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EXCHANGE RATE DYNAMICS, ASSET MARKET STRUCTURE, AND THE ROLE OF THE TRADE ELASTICITY

CHRISTOPH THOENISSEN
Victoria University of Wellington

A canonical flexible-price international real–business cycle model with incomplete financial markets can address the exchange rate–volatility puzzle, the exchange rate–persistence puzzle, and the consumption real–exchange rate anomaly, as well as the quantity anomaly. Crucial for the success of the model is the choice of the elasticity of substitution between home and foreign produced goods. The paper shows that the range of this parameter that allows the model to address these international macroeconomics anomalies is very narrow. Furthermore, the paper highlights an anomalous relationship between real–exchange rate persistence and the elasticity of substitution between home- and foreign-produced goods.

Keywords: Real Exchange Rate Dynamics, Incomplete Financial Markets, Backus–Smith Puzzle, Exchange Rate Persistence, Trade Elasticity

1. INTRODUCTION

How well does the canonical flexible-price international real–business cycle (IRBC) model fit the data? Early evidence from Backus et al. (1994, 1995) suggests that the model departs from the data on a number of important dimensions. Compared to the data, the basic flexible-price IRBC model generates international relative prices that are neither volatile nor persistent enough. Even with incomplete financial markets, the model generates unrealistically high levels of international risk sharing, as indicated by a near-unitary cross correlation between the real exchange rate and relative consumption. High degrees of international risk-sharing and low exchange-rate volatility also imply that home and foreign consumption are highly correlated, more so than home and foreign output. In the data, the ordering of these cross-country correlations is reversed.

Successful attempts have been made to address individual shortcomings or puzzles thrown up by the model. Stockman and Tesar (1995) introduce nontraded

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goods into an otherwise canonical IRBC model and show that such a modification can go some way toward addressing the quantity anomaly, the relative ordering of the cross correlation between home and foreign consumption and GDP. Benigno and Thoenissen (2008) add incomplete financial markets to the model of Stockman and Tesar (1995) and show that this simple modification can help address the Backus–Smith puzzle, breaking the strong link between the real exchange rate and relative consumption. However, even with a nontraded-goods sector and incomplete financial markets, the model still does not generate enough volatility of the real exchange rate or the terms of trade. Heathcote and Perri (2002) succeed in addressing the issue of relative-price volatility and the ordering of cross-country correlations by eliminating trade in financial assets. They show that for low values of the trade elasticity, the elasticity of substitution between home- and foreign-produced goods, their financial autarky model generates realistic levels of relative-price volatility while lowering the counterfactually high cross-country correlation of consumption evident in versions of their model with trade in financial assets.

Recent work by Corsetti et al. (2008a, 2008b) takes Heathcote and Perri's work a step further by introducing, among other features, consumption home bias, a nontraded-goods sector, distribution services, and incomplete financial markets into the standard IRBC framework. Their work suggests that the value of the trade elasticity not only lies at the heart of the volatility of relative prices and the ordering of international comovements, but also can be used to explain most of the irregularities thrown up by the canonical IRBC model, without the need to assume financial autarky. They show that models with substantial complementarity between imported and exported goods can yield volatile and persistent real exchange rates, address the Backus–Smith puzzle, and reduce the correlation between home and foreign consumption below that between home and foreign GDP. Because of the assumption of consumption home bias, most of these anomalies can be addressed with two values of the substitution elasticity. The higher of the two elasticities corresponds to the case where the terms of trade depreciate following a positive shock to home total-factor productivity. For the lower of the two elasticities, the terms of trade appreciate following a positive home-country supply shock. Here, the terms of trade amplify instead of dampening the effects of productivity shocks on home consumption relative to foreign consumption. The implication is a radically different international transmission mechanism for asymmetric supply shocks. Corsetti et al. (2006), Kollmann (2006), and Enders and Müller (2009) show that for the U.S. economy this alternative view of the transmission mechanism, what they call *negative transmission*, is not entirely without empirical support.

The purpose of this paper is to analyze if these encouraging results also hold in a canonical flexible-price IRBC model and if so, how robust these findings really are. Depending on the calibration, the canonical flexible-price IRBC model performs surprisingly well, and does so without modeling features designed to address key open-economy macroeconomic facts. The performance of the baseline model has to be set against the robustness of the model to changes in key deep parameters. Robustness is measured by the size of the parameter space that allows the model to perform in a data-congruent fashion. One is more likely to find empirical support for the simple IRBC model if the permissible parameter range is large. The smaller the range of values of elasticity of substitution between home- and foreign-produced goods, θ, that support the model, the less likely one is to find empirical support for it. The results of the paper suggest that, for the flexible-price IRBC model with incomplete financial markets, the range of θ that supports the model is quite narrow indeed. For values outside this range, for either larger or smaller values of θ, the model displays all the usual exchange-rate puzzles. Not just that, but the permissible range of θ is itself a function of, among other factors, the degree of home bias in consumption and investment expenditure, as well as the structure of the financial asset market. For example, if the degree of home bias in investment is less than that in consumption, or if home- and foreign-produced investment goods are better substitutes for one another than are home- and foreign-produced consumption goods, then the model performs quite poorly, regardless of the level of θ. Likewise, the ability of the model to generate a negative transmission mechanism of supply shocks depends not just on the nature of investment demand, but also on how one models the asset market. There can be no negative transmission under complete financial markets, or if one rules out unit roots in bond holding via a bond-holding cost. Whereas the baseline model under the assumption of financial autarky generates negative transmission for all values of θ below a given threshold, the same is not the case for an incomplete financial market specification "closed" by an endogenous discount factor. Here, negative transmission occurs only in the neighborhood of the threshold level of θ, reverting to the traditional transmission mechanism for smaller values of θ, confining *negative transmission* to a very narrow range of the parameter space. The paper also shows that when the simple model generates realistic levels of exchange-rate volatility, it also generates realistic levels of exchange-rate persistence. This persistence result is somewhat puzzling, especially because it occurs even when the model is driven only by nonpersistent white noise shocks.

The remainder of the paper is structured as follows: Section 2 sets out the baseline model. Section 3 provides the main intuition behind our results. Section 4 discusses the calibration of the structural parameters as well as the shock processes. Section 5 presents a selection of second moments generated by the baseline calibration put forward in Section 4 and then proceeds to choose values of the elasticity of substitution between home- and foreign-produced goods, θ, that allow the model to address various discrepancies between the model and the data present under the baseline calibration. Section 6 carries out a number of robustness checks and finds that the choice of θ and the model's ability to address the key international macro puzzles is extremely sensitive to the degree of home bias, the composition of investment goods, and the structure of asset markets. Section 7 concludes.

2. THE MODEL

The paper puts forth an international real–business cycle model with flexible prices and incomplete financial markets. For ease of exposition, a decentralized market structure is chosen. The representative household in each country consumes a final consumption good, provides labor services, and smooths consumption over time by investing in a non–state contingent bond paying out in home-produced intermediate goods. The representative household receives a wage and a share of the income generated by the intermediate goods–producing sector. The intermediate goods–producing sector combines the household's labor with accumulated capital stock to produce intermediate goods that can be used to produce home and foreign consumption as well as investment goods. Final-goods producers produce consumption and investment goods using home- and foreign-produced intermediate goods. The share of home-produced intermediate goods differs across countries and final consumption versus investment goods. Agents are assumed to have a relative preference for home-produced intermediate goods in their final consumption basket. They have consumption home bias. The consumption-based real exchange rate deviates from purchasing power parity because of consumption home bias. This assumption makes the real exchange rate simply a function of the terms of trade.

2.1. Consumer Behavior

The world economy is populated by a continuum of agents on the interval [0, 1]. The population on the segment $[0, n)$ belongs to the country H (Home), whereas the segment $[n, 1]$ belongs to F (Foreign). The home-country consumer obtains utility from consumption, C, and receives disutility from supplying labor, h. Following Mendoza (1991) and Schmitt-Grohé and Uribe (2003), as well as Corsetti et al. (2008a), preferences for the representative home consumer are described by the utility function

$$U = E_0 \sum_{t=0}^{\infty} \xi_t \left[\frac{C_t^{1-\rho}}{1-\rho} + \chi \frac{(1-h_t)^{1-\rho}}{1-\rho} \right], \tag{1}$$

$$\xi_0 = 1, \tag{2}$$

$$\xi_{t+1} = \{1 + \vartheta[\tilde{C}_t + \chi(1-\tilde{h}_t)]\}^{-1} \xi_t, \quad t \geqslant 0, \tag{3}$$

where the discount factor is endogenous and depends on the sequence of consumption and labor effort. Specifically, the agent takes the average per capita levels of consumption and labor effort, $\tilde{C}_t$ and $\tilde{h}_t$, as given, so that the representative agent does not internalize the effect of consumption and labor choice on the discount factor. By assuming that $\xi_{\tilde{C}} < 0$ and $\xi_{\tilde{h}} > 0$, this preference specification allows the model to be linearized around a nonstochastic steady state that is independent of initial conditions such as the initial level of financial wealth, capital stock, or total factor productivity. The endogenous discount factor rules out unit roots in bond holding that arise in the pure bond economy.

