Can Self-Fulfilling Expectations Help Explain International Business Cycles?

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Abstract

Standard international real business cycle models perform poorly in their ability to match the quantitative properties observed for the terms of trade and net exports. Not only do these models counter-factually predict that net exports and the terms of terms are both pro-cyclical, they simultaneously generate volatilities that are significantly lower than the data. By allowing for indeterminacy we analyze whether endogenous fluctuations, so-called sunspot shocks, can help explain these anomalies. It is shown that a combination of technological and sunspot shocks can generate counter-cyclical net exports and terms of trade, while increasing significantly their volatilities. The major discrepancy with the data is the failure of the indeterminacy model to generate sufficient volatility for relative prices.

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1 Introduction

There are three puzzles in international business cycle fluctuations:

1. Consumption-output anomaly
2. Relative Price Anomaly
3. Consumption-real exchange rate anomaly

There is now a large literature that attempts to develop international business cycle models that can successfully mimic the empirical evidence.

Backus et. al (1992) find that international real business cycle models suffer from the consumption-output anomaly i.e. in the data cross-country output correlations are higher than cross-country consumption correlations. However the standard IRBC predicts that the opposite i.e. much higher consumption correlations and much lower output correlations. [also see

Backus et. al (1993) find a relative price anomaly i.e. variability of relative prices in the standard IRBC is too low relative to the data.

Examples: For the Consumption-real exchange rate anomaly, Chari, Kehoe and McGrattan (2002) show that changing the asset market assumption (i.e. removal of perfect financial markets) is not sufficient to replicate the observed evidence. Benigno and Thoenissen (2007) show that adding a non-traded goods sector with an incomplete asset market structure might account for this anomaly.

In regards to using sunspot shocks to explain these puzzles, the existing literature has focused on the consumption-output anomaly. Guo and Sturzenegger (1998) and Xiao (2004) find that sunspot shocks can account for this anomaly. However there are a number of weaknesses with these studies. Both studies consider one good economies. Guo and Sturzenegger (1998) requires a level of increasing returns to generate sunspots which is not supported by the empirical literature.

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The remainder of the paper is organized as follows. Section 2 outlines the two-country indeterminacy model. The solution technique and model parameterization are discussed in Section 3. Section 4 presents and discusses the simulation results. Section 5 considers model performance with relation to the real exchange rate. Finally, Section 6 concludes.

2 Model

Consider a global economy that consists of two countries denoted home and foreign. Within each country there exists a representative agent, two final good producers and a continuum of intermediate good producing firms. Intermediate firms operate under monopolistic competition and use domestic labor and capital as inputs to produce tradeable goods. The competitive final good producers use domestic and imported intermediate goods to produce non-tradeable consumption or investment goods, which are subsequently purchased by the domestic agent. However, final good producers are assumed to have a bias for domestically produced intermediate goods. While the law of one price is assumed to hold for all intermediate goods, with *home bias*, the real exchange rate deviates from purchasing power parity. The following presents the features of the model for the home country on the understanding that the foreign case can be analogously derived. All foreign variables are denoted by an asterisk.

2.1 Final good producers

In each country, there are two final goods, consumption and investment, which are produced with homogenous of degree one production functions, using the intermediate goods as the only inputs. The home consumption final good (C) is produced by a competitive firm that uses C_H and C_F as inputs according to the following CES aggregation technology index:

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

where the constant elasticity of substitution between aggregate home and foreign intermediate goods is $\theta > 0$ and the relative share of domestic and imported intermediate inputs used in the production process is $0 < a < 1$. The home investment final good (I) is produced according to the following CES aggregation technology index:

$$I_t = \left[b^{\frac{1}{\rho}} I_{H,t}^{\frac{\rho-1}{\rho}} + (1-b)^{\frac{1}{\rho}} I_{F,t}^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{2}$$

where $\rho > 0$ and $0 < b < 1$. The inputs C_H, C_F, I_H and I_F are defined as the quantity indices of domestic and imported intermediate goods respectively:

$$C_{H,t} = \left[\int_0^1 c_t(j)^{\frac{\kappa-1}{\kappa}} dj\right]^{\frac{\kappa}{\kappa-1}}, \qquad C_{F,t} = \left[\int_0^1 c_t(j^*)^{\frac{\kappa-1}{\kappa}} dj^*\right]^{\frac{\kappa}{\kappa-1}},$$
$$I_{H,t} = \left[\int_0^1 i_t(j)^{\frac{\kappa-1}{\kappa}} dj\right]^{\frac{\kappa}{\kappa-1}}, \qquad I_{F,t} = \left[\int_0^1 i_t(j^*)^{\frac{\kappa-1}{\kappa}} dj^*\right]^{\frac{\kappa}{\kappa-1}},$$

where the elasticity of substitution across domestic (foreign) intermediate goods is $\kappa > 1$, and $c(j)$, $c(j^*)$, $i(j)$, $i(j^*)$ are the respective quantities of the domestic and imported type j and j^* intermediate goods. Intermediate firms sell their products to both final consumption and investment final good producers, where it is assumed that the law of one price holds. Cost minimization in final good production yields the aggregate demand conditions for home and foreign goods:

$$C_{H,t} = a\left(\frac{P_{H,t}}{P_t}\right)^{-\theta} C_t, \qquad C_{F,t} = (1-a)\left(\frac{P_{F,t}}{P_t}\right)^{-\theta} C_t, \tag{3}$$

$$I_{H,t} = b\left(\frac{P^I_{H,t}}{P^I_t}\right)^{-\rho} I_t, \qquad I_{F,t} = (1-b)\left(\frac{P^I_{F,t}}{P^I_t}\right)^{-\rho} I_t, \tag{4}$$

and the corresponding aggregate price indices are given by:

$$P_t = \left[aP_{H,t}^{1-\theta} + (1-a)P_{F,t}^{1-\theta}\right]^{\frac{1}{1-\theta}}, \quad P^I_t = \left[b(P^I_{H,t})^{1-\rho} + (1-b)(P^I_{F,t})^{1-\rho}\right]^{\frac{1}{1-\rho}}, \tag{5}$$

where P is the consumer price index, P^I is the price of investment goods and P_H, P_F, P^I_H, P^I_F are the respective price indices of home and foreign intermediate goods.

2.2 Intermediate goods producers

All intermediate firms have access to the same technology. A firm of type j has a production technology given by

$$Y_t(j) = Z_t\left(u_t K_t(j)\right)^{\alpha} L_t(j)^{\gamma} - \phi, \quad j \in [0,1] \tag{6}$$

where K and L represent capital and labor usage respectively, Z_t is an aggregate productivity shock with unconditional mean and the input share is $\alpha+\gamma \geq 1$. The rate of capacity utilization $u_t \in (0,1)$ is endogenously determined. Following Greenwood *et al.* (1988) it is assumed that the depreciation rate of capital δ_t is higher if it is used more intensively:

$$\delta_t = \frac{1}{\eta} u_t^{\eta}, \tag{7}$$

where $\eta > 1$. In addition, we also introduce a fixed cost of production $\phi > 0$. Therefore, regardless of how much output is produced, a proportion ϕ of the intermediate good is used up in each period. As in Schmitt-Grohe (1997), allowing for a fixed production cost enables the model to generate zero profits without imposing any restrictions on the size of the steady state markup.[1] Given competitive prices of labor and capital, cost-minimization yields:

$$w_t = \gamma mc_t(j) Z_t \left(u_t K_t(j)\right)^{\alpha} L_t(j)^{\gamma-1}, \tag{8}$$

$$rr_t + \delta_t = \alpha mc_t(j) Z_t u_t^{\alpha} K_t(j)^{\alpha-1} L_t(j)^{\gamma}, \tag{9}$$

$$u_t^{\eta} = \alpha mc_t(j) Z_t u_t^{\alpha} K_t(j)^{\alpha-1} L_t(j)^{\gamma}, \tag{10}$$

where mc_t is real marginal cost and w_t and $(rr_t+\delta_t)$ are the respective real wage and user cost of capital.

