmission of productivity shocks. 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.

In this paper, we explore a different avenue to replicate the above empirical findings: news shocks to total factor productivity (TFP). News shocks consist of information about future 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; 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, 2007), Jaimovich and Rebelo (2009), Schimitt-Grohe and Uribe (2009) among others. In a standard sticky-price DSGE model with news shocks to TFP, we show that a country's terms of trade and the real exchange rate can appreciate rather than depreciate when its labor productivity increases relative to the rest of the world.

Besides news shocks, other crucial elements in our model include: variable capital utilization, price stickiness, and inflation-targeting monetary policy. Under the standard setup with contemporaneous productivity shocks, our model performs similarly to other standard models: predicting a depreciation of the terms of trade and the real exchange rate after a positive productivity shock. In this case, home goods prices decline when the home productivity rises relative to the foreign country. Inflation and therefore the nominal interest rate decrease when the central bank responds to the decline of the inflation rate. As a result, the nominal exchange rate depreciate, which reinforces the decline of home good prices when the prices are sticky in the short run.

In the case of a positive news shock, labor productivity in our model also rises immediately though TFP remains constant, because the capital utilization increases after the shock. The positive news shock has two effects on the nominal exchange rate that move in the opposite directions. First, due to the wealth effect of good news about future productivity, home demand and therefore the inflation rate increases. The inflation-targeting central bank will raise the interest rate in response, which tends to appreciate the nominal exchange rate. However, there is a second effect. The inflation rate and the interest rate are expected to decline in the future when the expected increase of TFP realizes. This effect tends to depreciate the current exchange rate. Under some reasonable calibrations, we find that the first effect can dominate the second and induce an appreciation of the nominal exchange rate. Because prices are sticky in the short run, the terms of trade and the real exchange rate appreciate in this case. That is, after a positive news shock, the terms of trade and the real exchange rate appreciate while the labor productivity increases.

Using long-run restrictions, we first estimate the impulse response functions of the real exchange rate and the terms of trade in a VAR estimation 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 its labor productivity increases. The terms of trade and the real exchange rate depreciate in most of other countries in our sample after an increase in labor productivity. Then in a two-country DSGE model with sticky prices, we show that incorporating news shocks in such a model can help the model replicate the above empirical findings. Our model is similar to the one in Kollmann (2004) and Wang (2010) with a few modifications. First, we incorporate news shocks to TFP into the model. Second, we incorporate variable capital utilization. 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. That is, good news about future productivity induces a recession instead of a boom in standard real business cycle models. Jaimovich and Rebelo (2009) find incorporating variable capital utilization in the model can alleviate this issue. 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 induced by the wealth effect. Following Jaimovich and Rebelo (2009) and Schimitt-Grohe and Uribe (2009), we consider news shocks to permanent changes of TFP. Schmitt-Grohe and Uribe (2009) find that anticipated shocks to the permanent component of TFP explain a large fraction of the variance of output growth in the US.

We inspect the theoretical impulse response functions of the terms of trade and the real exchange rate in response to news shocks. 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 labor productivity rises while the terms of trade and the real exchange rate appreciate after a positive news shock. Under our benchmark setup, the terms of trade and the real exchange rate appreciate after a positive news shock when the news shock arrives six or more periods in advance. 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 robustness checks, we have also tried the class of utility functions used in Backus, Kehoe, and Kydland (1992) with and without habit formation. We also use different capital adjustment costs, capital depreciation parameters, and monetary policy parameters. Our results hold up qualitatively well in all of these cases.

Following Jaimovich and Rebelo (2009), we use the accuracy of survey forecasts for output growth (Consensus Forecasts) as a measure of news shocks. The output growth forecasts seem more accurate (measured by the sum of percentage forecast errors) for the US than other G7 countries at both one- and two-year forecast horizons. This finding suggests that news shocks may be more important or arrives earlier in the US than in other G7 countries. This finding is consistent with the fact that the terms of trade and the real exchange rate appreciate in the US but depreciate in other countries when the labor productivity rises.

Compared to empirical results, we acknowledge a shortcoming of our benchmark results: the appreciation of the terms of trade and the real exchange rate is less persistent in our model than in the data. However, the appreciation becomes more persistent in our model when the news shock is more persistent or the length of new shocks is longer. For instance, when the news 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. We acknowledge that labor productivity and international relative prices are also jointly driven by other shocks and it is not appropriate to attribute all dynamics of international relative prices to news shocks only.

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 (Heathcote and Perri, 2002) and a dynamic stochastic general equilibrium (DSGE) model with sticky prices. 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 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 the extension of the IRBC model that assumes monopolistic competition, trade in nominal bonds, Calvo staggered price setting, and a monetary policy (Taylor) rule. This type of models are 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 included 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 of the relative prices means a depreciation of the terms of trade and the real exchange rate in the home country. Figure 1 shows the impulses 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 good prices relative to foreign prices.[1] These models suggest a positive international transmission of productivity shocks: the foreign country shares home country's productivity gains through the price increase of its products.

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 US. The choice of these countries is dictated by the data availability in the G10 dataset of Haver Analytic. We run structural VARs for each country using long-run restrictions as in Gali (1999) to identify productivity shocks. The following variables in each country are included in the VAR exercise: labor productivity (A_t), GDP (Y_t), consumption (C_t), net exports ($\frac{NX_t}{Y_t}$), the real exchange rate (Q_t), and the terms of trade (TOT_t). The labor productivity is measured by output per employed person. As a robustness check, we also use the 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 are not available in the G10 dataset. Following the literature, next exports are divided by GDP in our data. 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 price relative to home price. In this case, an increase of these variables means a depreciation for the home country. Other than 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 1989Q1 to 2009Q1 and) is the same for all countries in our sample to facilitate cross-country comparison of our results. Some countries have data before 1989Q1. Including the data in early periods does not change our results qualitatively.