International asset markets are assumed to be incomplete. Home and foreign agents can trade in one non–state contingent bond, B_t, that pays out one unit of home-produced intermediate goods in period $t+1$. Denote by B_t the quantity and by R_t the price of the bond purchased by home agents at the end of period t. The representative consumer faces the following budget constraint in each period t:

$$C_t + \frac{P_{H,t}}{P_t} R_t B_t = \frac{P_{H,t}}{P_t} B_{t-1} + w_t h_t + \Pi_t, \tag{4}$$

where P_t is the price index of the consumption bundle, $P_{H,t}$ is the price of home-produced intermediate goods, and w_t is the real wage. In addition to the wage, the representative household receives dividends, Π_t, from holding a share in the equity of domestic firms. All domestic firms are wholly owned by domestic agents and equity holding within these firms is evenly divided between domestic households. When optimizing, the representative household takes the flow of dividends as given.

The maximization problem of the Home representative agent consists of maximizing (1) subject to (4), along with the usual transversality condition

$$\lim_{T\to\infty} E_t \prod_{s=1}^{T} R_s B_{t+T} = 0, \tag{5}$$

in determining the optimal profile of consumption and bond holding and the labor supply schedule. Using first-order conditions for optimal consumption, labor effort, and bond holdings one can derive the static efficiency condition for the consumption–labor choice as well as the consumption Euler equation:

$$\frac{U_h[C_t, (1-h_t)]}{U_C[C_t, (1-h_t)]} = w_t \tag{6}$$

$$U_C[C_t, (1-h_t)] \frac{P_{H,t}}{P_t} = \xi_t \frac{1}{R_t} \mathrm{E}_t \left\{ U_C[C_{t+1}, (1-h_{t+1})] \frac{P_{H,t+1}}{P_{t+1}} \right\}. \tag{7}$$

In equilibrium, the household and average per capita levels of consumption and effort are the same, such that

$$C_t = \tilde{C}_t \tag{8}$$

$$h_t = \tilde{h}_t. \tag{9}$$

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2.2. Final Consumption Goods Sector

Home final consumption goods (C) are produced with the aid of home- and foreign-produced intermediate goods (c_H and c_F) in the following manner:

$$C_t = \left[v^{\frac{1}{\theta}} c_{H,t}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} c_{F,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{10}$$

where θ is the elasticity of intratemporal substitution between home- and foreign-produced intermediate goods. Final goods in the home and the foreign country differ in terms of their composition of home- and foreign-produced intermediate goods, $v > v^*$, where v^* is the share of home-produced goods in the foreign country's final consumption good.

The final goods producer's maximization yields the following input demand functions for the home economy (similar conditions hold for foreign producers):

$$c_{H,t} = v \left(\frac{P_{H,t}}{P_t} \right)^{-\theta} C_t, \quad c_{t,F} = (1-v) \left(\frac{P_{F,t}}{P_t} \right)^{-\theta} C_t. \tag{11}$$

The price index that corresponds to the previous demand function is defined as

$$P_t^{1-\theta} = \left[v P_{H,t}^{1-\theta} + (1-v) P_{F,t}^{1-\theta} \right]. \tag{12}$$

An analogous production structure exists for the production of foreign final consumption goods.

2.3. Intermediate Goods Sectors

Firms in the intermediate goods sector produce output, y_t, that is used in the production of the final consumption and investment goods at home and abroad using capital and labor services employing the constant–returns to scale production function

$$y_t = A_t f(k_{t-1,} h_t), \tag{13}$$

where A_t is a stochastic variable that follows an AR(1) process and is interpreted as total factor productivity . The real value of cash flow of this typical firm in the intermediate goods–producing sector is

$$\Pi_t = \frac{P_{H_t}}{P_t} A_t f(k_{t-1,} h_t) - w_t h_t - \frac{P_{x,t}}{P_t} x_t, \tag{14}$$

where w_t is the real wage and $P_{x,t}$ is the investment goods deflator. The baseline specification assumes that home firms turn home-produced intermediate goods into capital stock, and the foreign firm uses only foreign-produced intermediate goods for investment. Thus $P_{x,t} = P_{H,t}$ and $P_{x,t}^* = P_{F,t}^*$. The firm faces the capital accumulation constraint

$$k_t = (1-\delta) k_{t-1} + \left[1 - s \left(\frac{x_t}{x_{t-1}} \right) \right] x_t, \tag{15}$$

where the initial capital stock, k_{-1}, is given, δ is the rate of depreciation of the capital stock, and $[1-s(\frac{x_t}{x_{t-1}})]x_t$ captures investment adjustment costs as proposed by Christiano et al. (2005); i.e., it summarizes the technology that transforms current and past investment into installed capital for use in the following period. Following Christiano et al., it is assumed that the function $s(\frac{x_t}{x_{t-1}})$ has the following steady-state properties: $s(1) = s'(1) = 0$ and $s''(1) > 0$. Schmitt-Grohé and Uribe (2004) suggest the functional form $s(\frac{x_t}{x_{t-1}}) = \frac{\kappa}{2}(\frac{x_t}{x_{t-1}} - 1)^2$. For the purposes of this paper, all that is needed is a value for $s''(1)$, which according to the functional form suggested by Schmitt-Grohé and Uribe is a constant, κ.[1]

The firm maximizes shareholder's value using the household's intertemporal marginal rate of substitution as the stochastic discount factor. The first-order conditions for the choice of labor input, investment, and capital stock in period t are

$$\frac{P_{H,t}}{P_t} A_t F_h(k_{t-1,} h_t) = w_t, \tag{16}$$

$$q_t \left[1 - s\left(\frac{x_t}{x_{t-1}}\right)\right] = q_t s'\left(\frac{x_t}{x_{t-1}}\right)\frac{x_t}{x_{t-1}} - \xi_t \mathrm{E}_t q_{t+1}\frac{\mu_{t+1}}{\mu_t} s'\left(\frac{x_{t+1}}{x_t}\right)\frac{x_{t+1}}{x_t}\frac{x_{t+1}}{x_t} + \frac{P_{x,t}}{P_t}, \tag{17}$$

$$\xi_t \mathrm{E}_t \frac{\mu_{t+1}}{\mu_t}\left[\frac{P_{H,t+1}}{P_{t+1}} A_t F_{k_t}(k_{t,} h_{t+1}) + q_{t+1}(1-\delta)\right] = q_t, \tag{18}$$

where Tobin's q is defined as $q_t \equiv \frac{\lambda_t}{\mu_t}$.

2.4. International Relative Prices

The terms of trade are defined as the ratio of import to export prices expressed in a common currency: $T = P_F/SP_H^*$. Because the model assumes that the law of one price holds for individual goods, the expression for the terms of trade can be rewritten as $T = P_F/P_H$. A depreciation (appreciation) of the terms of trade is a rise (fall) in T. The consumption-based real exchange rate is defined as the price of the foreign consumption basket relative to the home consumption basket, in terms of home currency units. Because the model assumes that the law of one price holds for all goods and abstracts from a nontraded goods sector, the only channel through which the consumer price–based real exchange rate can deviate from purchasing power parity is via cross-country differences in consumption shares of the two goods. It is assumed that v, the share of home-produced goods in domestic final consumption, exceeds v^*, the share of home-produced goods in foreign final consumption. The difference $v - v^*$ captures the degree of consumption home bias.[2]

Taking a log-linear approximation to the definition of the real exchange rate, $RS = SP^*/P = P_H/P\ P^*/P_H^*$, yields a linear relationship between the real

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exchange rate and the terms of trade,

$$\widehat{RS}_t = (v - v^*)\hat{T}_t, \tag{19}$$

where for any variable z_t, whose steady state value is $\bar{z}$, I define $\hat{z}_t = \frac{z_t - \bar{z}}{\bar{z}}$; thus a "$\wedge$" signifies a log deviation from steady state. The implication of this is that the real exchange rate is perfectly correlated with and less volatile than the terms of trade. Both of these characteristics are at odds with the data.