Given that the total demand for firm j's output can be expressed as:

$$Y_t(j) = \left(\frac{p_t(j)}{P_{H,t}}\right)^{-\kappa} \left[C_{H,t} + C_{H,t}^*\right] + \left(\frac{p_t(j)}{P_{H,t}^I}\right)^{-\kappa} \left[I_{H,t} + I_{H,t}^*\right],$$

it follows from the firm's profit maximization problem that the optimal price-setting rule is:

$$p_t(j) = \chi mc_t(j) P_t, \tag{11}$$

where $\chi \equiv \frac{\kappa}{\kappa-1}$ is the mark-up.

[1] As discussed by Rotemberg and Woodford (1996), Schmitt-Grohe (1997) and Jaimivich (2007), positive profits are not observed in the US economy despite the presence of market power.

2.3 Representative agent

The representative agent has an expected utility function of the form:

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

where C_t and L_t are consumption and work effort, and the discount factor is $0 < \beta < 1$. Following Greenwood *et. al* (1988) we assume that the period utility function is given by:

$$U(C, 1-L) = \frac{1}{1-\sigma}\left[\left(C_t - \frac{\psi}{1+\nu} L_t^{1+\nu}\right)^{1-\sigma} - 1\right],$$

where $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution in consumption, $\nu \geq 0$ is the intertemporal elasticity of substitution in labor supply and $\psi > 0$.

The agent during period t supplies labor and capital to the intermediate good producing firms, receiving real income from wages w_t, a rental return on capital rr_t and nominal profits from the ownership of domestic intermediate firms Π_t. The agent then uses these resources to purchase the two final goods, dividing purchases between consumption C_t and investment I_t. The purchase of an investment good forms next period's capital according to the law of motion

$$K_{t+1} = (1-\delta_t)K_t + I_t. \tag{12}$$

The asset market structure is assumed to be incomplete. The foreign agent is able to trade two non-state contingent bonds, $B^*_{H,t}$ and $B^*_{F,t}$, whereas the home agent can only purchase domestic bonds denoted by $B_{H,t}$. All bonds are denominated in units of the domestic aggregate consumption index. For the foreign agent, there is a transaction cost Ψ of purchasing the internationally traded bond $B^*_{H,t}$, where it is assumed that Ψ is a positive and differentiable function.[2] This transaction cost captures the costs of adjusting bond holdings and is sufficient to ensure that bond holdings and consumption are stationary.[3] Consequently, in real terms the period budget constraints of the home and foreign agent

[2]Following Benigno (2001), we assume that $\Psi = 1$ when bond holdings are at their steady state level, $B^*_{H,t} = \overline{B}^*_H$ and Ψ is strictly decreasing in the neighborhood of the steady state.

[3]For an in-depth discussion of the stationary problem of incomplete market, open-economy models, see Schmitt-Grohe and Uribe (2003) and Ghironi (2006).

can be expressed as:

$$\frac{B_{H,t}}{r_t} + C_t + \frac{P_t^I}{P_t} I_t \leq B_{H,t-1} + w_t L_t + (rr_t + \delta_t) K_t + \int_0^1 \Pi_t(j) d(j) + R_t, \tag{13}$$

$$\frac{B_{H,t}}{Q_t r_t} \frac{1}{\Psi(B^*_{H,t})} + \frac{B^*_{F,t}}{r^*_t} + C^*_t + \frac{P^{*I}_t}{P^*_t} I^*_t \leq \frac{B_{H,t-1}}{Q_t} + B^*_{F,t-1} + w^*_t L^*_t + (rr^*_t + \delta^*_t) K^*_t + \int_0^1 \Pi^*_t(j^*) d(j^*) + R^*_t, \tag{14}$$

where R_t and R^*_t denote rebates from financial firms, r_t and r^*_t denotes the home and foreign (gross) real interest rates, and Q_t denotes the the CPI-based real exchange rate.

The first-order conditions from the home agent's maximization problem yield:

$$U_c(C_t, L_t) = \left(C_t - \frac{\psi L_t^{1+\nu}}{1+\nu} \right)^{-\sigma} = \lambda_t \tag{15}$$

$$-\frac{U_L(C_t, L_t)}{U_c(C_t, L_t)} = \psi L_t^{\nu} = w_t \tag{16}$$

$$\lambda_t \frac{P_t^I}{P_t} = \beta E_t \lambda_{t+1} \left[rr_{t+1} + \delta_{t+1} + (1 - \delta_{t+1}) \frac{P_{t+1}^I}{P_{t+1}} \right] \tag{17}$$

$$\beta r_t E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \right] = 1, \tag{18}$$

where λ_t denotes the shadow price of wealth. Analogous conditions to (15)-(18) apply for the foreign agent, where the interest rate parity condition can be derived to yield:

$$r_t = \frac{r^*_t}{\Psi(B^*_{H,t})} E_t \left[\frac{Q_{t+1}}{Q_t} \right]. \tag{19}$$

Optimizing behavior implies that the budget constraints (13) and (14) hold with equality in each period and the appropriate transversality conditions are satisfied.

2.4 Market clearing and equilibrium

Market clearing requires that

$$Y_t = C_{H,t} + C^*_{H,t} + I_{H,t} + I^*_{H,t}, \tag{20}$$

and assuming that the foreign non-state contingent bond is in zero net supply, bond markets clearing requires that:

$$B_{H,t} + B^*_{H,t} = 0 \quad B^*_{F,t} = 0. \tag{21}$$

Finally, the aggregate resource constraint is given by:[4]

$$C_t + \frac{P^I_t}{P_t} I_t + \frac{B_{H,t}}{r_t} = B_{H,t-1} + \frac{P_{H,t}}{P_t} Y_t. \tag{22}$$

From the price indices (5) and their foreign equivalents, the following relative prices can be derived:

$$\frac{P^I_t}{P_t} = \frac{\left[b_H + (1-b_H)T_t^{1-\rho}\right]^{\frac{1}{1-\rho}}}{\left[a_H + (1-a_H)T_t^{1-\theta}\right]^{\frac{1}{1-\theta}}}, \tag{23}$$

$$\frac{P_{H,t}}{P_t} = \left[a_H + (1-a_H)T_t^{1-\theta}\right]^{\frac{1}{\theta-1}}, \tag{24}$$

$$T_t = \frac{\left[a_F + (1-a_F)T_t^{\theta-1}\right]^{\frac{1}{\theta-1}}}{\left[a_H + (1-a_H)T_t^{1-\theta}\right]^{\frac{1}{\theta-1}}} Q_t, \tag{25}$$

where T_t is the terms of trade.[5] Real net exports can be defined as the difference between exports and imports (evaluated at the steady state terms of trade $\overline{T}$):

$$NX_t = \frac{C^*_{H,t} + I^*_{H,t} - \overline{T}\left(C_{F,t} + I_{F,t}\right)}{C_{H,t} + C^*_{H,t} + I_{H,t} + I^*_{H,t}}. \tag{26}$$

We restrict our analysis to a symmetric equilibrium in which all intermediate firms produce the same quantity of their respective good $Y_t(j) = Y_t$ and prices of all intermediate goods are identical $p_t(j) = P_{H,t} = P^I_{H,t}$.