Figure 2 shows impulses response functions in the US with respect to a positive productivity shock. In response to an increase in labor productivity, US output and consumption increase while trade balance declines. In particular, an increase of the labor productivity in the US induces an appreciation of its terms of trade and the real exchange rate, which is at odds with the predictions of standard international macroeconomic models that we just show. 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 countries in our sample. These impulse response functions are generally consistent with the standard theoretical prediction: a country's terms of trade or the real exchange rate or both depreciate after its labor productivity increases.

[1] When the elasticity of substitution between the 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 good prices can increase relative to foreign prices after a positive productivity shock in the home country if the trade elasticity is low and consumption is biased toward home goods. The equilibrium of the IRBC and DSGE models is indeterminate when γ is less than 0.313.

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 $Y_{Ht}(f)$ ($Y_{Ft}(f)$). In the intermediate good 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 (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 good 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 $P_t = \left[\int_0^\infty P_t(f)^{1-\theta_F} df\right]^{\frac{1}{1-\theta_F}}$ 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, the 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 has a probability of $1 - \alpha_F$ to re-optimize its price. Otherwise, it will charge a price equal to last periods price multiplied by the long-run inflation rate (π). When a final good firm re-optimizes its price, it will choose a price $\tilde{P}_t(f)$ to maximize the expected lifetime real profit:

$$\prod(f) = \max_{\tilde{P}_t(f)} \sum_{k=0}^{\infty} E_t \left\{ \alpha_F^k \Gamma_{t,t+k} P_{t+k}^{-1} \left[\left(\pi^k \tilde{P}_t(f) - mc_{t+k}(f) \right) \left(\frac{\pi^k \tilde{P}_t(f)}{P_{t+k}} \right)^{-\theta} Y_{t+k} \right] \right\}, \tag{4}$$

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 good producers is made from a continuum of differentiated intermediate goods indexed by $i \in [0,1]$ according to equation (5):

$$Y_{Ht} = \left[\int_0^1 Y_{Ht}(i)^{\frac{\theta_I - 1}{\theta_I}} di \right]^{\frac{\theta_I}{\theta_I - 1}}. \tag{5}$$

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 the Law of One Price (LOP) holds for intermediate goods.

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

$$Y_{Ht}(i) = A_t^{1-\varphi} \left[u_t K_t(i) \right]^{\varphi} L_t(i)^{1-\varphi}, \tag{6}$$

where u_t is the capital utilization rate and A_t is a labor-augmented total factor productivity (TFP) shock. Following King, Plosser, and Rebelo (1988), we will assume that A_t causes permanent technology changes.[2] $K_t(i)$ and $L_t(i)$ are, respectively, capital and labor used by firm i. We follow the same way as in the final goods sector to introduce staggered prices. $1 - \alpha_I$ is the probability for intermediate firms to re-optimize their prices in each period.

[2] Our theoretical results also hold in the case with stationary TFP shocks. Considering a stochastic growth model allows us to confirm our results with simulated data using long-run restrictions, the method that is used in empirical studies.

3.2 Household

The representative household maximizes expected lifetime utility

$$U = E_0 \left[\sum_{t=0}^{\infty} \beta^t u_t \left(C_t, L_t, X_t \right) \right]. \tag{7}$$

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

$$u_t \left(C_t, L_t, X_t \right) = \frac{\left(C_t - \chi L_t^{\eta} X_t \right)^{1-\rho}}{1-\rho}, \tag{8}$$

where

$$X_t = C_t^{\gamma} X_{t-1}^{1-\gamma}. \tag{9}$$

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. As robustness checks, we also consider several other utility functions used in the literature such as habit formation. Habit formation has been found helpful in explaining some empirical findings such as the smoothness of consumption. For instance, see Christiano et al (2007) and Schimitt-Grohe and Uribe (2009).

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

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

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

$$\delta(\mu) = \delta_0 + \delta_1(\mu - 1) + \frac{\delta_2}{2}(\mu - 1)^2. \tag{11}$$

The function $S_1(\cdot)$ represents investment adjustment costs following Christiano, Eichenbaum, and Evans

(2005). It takes the following form in our model

$$S_1(x) = 1 - \frac{\kappa}{2}(x - \bar{\mu}_I)^2, \tag{12}$$

where $\bar{\mu}_I$ denotes the steady state growth rate of investment.