2.5. Market Equilibrium

The solution to our model satisfies the following market equilibrium conditions for the home and foreign country:

1. Home- and Foreign-produced intermediate goods markets clear:
$$y_t = c_{H_t} + c^*_{H_t} + x_{H_t} + x^*_{H_t} \quad \text{and} \quad y^*_t = c_{F_t} + c^*_{F_t} + x_{F_t} + x^*_{F_t}. \tag{20}$$
2. The bond market clears:
$$B_t + B^*_t = 0. \tag{21}$$

2.6. Solution Technique

Before it is solved, the model is linearized around the nonstochastic steady state. In a neighborhood of the nonstochastic steady state, one can analyze the linearization of the model, provided that the random shocks are sufficiently small. This procedure is standard in stochastic rational-expectations macroeconomic models and is valid (i.e., yields a close approximation) provided the stochastic disturbances have sufficiently small support. For a justification see Appendix A.3 of Woodford (2003). The linearization thus yields a set of equations describing the equilibrium fluctuations of the model. The log linearization yields a system of linear difference equations that can be expressed as a singular dynamic system of the form

$$\mathbf{A}\mathrm{E}_t\mathbf{y}(t+1 \mid t) = \mathbf{B}\mathbf{y}(t) + \mathbf{C}\mathbf{x}(t),$$

where $\mathbf{y}(t)$ is ordered so that the nonpredetermined variables appear first and the predetermined variables appear last, and $\mathbf{x}(t)$ is a martingale difference sequence. There are two shocks in $\mathbf{C}$: shocks to the home and foreign intermediate-goods sectors' productivity. The variance–covariance and autocorrelation matrices associated with these shocks are described in Table 1. Given the parameters of the model described in Section 4, this system is solved using the King and Watson (1998) solution algorithm.

3. THE ROLE OF THE TRADE ELASTICITY θ

The model having been described, this section outlines the intuition behind the key results of this paper. As long as the trade elasticity is such that the model implies a

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TABLE 1. Baseline calibration

Preferences	$\xi = 1/1.01$, $\rho = 1$, $\bar{h} = 1/3$,
Final goods tech	$v = (1 - v^{*}) = 0.88$, $\theta = 2$, $\tau = 1$, $\varphi = (1 - \varphi^{*}) = 1$
Intermediate goods	$\alpha = 0.64$, $\delta = 0.025$, $s'' = 0.1$
Shocks	$\Omega = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix}$
	$V[\mu] = 10^{-4} \begin{bmatrix} 0.726 & 0.187 \\ 0.187 & 0.726 \end{bmatrix}$

positive international transmission of productivity shocks, lowering θ can address the volatility puzzle, because as home and foreign goods become complements in consumption and thus less substitutable for one another, a larger depreciation of the terms of trade (fall in the relative price of home-produced goods) is required to clear the market following an asymmetric supply shock. Thus as θ declines, the relative volatility of the terms of trade and thus the real exchange rate increases.

When relative terms-of-trade volatility is high, the cross correlation between the real exchange rate and relative consumption is low. As is familiar from Cole and Obstfeld (1991), the terms of trade can act to share idiosyncratic risk across countries. In the special case where $\theta = 1$, the model replicates the complete financial markets allocation where risk is perfectly shared between the home and foreign economies. The smaller (larger) is the value of θ, the more (less) the terms of trade respond to an asymmetric supply shock. For sufficiently small values of θ, the response of the terms of trade is to depreciate (rise) by so much that relative consumption actually falls following a home TFP shock. Thus relative consumption and the real exchange rate are negatively correlated.

The quantity anomaly can be addressed by choosing a particular value of θ that generates a terms-of-trade depreciation large enough to cause home consumption to actually fall while foreign consumption rises following a home productivity increase (home and foreign consumption are negatively correlated). Because the cross correlation between home and foreign GDP is determined mostly by the cross correlation of the TFP process, which is positive, home and foreign consumption are not as highly correlated as home and foreign GDP.

When the trade elasticity is such that the model implies a negative international transmission of productivity shocks, the terms of trade appreciate (fall) following a rise in domestic TFP. This shifts purchasing power away from foreign to home consumers. Instead of helping to share risk, the terms of trade actually reenforce the effects of an asymmetric shock on relative welfare. Corsetti et al. (2008b) provide an elegant intuition for this phenomenon, which I attempt to abridge. One can easily decompose the responses of domestic and foreign demand for home-produced goods to a change in the terms of trade into a substitution and an income effect. In the home economy, where the supply shock occurs, the substitution effect

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and the income effect have opposite signs. For a depreciation of the terms of trade, the substitution effect is positive, because home goods become relatively cheaper if the terms of trade depreciate. The income effect, on the other hand, is negative, because a depreciation reduces the value of the home-produced output. Abroad, both the substitution and the income effects are positive—home-produced goods are relatively cheaper and the value of foreign output rises. Negative international transmission of supply shocks can occur when the negative home income effect on demand outweighs both the positive home substitution effect and the positive foreign substitution and income effects. In this case, following an increase in productivity that raises the supply of home-produced goods, world demand for home-produced goods actually falls if the terms of trade depreciate. Thus, to clear the market, the terms of trade have to appreciate, so that the dominant home income effect becomes positive. Negative transmission becomes more likely if the home country is the main source of demand for home-produced goods, i.e., with strong home bias and, as is shown below with high relative price volatility, to increase the size of the income effect.

With negative transmission the terms of trade and by implication the real exchange rate appreciate while relative consumption rises; the correlation between the real exchange rate and relative consumption is negative. Thus negative transmission also addresses the Backus–Smith puzzle. The correlation between home and foreign consumption is reduced, as the negative terms of trade, or wealth effect on foreign consumers, tends to drive home and foreign consumption in opposite directions.

Whereas the baseline calibration where $\theta = 2$ yields a procyclical trade balance, this paper's attempts to resolve various international macroeconomics puzzles also result in a data-congruent countercyclical trade balance. Sensitivity analysis on this cross correlation suggests that, for the current specification of preferences, net trade becomes countercyclical for values of θ less than one.[3] In the baseline model, net trade is driven by movements in the terms of trade, home consumption of foreign-produced goods, and foreign consumption of home-produced goods. If imports and exports are highly substitutable (high θ), then a home supply shock raises home output and depreciates the terms of trade (worsens net trade); it also raises foreign consumption of home-produced goods (improves net trade) and lowers home consumption of foreign-produced goods (improves net trade). On balance, net trade improves along with home output. If home- and foreign-produced goods are complements (low θ), then the terms-of-trade depreciation will be larger; foreign consumption of home goods will still increase, but so will home consumption of foreign goods, worsening net trade. Overall, net trade worsens as home output increase.

The fact that values of θ that address the volatility and Backus–Smith puzzles also raise the persistence of the real exchange rate has been noted before—see for example Corsetti et al. (2008a)—but is not usually rationalized. Indeed it is not straightforward to come up with a convincing economic argument as to why the persistence of the terms of trade (and by construction the real exchange rate) should rise so dramatically for certain low values of θ. Section 6 analyzes the robustness of the persistence of the terms of trade further by, among others, stripping out any persistence from the shock process, and changing the structure of the asset market.

4. CALIBRATION

Countries Home and Foreign are of the same size, and are symmetric in terms of their deep structural parameters. The parameter ρ from the utility function (risk aversion) is the same for consumption and leisure. To avoid biasing the results through the functional form assumption of the utility function, the simplest functional form, log-utility, is chosen for the baseline calibration.[4] The baseline calibration assumes moderate amounts of consumption home bias, $v = (1 - v^*) = 0.88$, which corresponds to the share of home-produced traded goods in the U.S. consumption basket and complete specialization in the production of the final investment good, $\varphi = (1 - \varphi^*) = 1$. The latter assumption is unrealistic, but commonly used in the literature [see Corsetti et al. (2008b)], and in the sensitivity analysis below φ is allowed to differ from unity. Following Benigno and Thoenissen (2008), the intratemporal elasticity of substitution between home- and foreign-produced intermediate goods in consumption, θ, is set to 2. τ, the intertemporal elasticity of substitution between home and foreign intermediate goods in investment goods, is set to 1. As there is no clear empirical evidence on this parameter, several different values have been examined. The results are robust to changing τ. As is common in the real business cycle literature, such as Hansen (1985), the share of labor in production is set to 0.64 and a 2.5% depreciation rate of capital per quarter is assumed. There is considerable uncertainty regarding the curvature of the investment adjustment cost function $s''(.)$. Christiano et al. (2005), who first proposed this specification, interpret $1/s''(.)$ as the elasticity of investment with respect to a 1% temporary increase in the current price of installed capital. Their empirical evidence suggests a value of $s''(.) = 2.5$. Smets and Wouters (2004) estimate this parameter using Bayesian techniques in the context of a model of the U.S. economy. Their median estimate is around 6. Enders and Müller (2009) estimate $s''(.)$ in an international real–business cycle model, driven only by productivity shocks. Their estimates are between zero and 0.4. Groth and Kahn (2007) look at disaggregated data for the United Kingdom and the United States and for the United States find a value of κ of 0.17, much lower than Christiano's estimate based on aggregate data. Given this uncertainty in the literature, I have chosen to set κ to 0.1. This is deliberately small, thus ensuring that the results of the model are not unduly influenced by a parameter for which the literature does not have a consistent value. This value of $s''(.)$ allows the calibrated model to come close to matching the relative volatility of investment to GDP.[5]