An equilibrium for the world economy consists of a set of real prices r_t, r^*_t, w_t, w^*_t, rr_t, rr^*_t, δ_t, δ^*_t, mc_t, mc^*_t, λ_t, λ^*_t; a set of relative prices $\frac{P_{H,t}}{P_t}$, $\frac{P^*_{F,t}}{P^*_t}$, $\frac{P^I}{P_t}$, $\frac{P^{*I}}{P^*_t}$, Q_t, T_t; a collection of allocations for the home and foreign agent C_t, C^*_t, I_t, I^*_t, L_t, L^*_t, K_t, K^*_t, u_t, u^*_t, $B_{H,t}$, $B^*_{H,t}$, $B^*_{F,}$; and a collection of allocations for home and foreign final and intermediate good producers Y_t, Y^*_t, $C_{H,t}$, $C_{F,t}$, $C^*_{H,t}$, $C^*_{F,t}$, $I_{H,t}$, $I_{F,t}$, $I^*_{H,t}$, $I^*_{F,t}$, NX_t satisfying (i) the optimality conditions of each agent; (ii) the optimality conditions of final and intermediate

[4] By Walras' Law, the aggregate resource constraint of the foreign country is redundant.

[5] The terms of trade T, is defined as: $T_t \equiv \frac{S_t P^*_{F,t}}{P_{H,t}} = \frac{P_{F,t}}{P_{H,t}}$ under the law of one price.

good producing firms; (iii) all markets clear; and (iv) the aggregate resource constraints of both countries.

2.5 Short-run dynamics and parameterization

2.5.1 The solution method

To solve the model, we log-linearize the equilibrium conditions around a symmetric deterministic steady state.[6] Letting a variable $\widehat{X}_t$ denotes the percentage deviation of X_t with respect to its steady state value $\overline{X}$, the linearized system yields an eight-dimensional system of difference equations:

$$\begin{bmatrix} S_{t+1} \\ \Lambda_{t+1} \end{bmatrix} = J \begin{bmatrix} S_t \\ \Lambda_t \end{bmatrix} + V \begin{bmatrix} \epsilon^z_{t+1} \\ \epsilon^s_{t+1} \end{bmatrix}, \tag{27}$$

where $S_t = \left[\widehat{K}_t, \widehat{K}^*_t, \widehat{b}_{H,t}, z_t, z_{t+1}\right]'$ is the state vector, $\Lambda_t = \left[\widehat{C}_t, \widehat{C}^*_t, \widehat{T}_t\right]$ is the co-state vector, ϵ^z is the vector of technological shocks and ϵ^s is the vector of sunspot shocks. The stability of the dynamic system (27) is determined by the number of eigenvalues of the coefficient matrix J that lie inside the unit circle. If marginal cost is assumed to be decreasing in output (i.e. $\alpha + \gamma > 1$), then the system (27) may not have a unique solution. With this additional returns to scale, the coefficient matrix J can have more eigenvalues inside the unit circle than the number of predetermined variables (K, K^*, b_H, z and z^*), and consequently, multiple solutions to (27) exist.

[Need to talk in detail about productivity shocks and sunspot shocks here]

2.5.2 Parameterization

The benchmark parameter values used to compute the equilibrium are summarized in Table 1. As is standard in the literature, we set the time interval to be a quarter, the discount factor $\beta = 0.99$ and the steady state depreciation rate $\overline{\delta} = 0.025$ (which implies that $\eta \simeq 1.4$). The labor share in production is set equal to 0.7 and the inverse elasticity of

[6] In the steady state the degree of increasing returns to scale can be expressed as the ratio between average and marginal costs, which in the steady-state is equal to markup: i.e. $\frac{(\alpha+\gamma)(\overline{Y}+\phi)}{\overline{Y}} = \chi$. Consequently, for a unique steady state to exist, the steady state markup cannot be lower than the degree of diminishing marginal cost i.e. $\chi = \frac{\lambda}{\lambda - 1} \geq \alpha + \gamma$.

Table 1: Baseline parameter values

β	0.99	Discount factor
$\overline{\delta}$	0.025	Steady state depreciation rate of capital
ν	0	Inverse elasticity of labor supply
σ	2	Inverse of the intertemporal substitution elasticity of consumption
θ	1	Elasticity of substitution between home & foreign consumption goods
ρ	1	Elasticity of substitution between home & foreign investment goods
a	0.88	Home bias in consumption goods
b	0.88	Home bias in investment goods
ω	0.001	Bond adjustment cost
$\overline{L}$	1/3	Steady state hours worked
S_L	0.7	Labor share in production
α	0.3 or 0.36	Elasticity of output with respect to capital
γ	0.7 or 0.84	Elasticity of output with respect to labor
χ	1.2	Steady state markup

labor supply is set $\nu = 0$ (i.e. indivisible labor), which is the standard assumption of the indeterminacy literature (see, for example, Benhabib and Farmer, 1994, 1996). The labor supply parameter, ψ is set so that in the steady state the agent in each country allocates one-third of their time to market activities. In the existing literature the inverse of the intertemporal elasticity of substitution typically chosen is $1 \leq \sigma \leq 2$. Following Stockman and Tesar (1995) we set $\sigma = 2$. In line with Benigno and Thoenissen (2008) we set the bond adjustment cost $\omega = 0.001$ and the steady-state ratio of bond holdings to GDP, $\frac{\overline{B}_H}{\overline{Y}} = 0$. We set $a = 0.88$, consistent with the ratio of imports to GDP of the US economy and we assume throughout that the degree of home bias is symmetric across consumption and investment goods by setting $b = 0.88$.[7]

Empirical studies offer no clear conclusion on the magnitude of the trade price elasticities, θ and ρ. As discussed by Corsetti *et al.* (2008a) estimates range from 0.1 to 2. Furthermore, recent studies (e.g. Corsetti *et al.*, 2008b; Thoenissen, 2010) have shown that the ability of flexible-price international business cycle models to match the data can depend significantly on the choice of these elasticities. As in Stockman and Tesar (1995) we initially set $\theta = \rho = 1$ consistent with the empirical estimates of Heathcote and Perri (2002) and Bergin (2006). However, the robustness of the numerical results are examined for variations in

[7] A sensitivity analysis was conducted under alternative values for the degree of home bias of investment goods. The results were found to be robust for variations in b.

these parameters. Specifically, following Backus *et al.* (1995) and Raffo (2008, 2010) we consider a high trade elasticity parameterization, by setting $\theta = \rho = 1.5$. A low trade elasticity parameterization is also considered, where we set $\theta = \rho = 0.5$. This value is broadly consistent with the estimates of Taylor (1993), Anderton *et al.* (2004) and Corsetti *et al.* (2008a).

A key issue is to generate equilibrium indeterminacy with empirically plausible values for the steady state markup χ. Since intermediate firms only use capital and labor in the production process (12), this implies that the markup is value added. As discussed by Jaimovich (2007), for the U.S. economy value added markups are estimated to lie between 1.2 to 1.4. We set the steady state markup $\chi = 1.2$, consistent with the lower range of the empirical estimates.[8] For the determinacy version of the model we assume that marginal costs are constant (i.e. $\alpha + \gamma = 1$). In this case, with $\chi = 1.2$, $\phi > 0$, and there are zero average profits. For the indeterminacy version we assume that marginal costs are declining (i.e. $\alpha + \gamma > 1$). The numerical analysis suggests that under the baseline parameterization there are many values of α and γ that generate indeterminacy for empirically plausible values of the steady state markup. Following Hornstein (1993) we set $\alpha + \gamma = \chi = 1.2$, which implies that profits are not only zero on average but also in every period.