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:

$$BC_t = \frac{\phi_d}{2}\left(\frac{B_{H,t+1}}{P_t}\frac{1}{A_t}\right)^2 A_t + \frac{\phi_a}{2}\left(\frac{S_t B_{Ft+1}}{P_t}\frac{1}{A_t}\right) A_t, \tag{13}$$

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 parameters of cost for holding domestic bonds and holding foreign bonds, respectively.[3] 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.[4]

3.3 Monetary Policy Rule and Process of Shocks

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

$$log(R_t/\bar{R}) = \Theta_\pi log(\Pi_t/\bar{\Pi}) + \Theta_y log(GDP_t/G\bar{D}P), \tag{14}$$

where R_t is the nominal interest rate, Π_t is the 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 interest rate to stabilize the deviation of the inflation rate and GDP from their steady states. 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, German central bank raised the annual nominal interest rate by only 50 basis points for a 10% depreciation of its real exchange rate. Wang (2010) find in a model similar to ours that optimal exchange rate stabilization

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

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

parameter is very small if the central bank target the CPI inflation rate optimally. Engel (2009) 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 technology processes are also used in Rabanal, Rubio-Ramirez, and Tuesta (2009). Rabanal, Rubio-Ramirez, and Tuesta (2009) show that the technology processes in the US and the "rest of the world" are characterized by a vector error correction model (VECM). 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

$$\epsilon_{A,t} = \xi_{A,t} + \zeta_{A,t-p}, \tag{15}$$

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 shocks. $\zeta_{A,t-p}$ 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. We will show that in response to a positive news shock, the labor productivity increases in our model. Meanwhile, the terms of trade and the real exchange rate appreciate as documented in the data.

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 equals one in the steady state. Following Jaimovich and Rebelo (2009), δ_2 is calibrated such that the elasticity of $\delta'(u)$ evaluated in the steady state ($\delta"(u)u/\delta'(u)$) is 0.15. The investment adjustment cost parameter κ is set to the same value as in Christiano, Eichenbaum, and Evans (2005). Since there is little guidance in the literature about appropriate values for δ_1, δ_2 and κ, we also consider several other values for these parameters as robustness checks.

The elasticity of substitution between the home and foreign goods is set to 1.1 following Bergin (2004) and Wang (2010). 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 (1998). 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 these are optimal values for policy parameters. Similar results are also found in Wang (2010) in an open-economy DSGE model. Other values of policy parameters are also considered in robustness checks.

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 (1998). Several other utility functions widely used in the literature are also considered in robustness checks.

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's (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. The mean of the posterior distribution for the AR(1) coefficient is 0.14 in their paper. 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 the annual frequency. The estimated AR(1) coefficient is 0.6, which implies a coefficient of about 0.85 at the quarterly frequency. So we set ρ_A to 0.85 in our benchmark model. A less persistent growth rate shock 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 0.0045 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 news shock lengths are also considered in robustness checks.

Following Schmitt-Grohe and Uribe (2003), foreign bond holding cost parameter (ϕ_a) is set to 0.000742. Home 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 small.

4.1 Theoretical Benchmark Results

We first consider a one-percent contemporaneous shock to the growth rate of Home country total factor productivity ($\mu_{A,t}$). Figure 4 shows the theoretical impulse response functions in this case with KPR preference. After a positive growth shock in Home country, its labor productivity, output, consumption and investment rise. The terms of trade and the real exchange rate depreciate after the shock. This is consistent with the prediction of the standard models shown in section 2. Figure 5 shows the same set of impulse response functions in the case with GHH preference. In both cases, the CPI inflation and therefore nominal interest rate in the home country increases relative to that in the foreign country in the first few periods after the shock. This is partially caused by the strong wealth effect from the persistent growth shock.[5] However, the home inflation rate the therefore the interest rate will become lower than the foreign one after the first few

[5] When the productivity shock is less persistent, for instance $\rho_A = 0$, the wealth effect is weak and the home inflation rate and the interest rate declines relative to that in the foreign right after the shock.

periods. It reflects the price reduction in the home country due to its increase in productivity. As a result, the nominal exchange rate depreciates on the impact of the shock, reinforming the depreciation of the terms of trade and the real exchange rate when prices are sticky.

Next we study the impulse response functions with respect to news shocks. We first still use KPR preference and Figure 6 presents the theoretical impulse response functions in response to a positive news shock with a length of 8. On impact, both the terms of trade and the real exchange rate appreciate in this case. [explanations from the UIP condition for why this happens]

Though the terms of trade and the real exchange rate appreciate on impact of the shock, they rise above zero shortly. That is, our model fails to replicate the persistence of appreciation. 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 the productivity shocks. In the two subfigures in upper panel, the AR(1) coefficient of the productivity shocks is fixed at zero. Then we change the length of news shocks from 4 to 12. In cases with longer news shocks, the appreciation of the terms of trade and the real exchange rate becomes more persistent. In the two subfigures in lower panel, the length of news shocks is fixed at 8 and the AR(1) coefficient of the productivity shocks increases from 0 to 0.9. It is evident that increasing the persistence of the productivity shocks also help our model replicate the persistent appreciation of the terms of trade and the real exchange in response to a positive shock.

Another discrepancy between our model and the data is the decline of output and labor after a positive news shock about future productivity. It is well known in the literature 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 8 shows the theoretical impulse response functions when we calibrate the utility function into the GHH one. Consistent with Jaimovich and Rebelo (2009), hours increase in response to a positive news shock though we still fail to generate an increase of investment in our model. Our finding that the terms of trade and the real exchange rate appreciate on the impact of a positive shock hold up well in this case.

[study individual effects of price stickiness, capital utilization, and the relation between s and i]

4.2 Simulated Impulse Response Functions

discussion about the length of news shocks, consensus forecast data.

4.3 Robustness Checks

In this subsection, 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:

$$u_t = \frac{\left[(C_t - bC_{t-1})^{\eta}(1-L_t)^{1-\eta}\right]^{1-\rho}}{1-\rho}. \tag{16}$$

In this utility function, we introduce internal habit formation following Constantinides (1990). The habit persistence parameter b is calibrated to 0.8. When b is set to zero, the utility function reduces to the one in Backus, Kehoe, and Kydland (1992).