The stochastic process for TFP is taken from the seminal work of Backus et al. (1995) on international real business cycles. The home country in this calibration is assumed to be the United States. Matrix $V[\mu]$ in Table 1 shows the

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TABLE 2. Second moments

	Data	Baseline	VP$^+$	VP$^-$	B-SP$^+$	B-SP$^-$	QA$^+$	QA$^-$	Min$^+$	Min$^-$
σ_y	1.57	1.42	1.40	1.38	1.40	1.39	1.42	1.38	1.40	1.38
σ_c/σ_y	0.78	0.48	0.47	0.63	0.47	0.52	0.68	0.68	0.47	0.63
σ_x/σ_y	3.18	2.63	2.71	2.65	2.72	2.68	2.79	2.64	2.71	2.65
σ_{rs}/σ_y	3.04	*0.21*	1.30	1.30	*1.39*	*0.18*	**4.09**	1.71	1.38	1.32
σ_t/σ_y	1.71	*0.28*	**1.71**	**1.71**	**1.83**	*0.24*	*5.39*	**2.25**	**1.82**	**1.74**
$\rho(y, y^*)$	0.53	*0.11*	*0.13*	**0.16**	*0.13*	*0.15*	**0.10**	**0.17**	*0.13*	**0.17**
$\rho(c, c^*)$	0.30	*0.83*	*0.95*	**0.10**	*0.94*	*0.60*	**−0.11**	**−0.052**	*0.94*	**0.09**
$\rho(rs, c\text{-}c^*)$	−0.45	*0.99*	**−0.27**	**−0.97**	**−0.45**	**−0.45**	**−0.99**	**−0.98**	**−0.44**	**−0.97**
$\rho(nx, y)$	−0.51	*0.53*	**−0.53**	**−0.56**	**−0.52**	**−0.55**	**−0.43**	**−0.56**	**−0.53**	**−0.56**
ρ_{rs}	0.81	*0.30*	**0.65**	**0.78**	**0.66**	**0.73**	**0.70**	**0.76**	**0.66**	**0.77**
ρ_A	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69

Notes: VP = volatility puzzle, VP(+) $\theta = 0.4702$, VP(−) $\theta = 0.4109$; B-SP = Backus–Smith puzzle, B-SP(+) $\theta = 0.4676$, B-SP(−) $\theta = 0.3242$; QA = quantity anomaly, QA(+) $\theta = 0.4455$, QA(−) $\theta = 0.4163$; Min = minimize the weighted sum on the three puzzles, Min(+) $\theta = 0.4678$, Min(−) $\theta = 0.4113$.
Baseline $\theta = 2$. A "+" ("−") indicates an equilibrium with positive (negative) international transmission of productivity shocks

variance–covariance matrix of our shock processes, and matrix Ω their first-order autocorrelation coefficients.

5. FOUR PUZZLES—ONE ANSWER?

Table 2 shows Hodrick–Prescott filtered quarterly data for the United States economy and for the model economy under various calibrations. The baseline international real–business cycle model, where the intratemporal elasticity of substitution $\theta = 2$, departs from the data in a number of ways. First, under this calibration, the model fails to generate sufficient volatility in relative prices. In the data, the consumer price index–based real exchange rate is 3.04 and the terms of trade are 1.71 times as volatile as GDP. The baseline model generates series for the real exchange rate and the terms of trade that are 0.21 and 0.28 times as volatile as GDP, respectively. In the literature this discrepancy between model and data is called the volatility puzzle. The second dimension along which this model departs from the data is the cross correlation between the real exchange rate and relative consumption at home and abroad. In the data, this cross correlation is small and often negative, −0.45, for this data sample, indicating a low level of international risk-sharing. In the baseline model, this correlation is close to unity, suggesting near-complete risk-sharing. This difference between model and data is sometimes called the Backus–Smith puzzle after Backus and Smith (1993), or the consumption real–exchange rate anomaly, following Chari et al. (2002). The third dimension along which the model departs from the data is the ranking of the international cross correlations of GDP and consumption. In the data, the correlation between home and foreign GDP is higher than that between home and foreign consumption; in the data sample, the difference is 0.23. In the baseline model, consumption is more highly correlated with its foreign counterpart than is GDP, the difference amounting to −0.72. Following Backus et al. (1995), this is often called the quantity anomaly. Finally, the persistence of the real exchange rate, measured by its first-order autocorrelation coefficient, is less than half that of the data and net trade is procyclical, as opposed to countercyclical in the data.

Backus et al. (1995) point out that the relative volatility of the terms of trade, and by construction that of the real exchange rate in this model, rises as the intratemporal elasticity of substitution between home- and foreign-produced goods declines. Therefore, a natural way to improve the fit of the model is to calibrate θ to match the relative volatility of the terms of trade. Corsetti et al. (2008b) show that there will be two values of θ that will allow us to match this second moment. The first value of θ is found by reducing the parameter from its baseline value of 2. The column labeled VP^{+} in Table 2 reports on the second moments generated by this calibration. Numbers appearing in bold type indicate a statistic that has significantly improved vis-à-vis the baseline calibration. Here, a low elasticity of substitution between home- and foreign-produced goods in final consumption results in large changes in the relative price for a given productivity shock. The model generates a large depreciation of the terms of trade and thus the real exchange rate following a rise in the home country's TFP. Calibrating the model in this way also turns out to resolve the Backus–Smith puzzle, as the real exchange rate and relative consumption are now negatively correlated. A trade elasticity of somewhat below unity also implies a countercyclical trade balance. For this calibration, the terms of trade/real exchange rate also displays realistic levels of persistence. Where the model continues to depart from the data in a serious way is in the ranking of cross-country correlations. Because with this calibration, a home productivity increase is associated with a large real depreciation that shifts purchasing power from home to foreign consumers, consumption across countries will be highly correlated.

The second value of θ that allows the model to match the relative volatility of the terms of trade is found by increasing the elasticity from the neighborhood of zero. The column in Table 2 labeled VP^{-} reports the selected second moments for this calibration. Here, an increase in home TFP leads to a large appreciation (fall) in the terms of trade that shifts purchasing power from foreign to home agents. Corsetti et al. (2008b), who first pointed out this behavior of the terms of trade, refer to this as "negative transmission." Table 2 suggests that for this calibration the model addresses all of the baseline model's major short comings. In addition to matching the relative volatility of the terms of trade, the model also appears to solve the Backus–Smith puzzle (although the correlation is now arguably too negative), the quantity anomaly, and the persistence puzzle and generates a countercyclical trade balance.

The columns labeled B-SP and QA report calibrations of θ that aim to match the cross correlation between the real exchange rate and relative consumption and the difference between the cross-country correlations between home and foreign GDP and consumption, respectively. Two values of θ, one for the positive and

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one for the negative transmission case, are reported. In each case, resolving one anomaly also addresses at least one if not two other anomalies.

The last two columns of Table 2 report results from a calibration strategy that aims to minimize the loss arising from a equal weighting of the model discrepancy from (i) the relative volatility, (ii) the correlation between the real exchange rate and relative consumption, and (iii) the difference between the cross-country correlations between GDP and consumption. The results, particularly for the negative transmission case, are encouraging for the model. The terms of trade are as volatile as in the data, and relative consumption and the real exchange rate are negatively correlated, but the correlation is too high in absolute value, GDP is more highly correlated across countries than is consumption, net trade is countercyclical, and the real exchange rate is almost as persistent as in the data.