3 The Determinacy Benchmark

This section presents the main quantitative findings of the determinacy version of the model, which will act as the benchmark for comparison. Using the parameter values summarized in Table 1, the unconditional second moments of each model are generated and compared against their empirical counterparts. Columns 2 and 3 of Table 2 report the estimated moments of Hodrick-Prescott filtered variables computed in Gao *et al.* (2012) and Karabarbounis (2013) respectively, using quarterly data for the period $1973(1) - 2007(4)$, where the U.S. is taken as the home country.[9] The moments for real net exports are additionally estimated from the authors' own calculations. Columns $4-7$ of Table 2 report the predicted

[8] A sensitivity analysis was conducted under a higher value for the steady state markup $\chi = 1.3$, with little significant change in the results found.

[9] All series are logged, except real net exports which is a level, and Hodrick-Prescott filtered with a smoothing parameter of 1600. The statistics in Gao *et al.* (2012) are computed where the foreign country is the aggregate of Canada, Japan and 19 European countries. In Karabarbounis (2013) the statistics are computed using Australia, Canada, Japan, Mexico, Korea and 12 European countries.

Table 2: Second moments of the determinacy model

	Data†		Det.	Variations on the Det. baseline		
	Gao	Kar	baseline	Low trade elasticity	High trade elasticity	Capacity utilization
Standard deviations‡						
Consumption	0.62	0.83	0.91	0.86	0.93	0.86
Investment	2.92	2.84	1.38	1.48	1.44	1.83
Employment	0.68	0.93	0.80	0.75	0.82	0.83
Terms of Trade	1.77	1.71	0.59	2.11	0.27	0.36
Real Ex. Rate	2.38	-	0.45	1.60	0.21	0.27
Real Net Exports	0.38*	0.38*	0.05	0.22	0.09	0.09
Correlations with output						
Consumption	0.82	0.86	0.99	0.94	1.00	1.00
Investment	0.94	0.95	0.96	0.94	0.95	0.96
Employment	0.85	0.87	1.00	0.95	1.00	1.00
Terms of Trade	-0.16	-0.17	0.45	0.45	0.42	0.44
Real Net Exports	-0.47*	-0.45	0.20	0.44	-0.31	-0.41
Cross-country correlations						
Output	0.58	0.37	0.58	0.58	0.58	0.58
Consumption	0.43	0.24	0.77	0.97	0.70	0.71
Investment	0.41	0.25	0.07	-0.06	-0.01	0.05
Employment	0.45	0.32	0.70	0.93	0.63	0.64
Correlation with the real exchange rate						
Rel. consumption	-0.17	-0.19	0.97	0.90	0.91	0.96

† The estimated sample moments for the data are taken from Gao *et al.* (2012) and Karabarbounis (2013) except for values denoted by $*$ which are from the authors own calculations.
‡ The standard deviations of all variables are divided by the standard deviation of output, except for the standard deviation of real net exports which is expressed in absolute terms.

statistics of the determinate economy under different calibrations, against the statistics for the actual data. In the first simulation we assume a fixed capacity utilization rate with unitary values for the trade price elasticities $\theta = \rho = 1$ ("Det. baseline"). In the second and third simulations we either assume low trade elasticities ($\theta = \rho = 0.5$), or high trade elasticities ($\theta = \rho = 1.5$), relative to the baseline. In the final simulation dynamic capacity utilization ("Capacity utilization") is introduced into the baseline model. For all simulations we set $\alpha + \gamma = 1$, so that marginal costs are constant and increasing returns to scale arise only because of the fixed production cost. Consequently, the system given by (27) always has a unique solution and sunspot shocks are not possible. Furthermore, with constant marginal costs, our imperfect competition model behaves very similar to standard IRBC models.[10] In terms of the steady state, the output-capital ratio and consumption-output ratio are the same as RBC. The only difference relates to levels, where steady-state output is lower because of the presence of monopoly power, and thus steady-state labor supply is also lower. In terms of the linearized model the only difference between our model and a typical IRBC economy comes via the aggregate production technology condition:

$$\widehat{Y}_t = \chi\alpha \left[\widehat{u}_t + \widehat{K}_t\right] + \chi\gamma\widehat{L}_t + \chi\widehat{Z}_t. \tag{28}$$

With imperfect competition $\chi > 1$, whereas in standard IRBC $\chi = 1$. Thus output fluctuations generated by productivity shocks are amplified under imperfect competition.

3.1 The International Macro Puzzles

Comparison of columns 2, 3 and 4 of Table 2, highlight some of the well-established discrepancies with the data of the predictions of standard flexible-price models. The determinacy baseline counter-factually predicts that net exports (0.23), and the terms of trade (0.53) are both pro-cyclical. However, business cycle statistics suggest that both the terms of trade and net exports are counter-cyclical for many developed countries.[11] Furthermore, a volatility puzzle arises where the predicted volatilities (relative to output) generated by the baseline model are significantly lower than the data. The statistics for the data suggest that investment is nearly three times more volatile than output ($2.84-2.92$), and real net exports (0.38) is nearly two-fifths the volatility of output. In terms of relative prices, both the real exchange rate (2.38) and the terms of trade ($1.71-1.77$) are significantly more volatile than output. In stark contrast, the determinacy baseline significantly underpredicts the volatility of these variables. Simulated volatilities for investment (1.38), real net exports (0.05), the real exchange rate (0.45) and the terms of trade (0.59) are all much smaller in comparison with the data. It is important to stress that the baseline model can generate sufficient volatility for consumption and employment. This is an important improvement from stan-

[10] In the standard IRBC model $\chi = \alpha + \gamma = 1$, given the absence of monopolistic competition.
[11] See, e.g., Raffo (2008), Engel and Wang (2011), and Rothert (2012).

dard flexible-price models and is due to the choice of GHH preferences.[12] In relation to the international cross-country predictions of the model, the determinacy baseline predicts that the cross-country correlation of consumption (0.77) is higher than the cross-country correlation of output (0.58). This is in stark contrast to the data where international cross-country correlations of output are greater than consumption. Finally, the baseline model suffers from the so-called Backus-Smith puzzle, where the model predict a high positive correlation between relative consumption and the real exchange rate (0.97), whereas in the data this correlation is negative for most OECD countries.[13]

3.2 The Importance of the Trade Price Elasticities

Recent studies (see, e.g., Corsetti *et al.*, 2008a, 2008b; Thoenissen, 2010) have highlighted the important role the trade elasticity parameters play in the relative price volatility predictions of IRBC models. The determinacy version of our model mirrors these findings. To see this, column 5 of Table 2, presents the predicted business cycle statistics of the model under a low trade elasticity calibration. By inspection, this more than triples the volatilities of the terms of trade and the real exchange rate, and more than quadruples the volatility of real net exports relative to the determinacy baseline. Consequently, with a low trade elasticity, the model can now replicate the volatility of the terms of trade observed in the data. Yet, despite these improvements, the model still generates less than 60 percent of the volatility observed for real net exports, and less than 70 percent of the volatility observed for the real exchange rate. Under a high trade elasticity calibration (column 6 of Table 2), the model can generate counter-cyclical net exports (-0.31) almost matching the data where the largest value is -0.45.[14] However, this is at the cost of further reducing the volatility of relative prices relative to the baseline. Therefore, conventional models appear to face an unpleasant trade-off. Relatively high trade elasticities can be selected to help generate counter-cyclical net exports, or relatively low trade elasticities can be chosen to help improve the volatilities of net exports and relative prices.