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

$$K_{t+1} = (1-\delta(u_t))K_t + S_2\left(\frac{I_t}{K_t}\right)K_t. \tag{17}$$

The function S_2 introduces the capital adjustment cost and takes the form of

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

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 types of investment adjustment cost function assumes that it is costly to change investment-to-capital ratio and is also widely used in the literature. For instance, see Baxter and Crucini (1995) among others.

[discuss depreciation parameters, monetary policy parameters and trade elasticity]

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 depreciate in other countries. Two potential explanations are consistent with our news shock story. First, the anticipated technology shocks may play a more important role in driving the economy in the US than in other countries. Second, the length of the news shock may be longer in the US than in other countries. That is, 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 of processing these data make it easier to forecast the future. 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 of Consensus Economics provide GDP growth forecasts at one- and two-year horizons for several countries. From 1992 to 2008, the GDP growth forecasts are available for the G7 countries: Canada, France, Germany, Italy, Japan, UK, and the US. We compare the accuracy of GDP growth forecasts between the US and the other G7 countries. The forecast errors are measured by

$$e_i = \frac{1}{T} \sum_{t=1}^{T} \frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}, \tag{19}$$

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. That is, we use the sum of percentage forecast errors in each period as a measure of forecast accuracy.

Table 2 shows the forecast errors in G7 countries relative to that in the US. All entries are greater than one, which indicates the GDP forecast errors in other G7 countries are bigger than that in the US. We notice that there are one or two outliers in some countries for $\frac{|g_{i,t}^f - g_{i,t}|}{|g_{i,t}|}$. To eliminate these outliers' effect on our results, we exclude the observations that are greater than two standard deviations of the full sample in each country. All countries have two or less outliers in our sample. Forecast errors of the US remain smaller than those in other G7 countries even after excluding these outliers.

5 Conclusion

to be written

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Figure 1: Impulse Response Functions in Standard Models

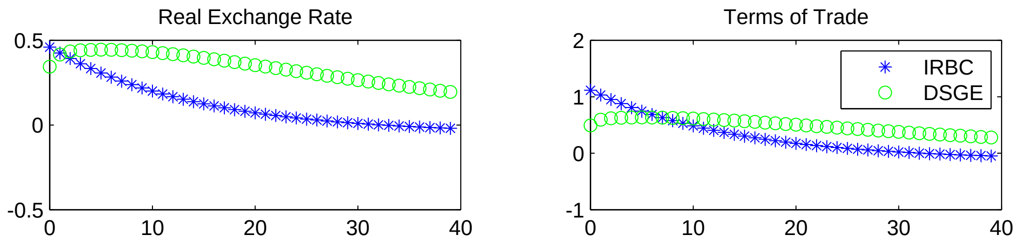

Figure 2: Impulse Response Functions Estimated with Long-run Restrictions: US

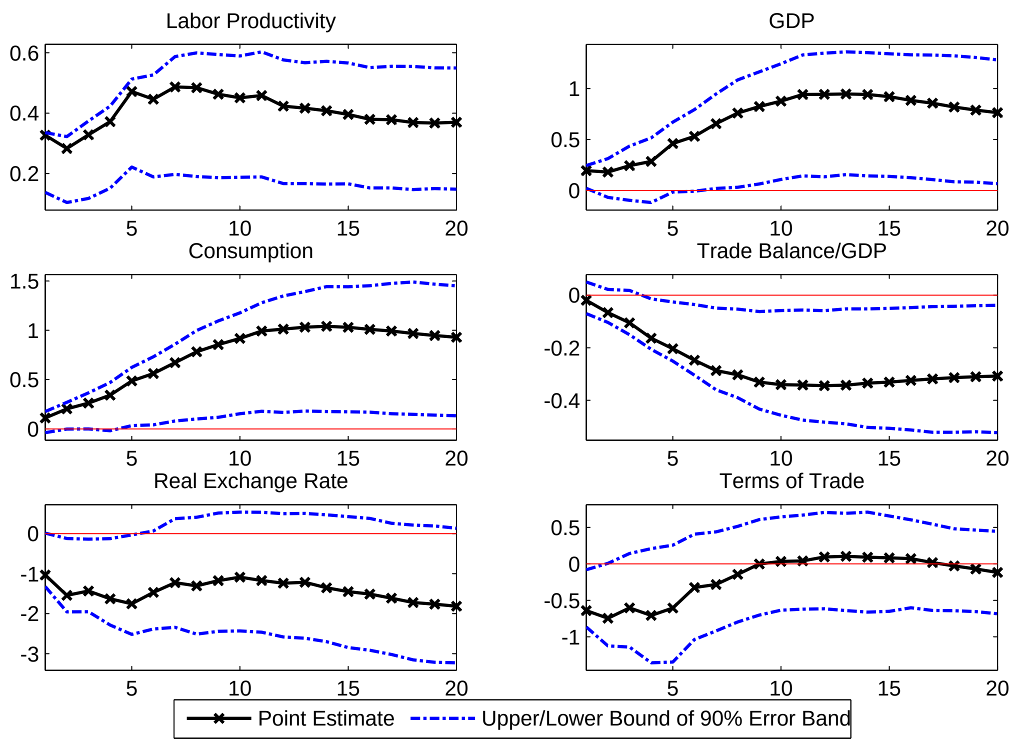

Figure 3: Impulse Response Functions Estimated with Long-run Restrictions: Other Countries