6. HOW ROBUST ARE THESE RESULTS?

The notes to Table 2 suggest that the parameter space of θ that helps the model to address the main international macro puzzles is quite narrow, ranging from 0.3242 to 0.4702. Figure 1 plots the relative volatility of the terms of trade (denoted by

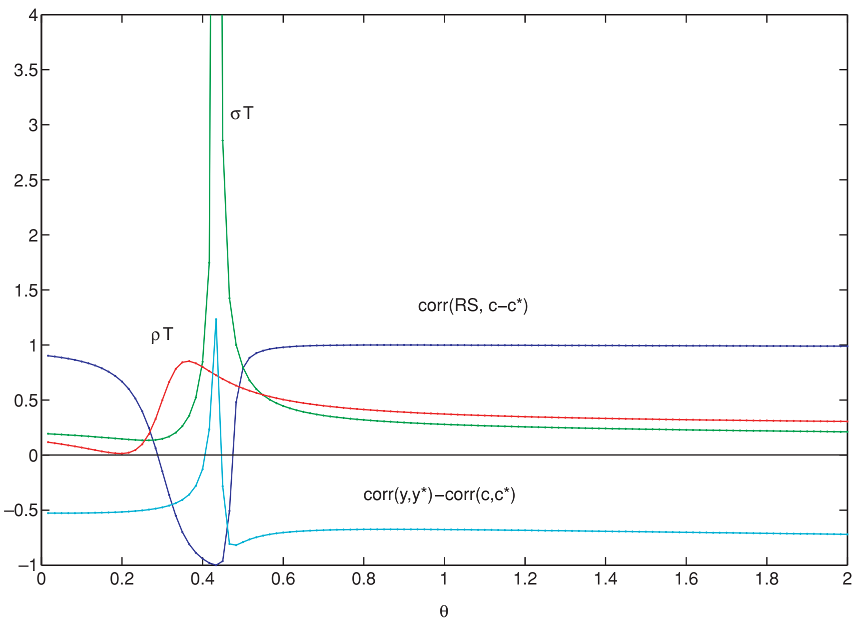

FIGURE 1. The volatility of the terms of trade relative to GDP, the correlation between the real exchange rate and relative consumption, the difference in the cross-country correlations between GDP and consumption, and the first-order autocorrelation coefficient of the terms of trade for various values of the elasticity of substitution, θ, from 0.05 to 2.00.

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σT), the Backus–Smith correlation [denoted by corr(RS, c-c^*)], and the difference between corr(y,y^*) and corr(c,c^*), as well as the persistence of the terms of trade (dented by ρT) for values of θ from close to zero to 2. For most values of θ, including very small ones, the model fails to address any of the major international macroeconomics puzzles. Only in a narrow range centered around $\theta = 0.45$ does the model perform well. Outside this region, the terms of trade are not volatile or persistent enough, consumption is more highly correlated with its foreign counterpart than is GDP, and the correlation between the real exchange rate and relative consumption is positive and close to unity.

The implication of Figure 1 is that the success of the model is limited to a very specific region of the parameter space. The following sections illustrate that the choice of θ for which the model performs well is sensitive to, among other parameters, the degree of consumption home bias and the composition of investment goods.

6.1. The Role of Consumption Home Bias

Heathcote and Perri (2002), although using a model similar to the current one, find only one value of θ that allows the model to match a given volatility of the terms of trade. A key feature of Heathcote and Perri's model is a lack of consumption home-bias. As is well known from Corsetti et al. (2008b), the value of θ that corresponds to the volatility spike is an increasing function of the degree of home bias. The greater the degree of consumption home bias, the larger the values of θ that correspond to data-congruent levels of relative price volatility. This suggests that the volatility of the terms of trade is quite sensitive to the degree of consumption home bias. The implication is that empirically observing a sufficiently low level of θ is not sufficient on its own for the model to generate high levels of relative price volatility. It is important to observe the correct level of consumption home bias, as well as the right level of θ.

6.2. Composition of Investment Goods

This section analyzes the role of the composition of investment goods. The IRBC literature is broadly arbitrary in its treatment of investment goods. The baseline specification assumes that all investment is undertaken using home-produced goods, an assumption also made in Benigno and Thoenissen (2008). Assume instead that investment goods (x) are produced with the aid of home- and foreign-produced intermediate goods (x_H and x_F) in the following manner:

$$x = \left[\varphi^{\frac{1}{\tau}} x_H^{\frac{\tau-1}{\tau}} + (1-\varphi)^{\frac{1}{\tau}} x_F^{\frac{\tau-1}{\tau}}\right]^{\frac{\tau}{\tau-1}}. \quad \textbf{(22)}$$

The investment goods producer's maximization yields the following investment-demand functions and price index:

$$x_H = \varphi \left(\frac{P_H}{P_x}\right)^{-\tau} x, \quad x_F = (1-\varphi)\left(\frac{P_F}{P_x}\right)^{-\tau} x, \quad \textbf{(23)}$$

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$$P_{x,t}^{1-\tau} = \left[\varphi P_{H,t}^{1-\tau} + (1-\varphi) P_{F,t}^{1-\tau}\right]. \quad \textbf{(24)}$$

The investment good's price index is a function of home- and foreign-produced intermediate goods prices. The price of investment relative to consumption goods differs from unity because φ, the share of home-produced intermediate goods in the home final-investment good, can differ from v, the share of home-produced intermediate goods in the final consumption good. The price of investment goods, relative to the price of consumption goods, $P_{x,t}/P_t$, is a function of the terms of trade. This can be illustrated by taking a log linear approximation of the investment price index,

$$\frac{P_{x,t}}{P_t} = \frac{P_{x,t}}{P_{H,t}} \frac{P_{H,t}}{P_t}, \quad \textbf{(25)}$$

around its steady state value, making use of the investment and consumption goods price indices:[6]

$$\widehat{\frac{P_{x,t}}{P_t}} = (v - \varphi)\hat{T}_t. \quad \textbf{(26)}$$

This shows that the log deviation of the price of investment goods from its steady state value is a linear function of the log deviation of the terms of trade from its steady state value. If home bias for investment goods is stronger (weaker) than for consumption goods, $v < \varphi$ ($v > \varphi$), then the price of investment goods is negatively (positively) related to the terms of trade.

Figures 2 and 3 analyze the case where the degree of home bias in investment is either somewhat lower than in consumption, $\varphi = 0.75$, or absent altogether, $\varphi = 0.5$. This small change in the structure of the model turns out to be of some importance. In Figures 2 and 3, the terms of trade are somewhat less volatile than the data throughout the range of θ, but the correlation between the real exchange rate and relative consumption is positive and close to unity throughout. The volatility of the terms of trade is also not significantly affected by the choice of θ. Interestingly, GDP across borders is more highly correlated than consumption in the no–home bias case (Figure 3), thus addressing the quantity anomaly, whereas in the low–home bias case (Figure 2), the ordering of the correlations is the other way around.[7]

6.3. Negative International Transmission of Productivity Shocks

One of the most interesting features of the model is that for a range of sufficiently small values of θ, the mechanism of international transmission of productivity shocks is reversed. Contrary to standard theory, negative transmission implies that a rise in home productivity is associated with a fall (appreciation) in the terms of trade. Instead of helping to share country-specific risk arising from productivity shocks, terms of trade movements actually hinder risk sharing, by amplifying the effects of a productivity shock. Recent work by Corsetti et al. (2008a, 2008b) and Enders and Müller (2009) has highlighted the phenomenon

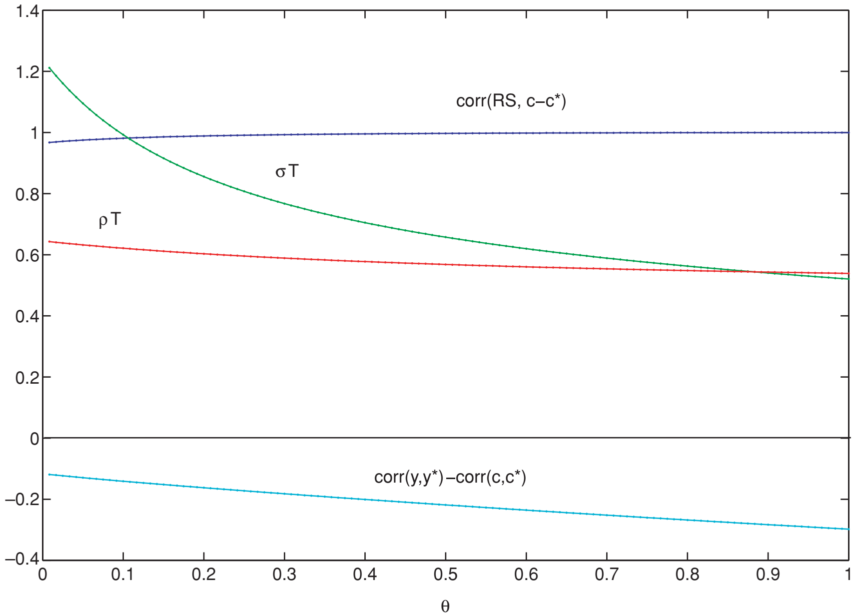

FIGURE 2. Same experiment as in Figure 1, assuming domestic investment is 75% made up of home-produced intermediate goods $\psi = 0.75$.