[12]The ability of GHH preferences to generate higher consumption volatility arises because of the absence of an income effect on labor supply (see equation (16)). Consequently, output changes generate a stronger response of both employment and consumption. For further discussion see Raffo (2008).

[13]See, e.g., Corsetti *et al.* (2008a).

[14]This replicates the findings of Raffo (2008) who found that the standard IRBC model can produce counter-cyclical net exports with GHH preferences and a high trade elasticity calibration.

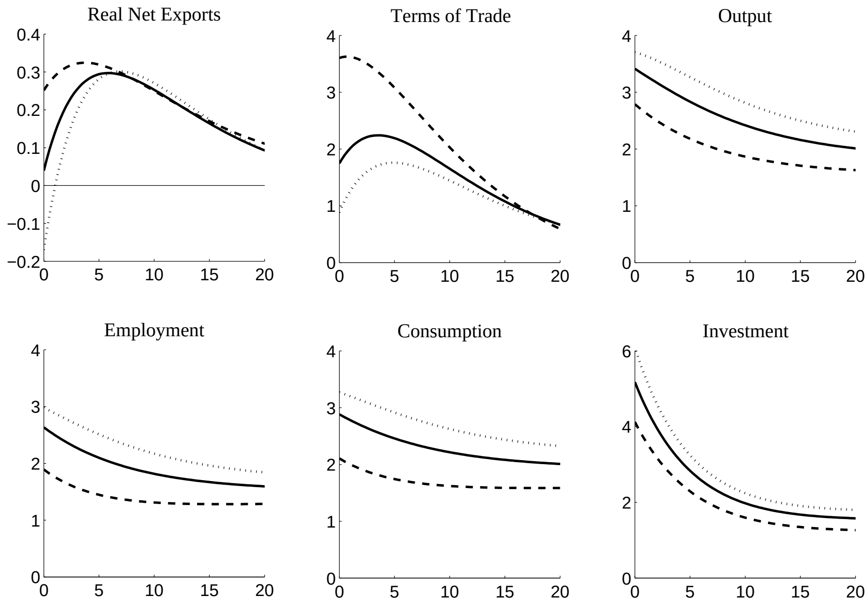

Figure 1: [The determinacy model] Selected Home impulse responses for a 1% positive Home productivity shock: Baseline (—); High trade elasticity (· · ·); Low trade elasticity (- - -)

The intuition behind these results follows from inspecting the transmission mechanism of productivity shocks in the determinacy model. Figure 1 reports selected impulse response functions of the home country after a 1% positive productivity shock. In each panel of Fig. 1 the impulse responses are plotted under three alternative values for the trade price elasticities $\theta = \rho = 0.5, 1.0, 1.5$. The trade elasticities crucially affect the response of the terms of trade after a productivity shock. If the trade elasticities are relatively low, home and foreign goods are less substitutable for one another. Consequently, a positive productivity shock results in a large deterioration in the terms of trade (i.e. a fall in the relative price of home-produced goods) and a lower increase in domestic output. Hence, the lower the trade elasticities, the higher the volatility of relative prices and the lower the volatility of output in response to productivity changes. Exports rise more than imports, and real net exports, in contrast to the data, are consequently pro-cyclical. With high trade elasticities, productivity shocks will have a lower impact on relative prices and a higher impact on output, thereby generating counter-cyclical real net exports. Therefore, it is not possible to match the volatility of relative prices, and the correlation between real net exports and

Table 3: Trade Elasticities and Dynamic Capacity Utilization

	Data		Dynamic Capacity Utilization		
	Gao	Kar	Baseline trade elasticity	High trade elasticity	Low trade elasticity
Standard deviations					
Terms of Trade	1.77	1.71	0.36	0.23	0.70
Real Exchange Rate	2.38	-	0.27	0.17	0.53
Real Net Exports	0.38	0.38	0.09	0.09	0.10
Correlations with output					
Net Exports	-0.47	-0.45	-0.41	-0.42	-0.41

output with the choice of trade elasticities alone.[15]

3.3 The Role of Dynamic Capacity Utilization

The final column of Table 2 summarizes the implications of introducing dynamic capacity utilization into the baseline determinacy model. This has one notable implication: the model can now generate a net exports correlation with output (-0.41) nearly matching the data. Furthermore, as highlighted by Table 3 this feature is robust to variations in the trade elasticity parameters. However, this comes at the cost of significantly lower relative price volatilities. For some intuition behind this result, Figure 2 compares the impulse responses of the dynamic capacity utilization simulation against the high trade elasticity simulation. As discussed by Baxter and Farr (2005), dynamic capacity utilization requires less volatility in productivity shocks than fixed capacity models in order to generate the same level of output volatility. By inspection of Fig. 2 after a positive technology shock, firms increase the utilization rate of capital and the response of output is magnified. This increases both spending on consumption and investment, while the strong demand for foreign investment goods ensures that real net exports become negative after a positive technology shock.

[15] By allowing for deviations in the law of one price due to distribution services, and non-traded goods with home bias in domestic spending on tradable goods, Corsetti, *et al.* (2008a) find that the IRBC model under a low trade elasticity parameterization can explain both the high volatility of the terms of trade, and counter-cyclical net exports. However, their model can only generate roughly a quarter of the volatility observed in the data for real net exports, and roughly 50 percent of the volatility observed for consumption and employment.

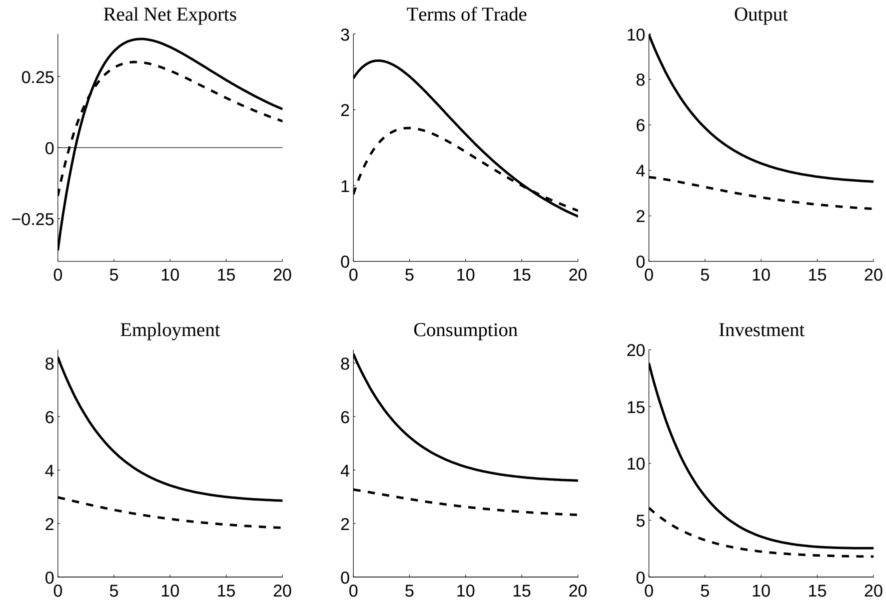

Figure 2: [The determinacy model] Selected Home impulse responses for a 1% positive Home productivity shock: High trade elasticity (- - -) vs. Dynamic capacity utilization (—)

Thus the cross-correlation between net exports and output is negative independent of the parameter values for the trade elasticities. However, given the large response of output to an exogenous productivity shock, the volatilities of relative prices are unsurprisingly reduced. Consequently, the determinacy version of the model with dynamic capacity utilization is unable to match the volatilities observed in the data.