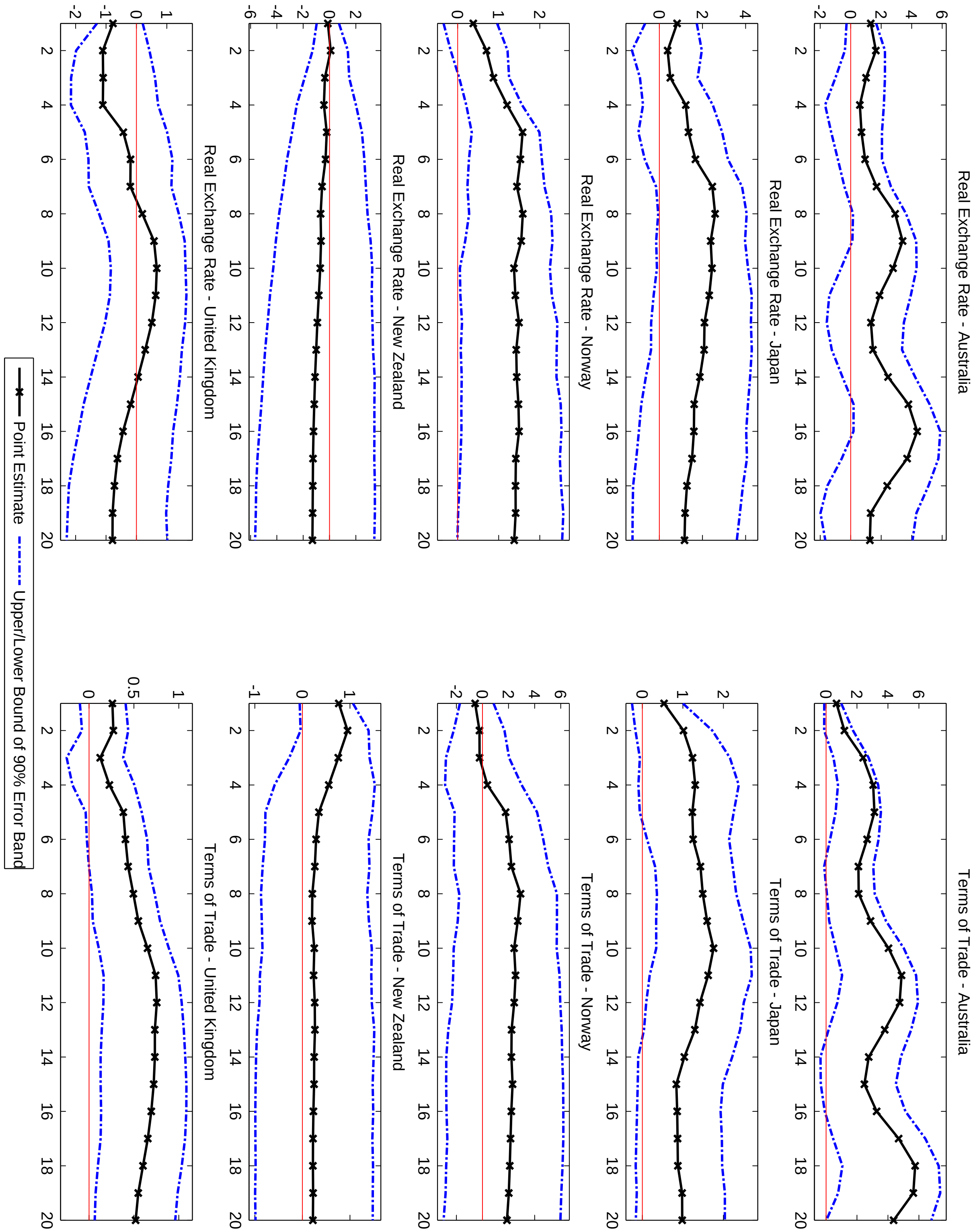

Figure 4: Impulse Response Functions: KPR Preference and Contemporaneous TFP Shock