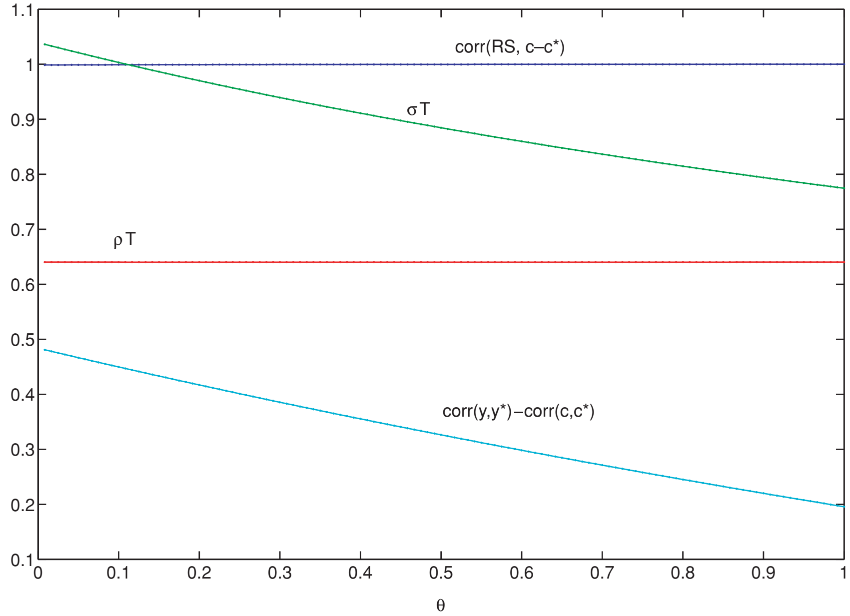

FIGURE 3. Same experiment as in Figure 1, assuming no home bias in investment goods.

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of negative transmission and its ability to help explain some key puzzles of international macroeconomics. The simple IRBC model's ability to address some of the key international macroeconomics puzzles having been shown quite sensitive to the precise choice of θ, this section analyzes how robust the phenomenon of negative transmission is to changes in θ and to changes in the structure of the model.

For illustrative purposes, consider an endowment version of the model with financial autarky. Combining the log linearized home and foreign intermediate goods sectors' market-clearing conditions with the log linearized home country's budget constraint, one can derive the following relationship between relative endowments of output and the terms of trade:

$$\hat{T}_t = \frac{\hat{y}_t - \hat{y}_t^*}{[1 - 2v(1-\theta)]}. \tag{27}$$

It follows that the correlation between relative output and the terms of trade will be negative, so that relative supply shocks result in terms-of-trade appreciations, for all values of $\theta < \frac{2v-1}{2v}$. Thus in an endowment economy under autarky, negative transmission occurs for all values of θ less than this threshold.[8]

Next, keep the financial autarky assumption, but reintroduce the supply side of the model:

$$(1-v)[\hat{y}_t - \hat{y}_t^*] - \frac{x}{y}(\varphi - v)[\hat{x}_t - \hat{x}_t^*]$$
$$= (1-v)\left(1 - \frac{x}{y}\right)[1 - 2v(1-\theta)]\hat{T}_t + \frac{x}{y}(1-\varphi)[1 - 2(v - \varphi\tau)]\hat{T}_t. \tag{28}$$

The resulting expression suggests that the relationship between relative output and the terms of trade also depends on the elasticity of substitution between home- and foreign-produced investment goods, τ, on the share of home-produced investment goods in total investment, φ, and on the dynamics of relative investment. This more complex relationship no longer guarantees negative transmission for sufficiently small values of θ.

An interesting special case arises if $v = \varphi$. This case illustrates the role of the elasticity of substitution between home and foreign intermediate inputs in investment, τ:

$$[\hat{y}_t - \hat{y}_t^*] = \left\{\left(1 - \frac{x}{y}\right)[1 - 2v(1-\theta)] + \frac{x}{y}[1 - 2v(1-\tau)]\right\}\hat{T}_t. \tag{29}$$

The range of θ that allows the model to generate negative transmission becomes larger if $\theta > \tau$, and smaller if $\theta < \tau$. For sufficiently large values of τ, there is no positive value of θ that allows the model generate a negative transmission mechanism.

Figure 4 plots a selection of second moments generated by the model for the baseline calibration but under the assumption of financial autarky for values of θ

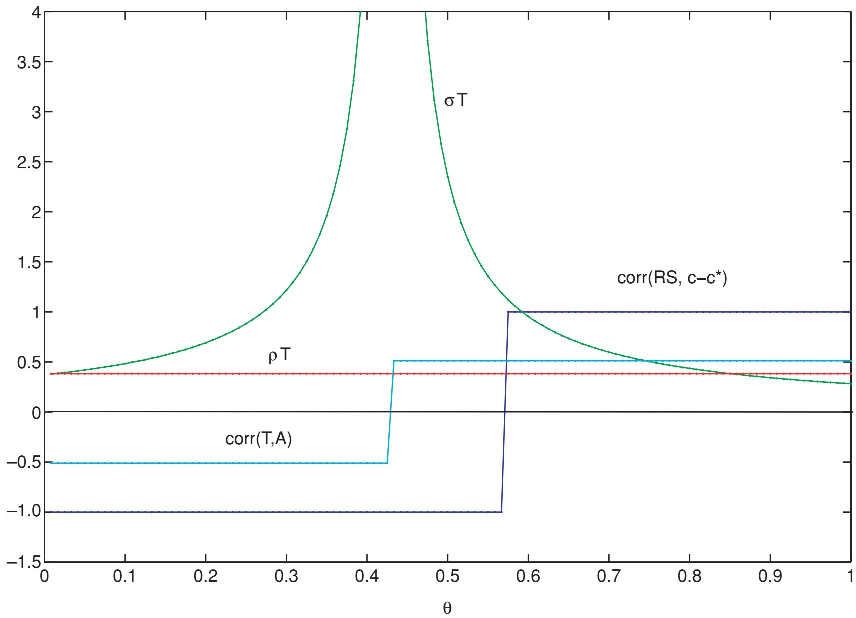

FIGURE 4. The volatility of the terms of trade relative to GDP, the correlation between the real exchange rate and relative consumption, the first-order autocorrelation coefficient of the terms of trade, and the correlation between home country TFP and the terms of trade (as a proxy for international shock transmission) for various values of θ in a model with financial autarky.

from 0.05 to 1.00. The line labeled corr(T, A) shows the cross-correlation between the terms of trade and domestic TFP, which is used as a proxy for international transmission. A positive correlation implies that the terms of trade depreciate (rise) following an increase in home TFP, the conventional international transmission mechanism. A negative correlation implies that the terms of trade appreciate (fall) following an increase in home TFP, negative transmission. Figure 4 shows that under the assumption of financial autarky, the international transmission of productivity shocks is negative for all positive values of θ below the cutoff point.

It can easily be shown that negative transmission is not possible under a complete financial market structure. The risk-sharing condition arising under complete financial markets rules out wealth effects and puts a restriction on the relative movements of the terms of trade and relative consumption in our model. In log linearized form, the risk-sharing condition implies the following link between the terms of trade and relative consumption:

$$\widehat{RS}_t = (v - v^*)\hat{T}_t = \rho(\hat{C}_t - \hat{C}_t^*). \tag{30}$$

Under complete financial markets, a terms-of-trade appreciation (fall) can only occur if relative consumption falls, but an appreciation of the terms of trade

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is associated with a rise, not a fall in relative consumption. Proceeding as in the autarky case, one can derive the following expression for relative output (productivity) and the terms of trade:

$$\hat{T}_t = \frac{\hat{y}_t - \hat{y}_t^*}{4\theta v(1-v) + \frac{(2v-1)^2}{\rho}}, \quad (\mathbf{31})$$

where the denominator is positive for all positive values of θ.[9]

Somewhere in between the assumption of financial autarky and that of the presence of a complete set of state-contingent claims lies the incomplete–financial markets assumption implicit in the baseline model of this paper. With only one tradable bond, the expression corresponding to (27) and (31) becomes

$$\hat{y}_t - \hat{y}_t^* = \left[4\theta v(1-v) + \frac{(2v-1)^2}{\rho}\right]\hat{T}_t - \frac{(2v-1)^2}{\rho}E_t\hat{T}_{t+1} + (2v-1)E_t(\hat{C}_{t+1} - \hat{C}_{t+1}^*), \quad (\mathbf{32})$$

where the link between relative supply (productivity) and the terms of trade is rather more complex than in either the autarky or the complete markets case. Figure 5 shows that for the baseline model with incomplete financial markets, negative transmission is confined to a narrow range of the parameter space between $\theta = 0.45$ and $\theta = 0.30$. For values of θ below 0.30, the short-run transmission mechanism is once again positive. Implicitly, the home-country income effect is not strong enough to require the terms of trade to appreciate following a home-country supply shock. Instead, short-term depreciation is sufficient to clear the market for home-produced goods. In this model, negative transmission does not occur for all values of θ below a defined cutoff as in the autarky model, but is limited to a narrow range of θ.