4 The Indeterminacy Model

This section considers the indeterminacy version of the model, and presents the main findings of the paper. Columns 5, 6, and 7 of Table 4 summarize the predicted statistics for the indeterminacy economy setting $\alpha + \gamma = \chi = 1.2$, under different calibrations for the trade elasticities. In the first simulation ("Indet. baseline") we generate sunspot equilibria employing unitary values for the trade price elasticities $\theta = \rho = 1$. In the final two simulations we either assume low trade elasticities ($\theta = \rho = 0.5$), or high elasticities ($\theta = \rho = 1.24$), relative to the indeterminacy baseline.[16] For comparative purposes, column 4 of Table 4

[16] We set $\theta = \rho = 1.24$ as this is the highest value for the trade price elasticities that generate indeterminacy under $\chi = 1.2$.

Table 4: Second moments of the indeterminacy model: sunspot shocks and productivity shocks

	Data		DMC†	Indet.	Variations on the Indet. baseline	
	Gao	Kar		baseline	Low trade elasticity	High trade elasticity‡
Standard deviations						
Consumption	0.62	0.83	0.82	0.91	0.91	0.90
Investment	2.92	2.84	1.69	2.40	1.87	2.83
Employment	0.68	0.93	0.91	1.01	1.01	1.02
Terms of Trade	1.77	1.71	0.04	1.68	1.77	1.63
Real Ex. Rate	2.38	-	0.03	1.27	1.34	1.24
Real Net Exports	0.38	0.38	0.03	0.68	0.38	0.80
Correlations with output						
Consumption	0.82	0.86	1.00	0.99	0.99	0.99
Investment	0.94	0.95	1.00	0.86	0.94	0.80
Employment	0.85	0.87	1.00	0.99	0.99	0.99
Terms of Trade	-0.16	-0.17	0.08	-0.22	-0.17	-0.20
Real Net Exports	-0.47	-0.45	-0.08	-0.41	-0.46	-0.41
Cross-country correlations						
Output	0.58	0.37	0.98	0.49	0.50	0.36
Consumption	0.43	0.24	0.99	0.50	0.50	0.38
Investment	0.41	0.25	0.96	-0.44	-0.16	-0.67
Employment	0.45	0.32	0.99	0.50	0.50	0.38
Correlation with the real exchange rate						
Rel. consumption	-0.17	-0.19	0.89	-0.13	-0.19	-0.04

† For the determinacy version in the presence of declining marginal costs we set $\alpha + \gamma = 1.099$. In this case sunspot shocks are not possible and thus the model is simulated with productivity shocks only.
‡ For the high trade elasticity simulation we set $\theta = \rho = 1.24$, the highest value for which indeterminacy is possible.

presents the predicted statistics when the model exhibits declining marginal costs but indeterminacy does not arise. For this case ("DMC") we assume that $\alpha + \gamma = 1.099$, which is sufficiently small given the steady state markup $\chi = 1.2$ to ensure that the equilibrium is determinate and sunspot shocks are not possible.

4.1 Main Results

The contribution of sunspot shocks to explaining the main features of international business cycles is evident from inspection of Table 4. With respect to reproducing the estimated business cycle statistics, the indeterminacy model performs significantly better than the benchmark determinacy model in nearly every single aspect. In terms of volatility, the indeterminacy baseline generates sufficient volatility of both consumption and employment. While investment is less volatile than the data (the indeterminacy baseline accounts for between $82\% - 84\%$ of the empirical estimates for investment) it is a significant improvement from the determinacy baseline which only accounts for approximately half. The first important feature of the indeterminacy model is its ability to simultaneously generate high volatilities for the terms of trade and real net exports. The volatility of the terms of trade is over 2.8 times greater in the indeterminacy baseline relative to the determinacy baseline, and 4.6 times greater compared to the dynamic capacity utilization variation. The volatility of real net exports in the indeterminacy baseline is 13.6 times greater relative to the determinacy baseline. Indeed, under a low trade elasticity calibration, the indeterminacy model generates volatilities for the terms of trade (1.77) and real net exports (0.38) that exactly match their empirical estimates. In terms of the real exchange rate the indeterminacy baseline generates a volatility over 2.8 times greater than the determinacy baseline, and 4.7 times greater than the dynamic capacity utilization extension. Unsurprisingly, the indeterminacy model still generates insufficient volatility for the real exchange rate relative to the data, given the assumption of the law of one price and the absence of non-traded goods.[17]

In terms of correlations with output, the model generates statistics for consumption, investment and employment that are all sufficiently pro-cyclical. In stark contrast to the benchmark determinacy model, the indeterminacy model not only predicts that real net exports and the terms of trade are both counter-cyclical, but the model can nearly match the data. By inspection of the final two columns of Table 4, these predictions are robust to alternative calibrations for the trade elasticities. Indeed with a low trade elasticity calibration, the correlation with output of the terms of trade (-0.17), and real net exports (-0.46) generated by the model exactly matches the empirical estimates.

[17] See Corsetti *et al.* (2008*a*) for further discussion.

In terms of the correlation between the real exchange rate and relative consumption, the indeterminacy model predicts that this correlation is negative, consistent with the data. As shown by columns 6 and 7 of Table 4, this negative correlation remains regardless of the choice of trade elasticities. Under a low trade elasticity calibration, the magnitude of the correlation between the real exchange rate and relative consumption (-0.19) generated by indeterminacy model exactly matches the empirical estimates.

The biggest weakness of the indeterminacy model relates to the cross-country correlations of output and consumption. As previously discussed, in the data the cross-country correlation of output is higher than consumption. Although the indeterminacy model does much better than the determinacy benchmark, the cross-country correlation of consumption (0.50) is slightly higher than output (0.49) under the baseline calibration, while these cross-correlations are equated (0.50) under the low trade elasticity calibration.

In summary, the indeterminacy model is able to account for a number of the international macroeconomics puzzles. It can simultaneously solve both the volatility and Backus-Smith puzzles, and it can generate the correct sign and magnitude for both the terms of trade, and real net exports, correlation with output. Similar, to the determinacy benchmark, the quantitative performance of the indeterminacy model is improved using a low trade elasticity parameterization. Column 4 of Table 4 outlines the implications of the model with decreasing marginal costs but where indeterminacy is not possible. By inspection the volatilities of real net exports and relative prices are significantly reduced. Now the model only accounts for around 2 percent of the empirical estimate for the terms of trade, and just under 8 precent for real net exports. The model cannot explain the other puzzles with the exception of generating counter-cyclical net exports, which as discussed in Section 3.3 above follows from the assumption of dynamic capacity utilization.