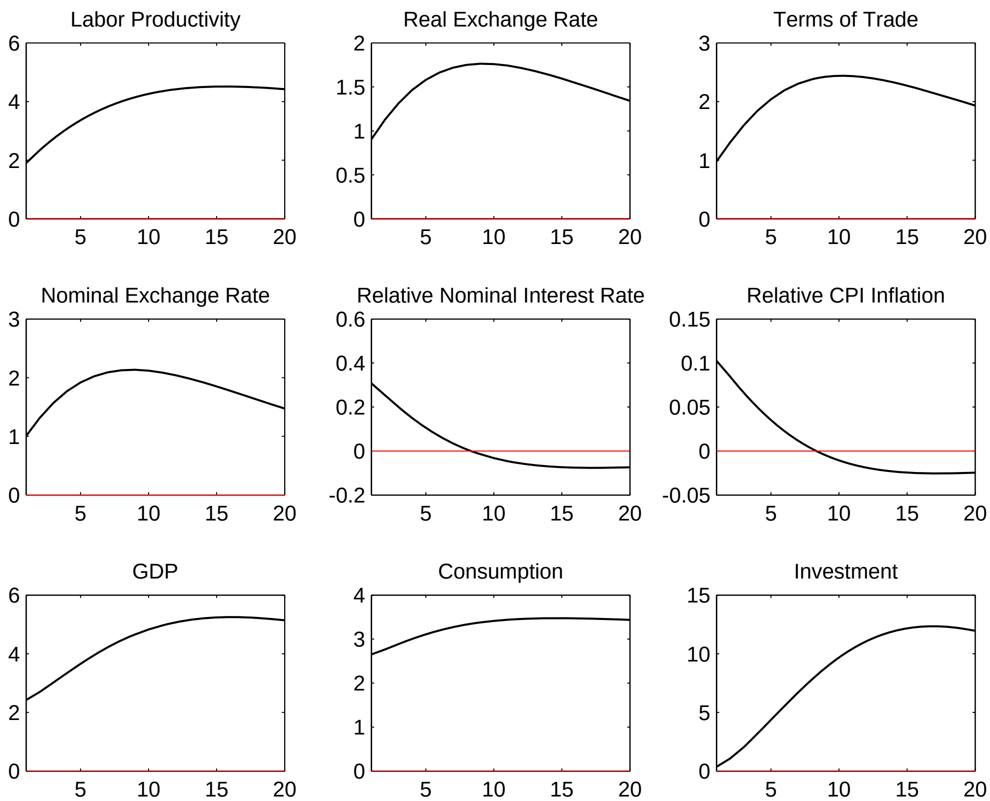

Figure 5: Impulse Response Functions: GHH Preference and Contemporaneous TFP Shock