A tentative conclusion one can draw from this analysis is that in this simple IRBC model the phenomenon of negative international transmission of supply shocks is much less general than would be the case in an endowment economy under financial autarky.

6.4. A Real Exchange Rate Persistence Puzzle

In the baseline calibration ($\theta = 2$) of the model, the persistence of the real exchange rate is less than half of what it is in the data. For values of θ that address the volatility puzzle, the Backus–Smith puzzle, or the quantity anomaly, however, the model generates quite realistic levels of relative price persistence.

Figure 1 plots the persistence of the real exchange rate (terms of trade) for different values of θ. The graph suggests that persistence is high, and thus data are congruent only in the region of the parameter space where the model also generates negative transmission (to the left of the volatility spike). In contrast, Figures 2

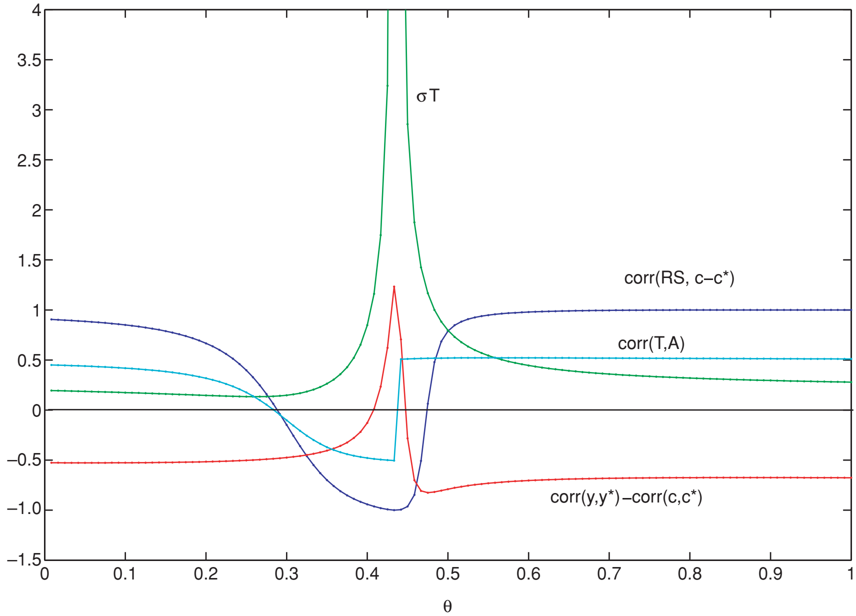

FIGURE 5. The volatility of the terms of trade relative to GDP, the correlation between the real exchange rate and relative consumption, the difference in the cross-country correlations between GDP and consumption, and the correlation between home country TFP and the terms of trade (as a proxy for international shock transmission) for various values of θ in the baseline model.

and 3 suggest that for calibrations where the model does not generate negative transmission, the persistence of the terms of trade is largely invariant to the choice of θ. Figure 4 also suggests that in the absence of an international bond market, the persistence of the terms of trade is also low and invariant to the choice of θ.

Given that the persistence of the real exchange rate in Table 2 is quite close to the first-order autocorrelation coefficient of the productivity process, it is worth checking if the persistence of the real exchange rate is driven by the persistence of the driving process. Figure 6 repeats the analysis from Figure 1, assuming zero persistence and no cross-country spillovers in the driving process; i.e.,

$$\Omega = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \quad \text{and} \quad V[\mu] = 10^{-4} \begin{bmatrix} 0.726 & 0 \\ 0 & 0.726 \end{bmatrix}.$$

With white noise TFP shocks, the persistence of the Hodrick–Prescott filtered time series for the terms of trade, and thus the real exchange rate is negative for most values of θ. For values of θ that generate high relative-price volatility, the real exchange rate also displays realistic levels of persistence. The transmission mechanism of supply shocks is negative when persistence is high, and positive elsewhere. Given that all that is driving the model is nonpersistent supply shocks,

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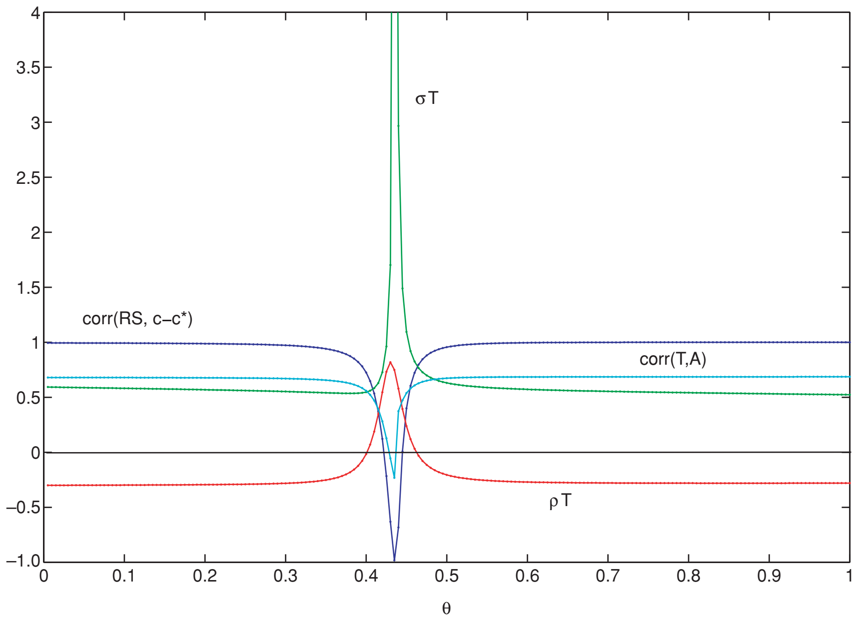

FIGURE 6. The volatility of the terms of trade relative to GDP, the correlation between the real exchange rate and relative consumption, the first-order autocorrelation coefficient of the terms of trade, and the correlation between home country TFP and the terms of trade (as a proxy for international shock transmission) for various values of θ in the model driven by white noise TFP shocks.

it is not entirely clear what the economic rationale is for the high persistence of the terms of trade.[10]

In summary, the baseline flexible-price model can generate high levels of real exchange/terms-of-trade persistence. However, sensitivity analysis suggests that high persistence is a feature of the incomplete markets model, not present either in complete-markets models or under financial autarky, and occurs only for certain values of θ regardless of the persistence of the shock process. As there are no obvious strong internal propagation mechanisms, the persistence of relative prices generated by the model represents somewhat of a puzzle.

7. CONCLUSION

This paper starts with the premise that given a careful choice of parameters, a simple flexible-price international real–business cycle model is able to address a number of hitherto puzzling discrepancies between data and models. Specifically, I show that a simple one-sector, two-country incomplete–financial markets IRBC model can generate volatile and persistent time series for the terms of trade and the real exchange rate, can generate a negative cross-correlation between the real exchange rate and relative consumption, thus addressing the Backus–Smith puzzle, and can address the quantity anomaly whereby the consumption has a higher cross-country correlation than GDP. The key parameter that enables the model to address all these puzzles is the elasticity of substitution between home- and foreign-produced intermediate goods, θ.

The main contribution of this paper is not, however, to highlight the success of the model, but to point out how sensitive the model's results are to the choice of parameters and model structure. The model performs in a data congruent fashion only in a narrow range of θ. Finding empirical support for one's choice of θ in this range is, however, not sufficient to justify the model. I show that the range of θ for which the model "behaves well" is itself a function of the degree of consumption home bias and the composition of investment demand, as well as the asset market structure.