4.2 Solving the Puzzles

4.2.1 The transmission mechanism of sunspot and productivity shocks

There are two important elements in understanding how sunspot shocks are transmitted. First, a sunspot shock acts like a demand shock, by initially shifting aggregate demand via a change in consumption. Second, as in Benhabib and Farmer (1994) with decreasing

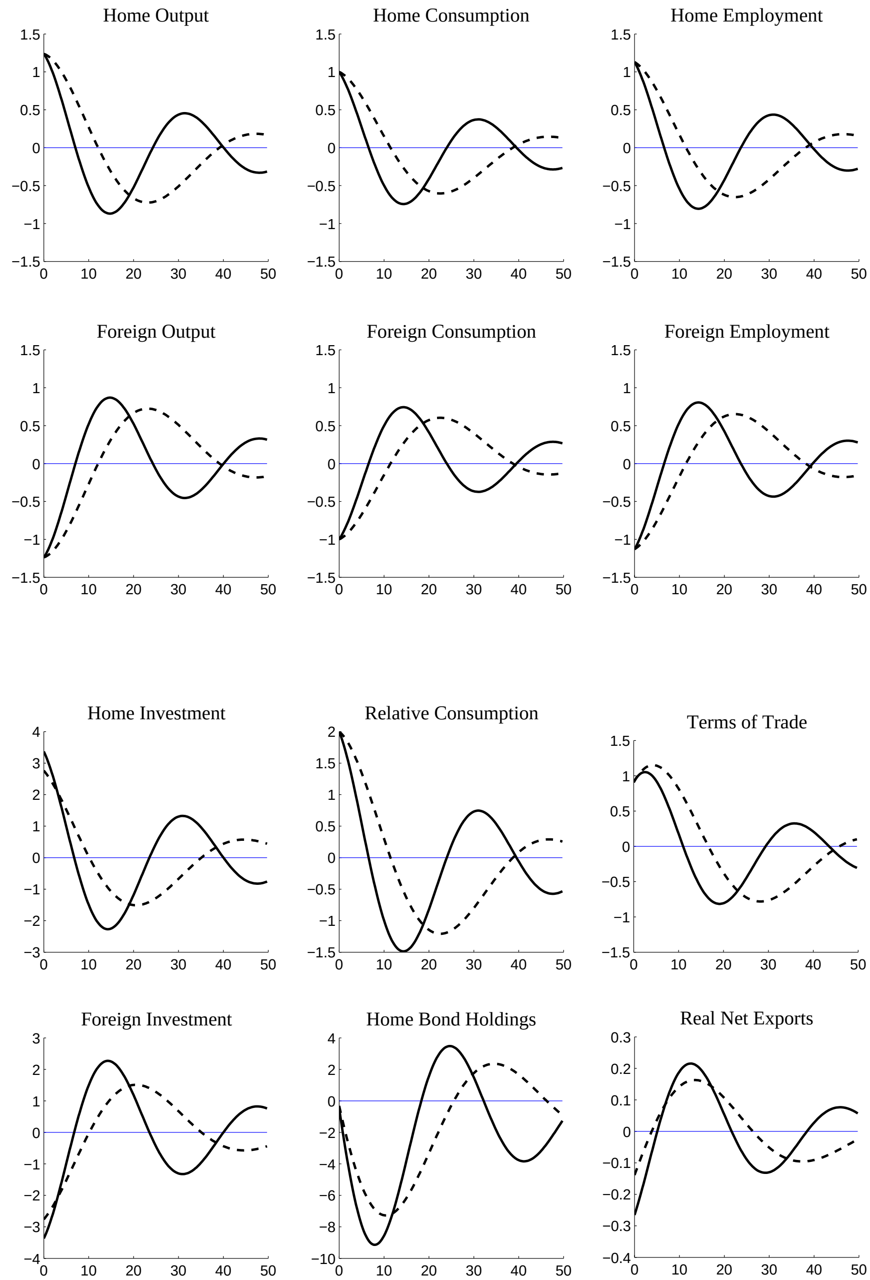

Figure 3: Dynamic responses for the indeterminacy model to a positive 1% sunspot shock: $\theta = \rho = 1$ (- - -) vs. $\theta = \rho = 0.5$ (—)

marginal costs the source of indeterminacy arises from an upward-sloping aggregate labor demand. Figure 3 depicts the impulse response functions generated by the indeterminacy version of the model after a 1 percent positive sunspot shock. Note that in response to a sunspot shock the economy returns to the steady state in an oscillating fashion. This is in contrast to the determinacy model where the economy converges to the steady state monotonically (see, for example, Figs. 1 and 2).[18] As illustrated by Fig. 3, a positive sunspot shock results in a relative change in marginal cost generating an increase in relative output and consumption, and a depreciation in the terms of trade and the real exchange rate. Given this positive transmission mechanism for sunspot shocks, this implies that the indeterminacy model using sunspot shocks alone cannot replicate the observed behavior for relative prices, or solve the Backus-Smith puzzle, since in the data positive output changes are associated with an appreciation of relative prices. Rather, the ability of the indeterminacy model to replicate the data depends on the inclusion of both sunspot and productivity shocks.

Figures 4 and 5 depict the impulse response functions generated by the indeterminacy model after a 1 percent positive productivity shock in the home country, and foreign country, respectively. A striking feature of the indeterminacy model is that the propagation mechanism of productivity shocks is asymmetric across countries. To see this first consider the transmission mechanism of a positive Home productivity shock. As shown in Fig. 4 this results in a depreciation of the terms of trade (as global demand shifts towards the now relatively cheaper Home goods) and an increase in Home investment (as Home investment goods are now relatively more productive). By inspection of the first row of Fig. 4 there is a delayed expansion in Home output, consumption and employment, since initially, the downward shift in the labor demand curve (caused by the terms of trade depreciation) is offset by the upward shift in labor demand (caused by the positive supply shock). Now consider the transmission mechanism of a positive Foreign productivity shock. As shown in Fig. 5 there is no initial change in the terms of trade. Instead, there is now an unconventional domestic transmission mechanism whereby Foreign quantities initially fall in response to the positive Foreign supply shock.[19] The positive supply shock causes an upward shift in the labor demand curve, and in the absence of an adjustment in the terms of trade, both employment and foreign output initially decline. Goods market clearing requires that Foreign goods become relative scarcer, which is ensured by a contraction in Foreign output

[18] Estimated impulse responses for the US are observed to be oscillatory or hump-shaped. For further discussion, see Farmer and Guo (1994), Cogley and Nason (1995), and Benhabib and Wen (2004).

[19] Without any initial change in the terms of trade, the Foreign supply shock is not transmitted to the Home country.