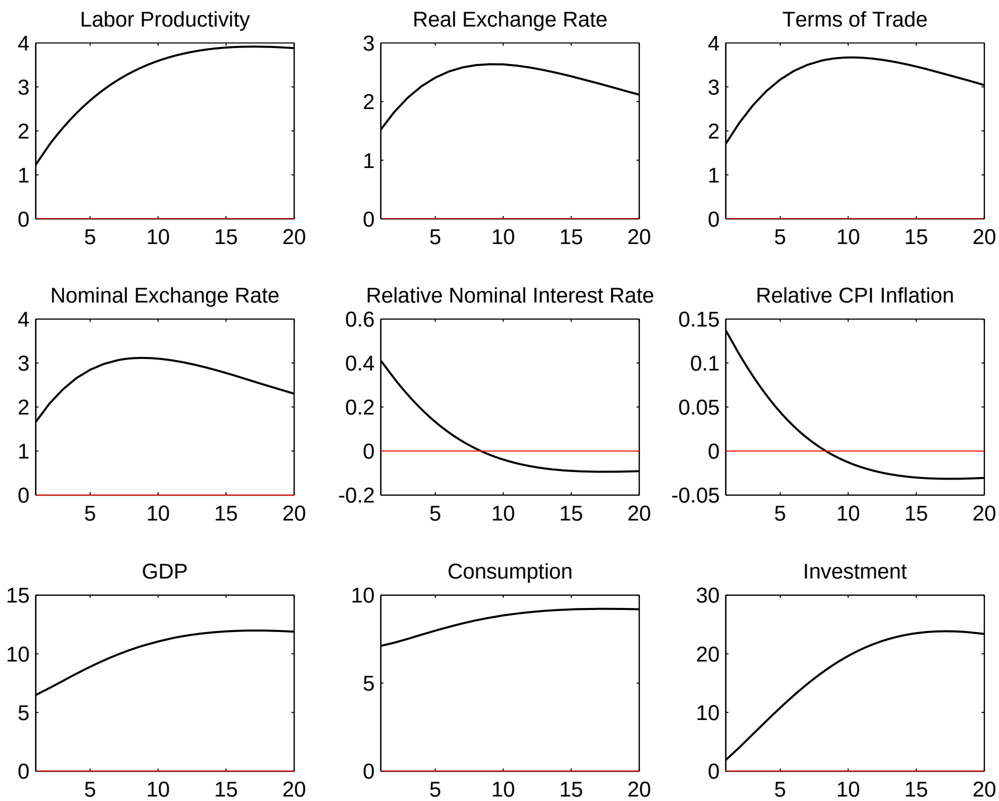

Figure 6: Impulse Response Functions: KPR Preference and News TFP Shock

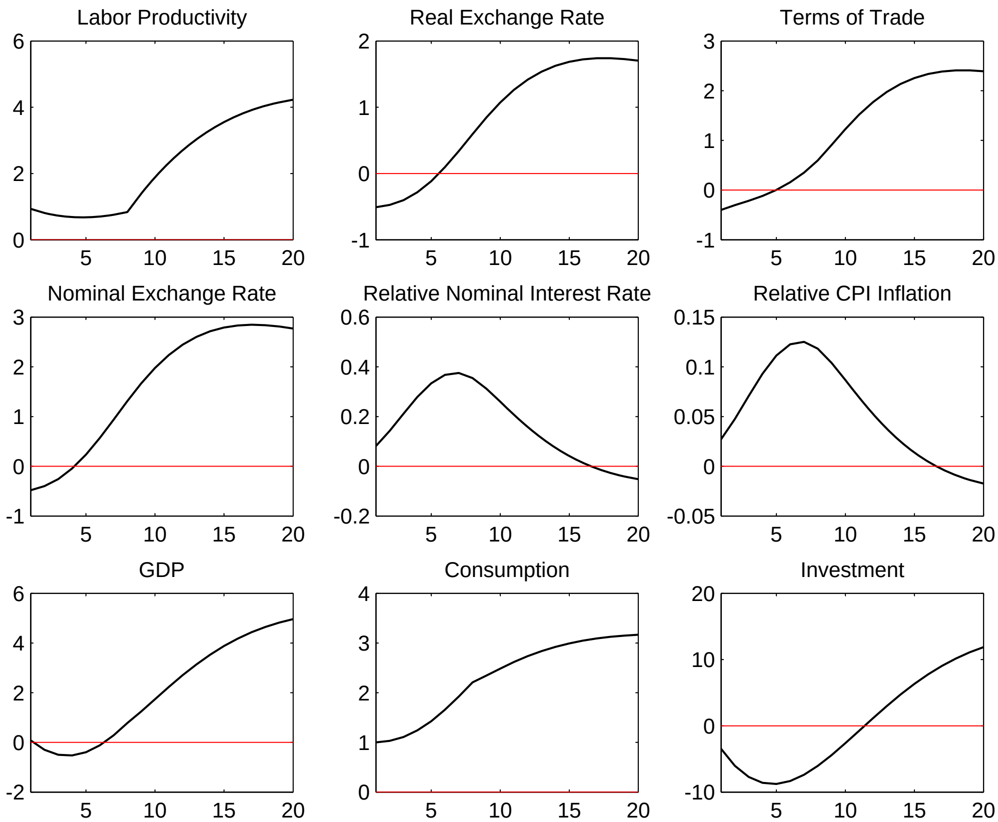

Figure 7: Impulse Response Functions: KPR Preference and Various Shock Lengths and Persistence

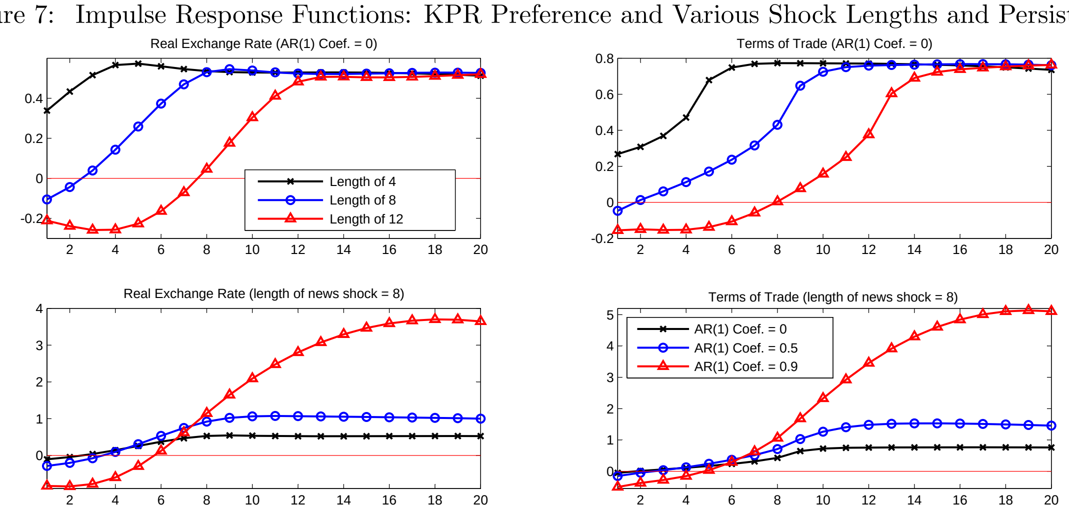

Figure 8: Impulse Response Functions: GHH Preference and News TFP Shock

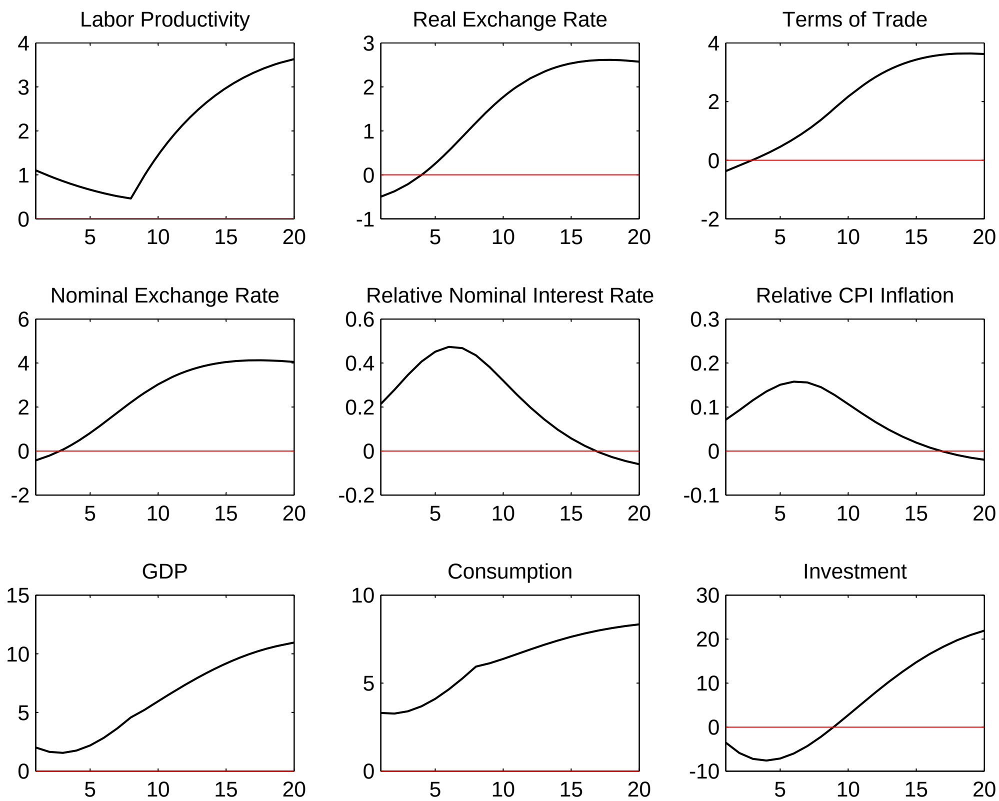

Figure 9: Estimated Impulse Response Functions: KPR Preference and News TFP Shock