For certain values of θ the model is able to generate a "negative" international transmission of supply shocks. Here the terms of trade appreciate following a transitory increase in the home country's TFP. The phenomenon of negative transmission has recently and prominently been credited with solving a number of open-economy puzzles. In this paper, I show that under incomplete financial markets, negative transmission is confined to an even narrower range of θ than the range that solves the terms-of-trade volatility puzzle or the Backus–Smith puzzle. Indeed, if firms display less home bias in their choice of investment goods than consumers do in their choice of consumption goods, or if home and foreign investment goods are more substitutable than consumption goods, then it is possible that no positive value of θ will generate negative transmission.

A puzzling aspect of the model analyzed in this paper is the fact that values of θ that solve the volatility puzzle or the Backus–Smith puzzle also tend to generate high levels of real–exchange rate persistence. The persistence result holds even if the model is driven only by nonpersistent white noise TFP shocks, but only in the incomplete markets model. Under financial autarky or under complete markets, the persistence of relative prices is largely invariant to the choice of θ.

As a critique of the literature that promotes low trade elasticities as a solution to a number of macro puzzles, the model presented in this paper is only partially suited. Low trade elasticities can be achieved not just through low values of θ, but also if home- and foreign-produced intermediate goods have to be combined with locally produced nontraded goods in order to reach the final consumer. It is possible that such a model's ability to capture key stylized facts of the international business cycle is more robust to changes in key parameters than is the case in the simple model presented here.

NOTES

1. It is easy to show that whereas the function $F(x) = [1 - s(x_t/x_{t-1})]x_t$ is not concave for all values of x, it is so in the vicinity of the steady state; thus the problem is standard in the sense that

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the conditions (16)–(18) plus the constraint and the relevant terminal conditions are necessary as well as sufficient. When approaching steady state $\frac{x_t}{x_{t-1}} \rightarrow 1$ and $F(x^*) \rightarrow x^*$; thus the steady state of $[1 - s(\frac{x_t}{x_{t-1}})]x_t \rightarrow x^*$ and can thus be represented by a 45° line. It is easy to show that the 45° line is tangent to the function $[1 - s(\frac{x_t}{x_{t-1}})]x_t$, where $[1 - s(\frac{x_t}{x_{t-1}})]x_t$ is concave. Indeed, the inflection point will always be to the left of the steady-state value of $x^* = 1$.

2. If consumption home bias is symmetric, i.e., if $v^* = 1 - v$, then degree of home bias can be expressed as $2v - 1$.

3. The model can also generate countercyclical trade balances for large values of θ if preferences are assumed to be of the GHH kind, which eliminates the wealth effect of consumption in labor supply.

4. The Backus–Smith correlation, defined as the correlation between relative consumption and the real exchange rate, for instance is more easily addressed by models of this type if consumption and leisure are nonseparable.

5. The working paper version, Thoenissen (2008), reports sensitivity analysis to ascertain whether the results of this paper are robust to the choice of $s''(.)$.

6. We make use of the consumption and investment goods price indices and normalize the price of home-produced traded goods so that in the steady state $P_H = P_F$. Because the law of one price holds, we can define the terms of trade as $T = P_F/P_H$.

7. The working paper version of this paper, Thoenissen (2008), reports additional sensitivity analysis of varying τ.

8. This expression shows why Heathcote and Perri (2002) did not detect a negative transmission mechanism of supply shocks when analyzing the effects of varying θ in their financial autarky model. Without consumption home bias, $v = 1/2$ and thus the transmission mechanism is positive for all positive values of θ.

9. One can easily check that when $\theta = \rho = 1$ the autarky model responds the same as the complete markets model. See the Appendix of the working paper version for derivations.

10. The working paper version of this paper, Thoenissen (2008), analyzes the effects of allowing for greater adjustment costs as well as adopting capital, as oppsed to investment adjustment costs. The analysis suggest that the puzzling persistence is not a feature of the adjustment-cost parameter or how one models adjustment costs.

REFERENCES

Backus, D.K., P.J. Kehoe, and F.E. Kydland (1994) Dynamics of the trade balance and the terms of trade: The J-curve? *American Economic Review* 84, 84–103.

Backus, D.K., P.J. Kehoe, and F.E. Kydland (1995) International business cycles: Theory and evidence. In Thomas F. Cooley (ed.), *Frontiers of Business Cycle Research*, pp. 331–356. Princeton, NJ: Princeton University Press.

Backus, D.K. and G.W. Smith (1993) Consumption and real exchange rates in dynamic economies with non-traded goods. *Journal of International Economics* 35, 297–316.

Benigno, G. and C. Thoenissen (2008) Consumption and real exchange rates with incomplete financial markets and non-traded goods. *Journal of International Money and Finance* 27, 926–948.

Chari, V.V., P.J. Kehoe, and E.R. McGrattan (2002) Can sticky price models generate volatile and persistent real exchange rates? *Review of Economic Studies* 69, 633–663.

Christiano, L.J., M. Eichenbaum, and C. Evans (2005) Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy* 113, 1–45.

Cole, H. and M. Obstfeld (1991) Commodity trade and international risk sharing: How much do financial markets matter? *Journal of Monetary Economics* 28, 3–24.

Corsetti, G., L. Dedola, and S. Leduc (2006) Productivity, external balance and exchange rates: Evidence on the transmission mechanism among G7 countries. In Lucrezia Reichlin and Kenneth West (eds.), *NBER International Seminar on Macroeconomics*, pp. 117–194. Chicago: Chicago University Press.

Corsetti, G., L. Dedola, and S. Leduc (2008a) High exchange-rate volatility and low pass-through. *Journal of Monetary Economics* 55, 1113–1128.

Corsetti, G., L. Dedola, and S. Leduc (2008b) International risk sharing and the transmission of productivity shocks. *Review of Economic Studies* 75, 443–473.

Enders, Z. and G.J. Müller (2009) On the international transmission of technology shocks. *Journal of International Economics* 78, 45–59.

Groth, C. and H. Kahn (2007) Investment Adjustment Costs: Evidence from UK and US Industries. Working paper 332, Bank of England.

Hansen, G.D. (1985) Indivisible labour and the business cycle. *Journal of Monetary Economics* 16, 309–327.

Heathcote, J. and F. Perri (2002) Financial autarky and international business cycles. *Journal of Monetary Economics* 49, 601–627.

King, R. and M. Watson (1998) The solution of singular linear difference systems under rational expectations. *International Economic Review* 39, 1015–1026.

Kollmann, R. (2006) Comment on "Productivity, external balance and exchange rates: Evidence on the transmission mechanism among G7 countries," by Corsetti et al. In Lucrezia Reichlin and Kenneth West (eds.), *NBER International Seminar on Macroeconomics*, pp. 117–194. Chicago: Chicago University Press.

Mendoza, E. (1991) Real business cycles in a small open economy. *American Economic Review* 81, 797–818.

Schmitt-Grohé, S. and M. Uribe (2003) Closing small open economy models. *Journal of International Economics* 61, 163–185.

Schmitt-Grohé, S. and M. Uribe (2004) Optimal Operational Monetary Policy in the Christiano–Eichenbaum–Evans Model of the U.S. Business Cycle. Mimeo, Duke University.

Smets, F. and R. Wouters (2004) Comparing shocks and frictions in US and euro area business cycles: A Bayesian DSGE approach. *Journal of Applied Econometrics* 20, 161–183.

Stockman, A.C. and L.L. Tesar (1995) Tastes and technology in a two-country model of the business cycle: Explaining international comovements. *American Economic Review* 85, 168–185.

Thoenissen, C. (2008) Exchange rate dynamics, asset market structure and the role of the trade elasticity. CDMA Working paper 08/03, St Andrews University.

Woodford, M. (2003) *Interest and Prices*. Princeton, NJ: Princeton University Press.

APPENDIX: DATA SOURCES

1. US quarterly data on the consumption-based real exchange rate, the terms of trade, and relative consumption are taken from Table 2A in Corsetti et al. (2008a).
2. GDP refered to in Table 2 real GDP per capita from BEA's NIPA Table 7.1. "Selected Per Capita Product and Income Series in Current and Chained Dollars," seasonally adjusted. The series was logged and H-P filtered.
3. Consumption referred to in Table 2 is total consumption expenditures deflated by the relevant GDP deflator, both from BEA's NIPA Tables 2.3.5 and 1.1.9.
4. Investment referred to in Tables 2 is real fixed investment per capita from BEA's NIPA Table 5.3.3, Real Private Fixed Investment by Type. Population is from NIPA Table 7.1.
5. The estimated Solow residual is taken from Backus et al. (1995), Table 11.3.