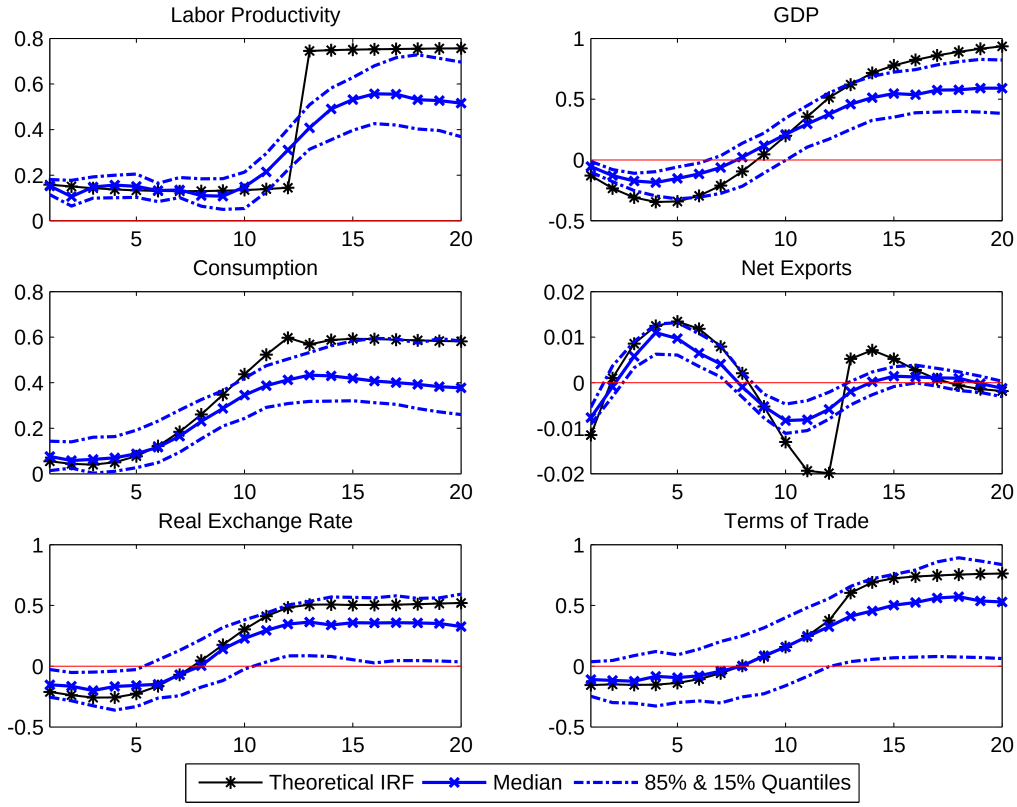

Table 1: Calibration of Benchmark Model

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 $\delta(u)''u/\delta(u)' = 0.15$
κ	2.79	Investment adjustment cost parameter
ψ	1.1	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 for final goods
α_I	0.75	Price stickiness 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	3.8194	Calibrated such that the steady state labor supply is 0.2
ρ_A	0.85	AR(1) coefficient of technology growth rate
ρ_R	0.0045	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: GDP Growth Forecast Errors in G6 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 G6 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 $e_i = \frac{1}{T}\sum_{t=1}^{T} \frac{|g^f_{i,t} - g_{i,t}|}{|g_{i,t}|}$, where $g^f_{i,t}$ 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 columns of "Exclude Outliers", observations of $\frac{|g^f_{i,t} - g_{i,t}|}{|g_{i,t}|}$ are excluded when calculating e_i if they are greater than two standard deviations of the full sample.

APPENDIX

A.1 Standard Models

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

A.1.1 RBC Model

The standard RBC model 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-good sector and final-good sector. Due to the symmetry, we focus 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 the Home intermediate goods used in the Home country and Y_{Ft}^{H} is the Home intermediate goods used in the Foreign country. A_{Ht} is the TFP shock, K_{Ht} is capital and L_{Ht} is labor supply. The 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 wage 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 country 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

It is a two-country symmetric model. We will focus on 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. The intermediate goods are aggregated into 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-good market is monopolistic competitive. The 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.

The 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 good market is competitive with the flexible price.

The household chooses sequences of consumption C_t, capital accumulation I_t, labor supply L_t, 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

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

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-good firms. Nominal interest rate follows Taylor rule

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

where π_t is inflation rate at time t.

The first order conditions of the household approximately imply the uncovered interest rate parity. In the UIP model, we break this condition with the uncovered interest rate parity shock by following Kollmann (2004). The values that we use to calibrate the DSGE model are listed in Table 3. Most parameter values are from Heathcote and Perri (2002) in order for us to compare between the IRBC and DSGE model. Parameters that are not in Heathcote and Perri (2002) are calibrated to the standard values used in the literature, for instance, Kollmann (2004) and Wang (2010).

Table 3: 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