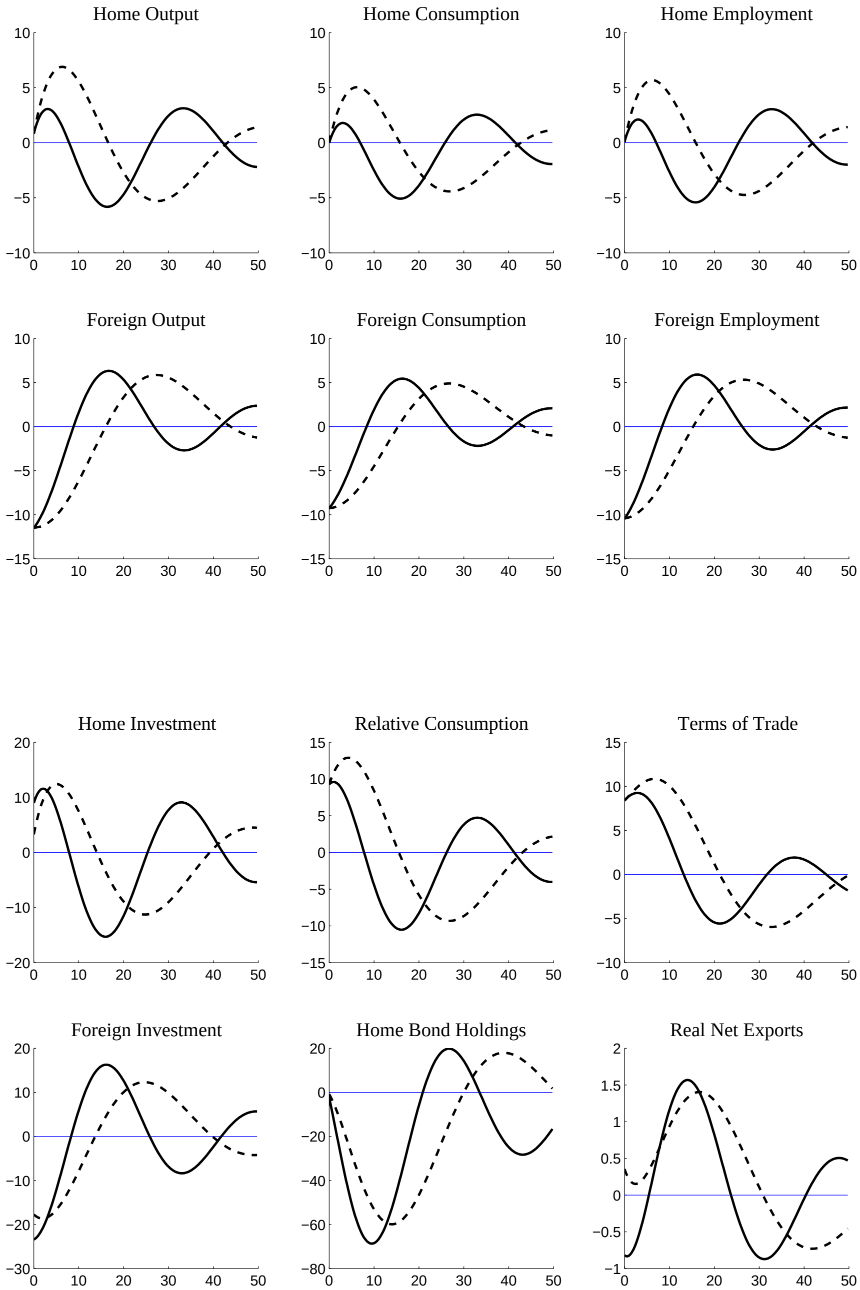

Figure 4: Dynamic responses for the indeterminacy model to a positive 1% Home productivity shock: $\theta = \rho = 1$ (- - -) vs. $\theta = \rho = 0.5$ (—)

rather than an appreciation of the terms of trade.[20] By inspection of the second row of

[20] A positive Home productivity shock implies a decline in the price of domestically produced goods and an increase in the price of the imported good. However, in the case of a positive foreign productivity shock there is no initial change in prices and thus Foreign quantities must fall.

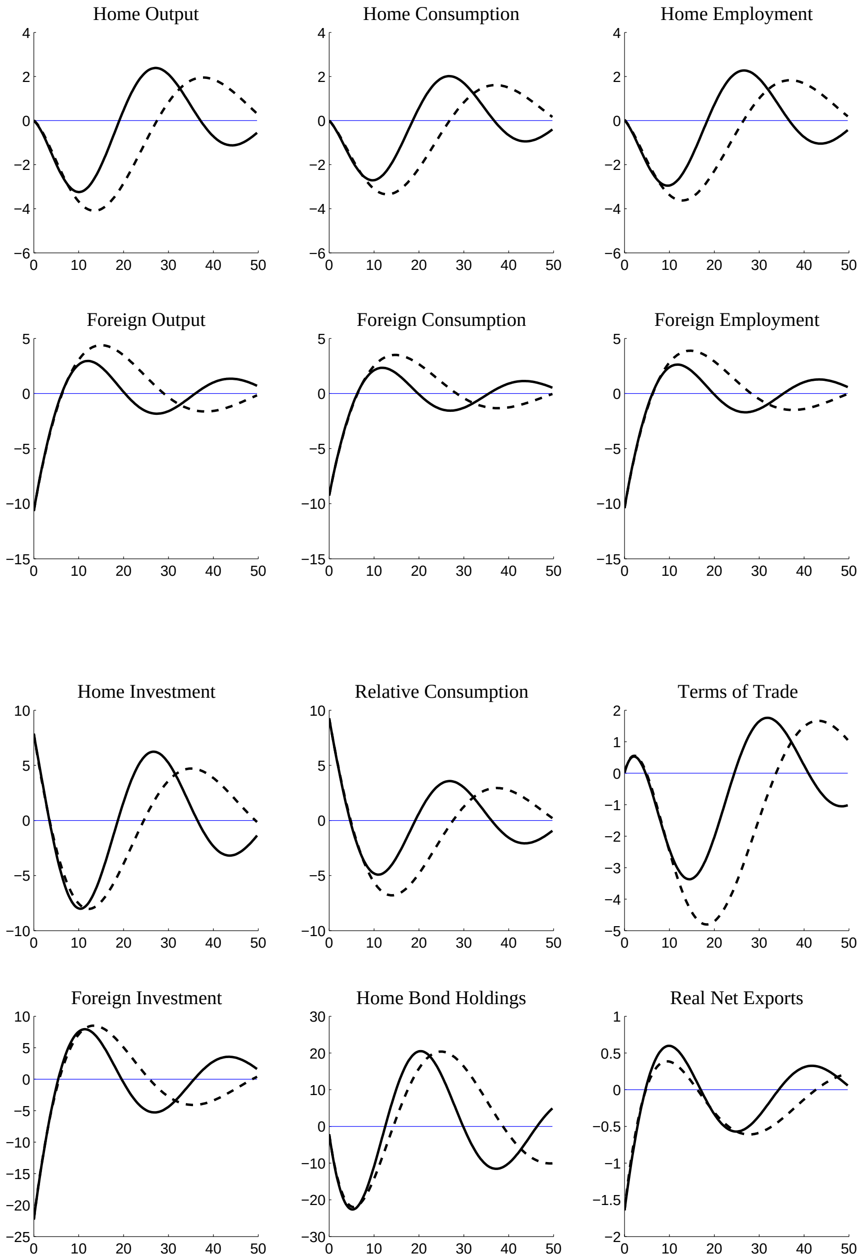

Figure 5: Dynamic responses for the indeterminacy model to a positive 1% Foreign productivity shock: $\theta = \rho = 1$ (- - -) vs. $\theta = \rho = 0.5$ (—)

Fig. 5 this effect is strong but temporary. For example, after the initial fall, Foreign output does increase (as we would expect after a positive domestic technology shock), but it takes a period of time for output to go above its steady state value.[21]

4.2.2 The Backus-Smith Puzzle

Recall that the empirical evidence suggests that the real exchange rate is negatively correlated with relative consumption, whereas standard IRBC models predict a strong positive correlation - the so-called Backus-Smith puzzle. One strand of the literature (see, e.g. Corsetti et al., 2008) has shown that standard IRBC models can be reconciled with the data if the model is parameterized to generate a negative transmission for supply shocks (i.e. the terms of trade appreciates when domestic production expands), which typically requires very low trade elasticities in order to generate a downward-sloping world demand for domestic traded goods (with respect to the terms of trade). One important insight of this paper is that the Backus-Smith puzzle can be resolved using a combination of sunspot shocks and the unconventional transmission mechanism for foreign productivity shocks that arises under equilibrium indeterminacy, discussed above.

Similar to standard IRBC models, in the indeterminacy model a positive Home productivity shock causes an increase in relative consumption and a depreciation in the terms of trade, implying a positive correlation. However, if the positive Home productivity shock is accompanied by a negative Foreign technology shock and a negative sunspot shock, which as discussed above, the impulse responses of both shocks are neither symmetric nor identical to Home productivity shocks, this can generate a negative correlation between relative consumption and the terms of trade. Together, the negative Foreign supply shock and the negative sunspot shock strongly counteract the increase in relative consumption caused by the positive Home supply shock, so that the overall effect on relative consumption is negative (i.e. relative consumption falls below the steady state in the short run). However, the impact of the negative Foreign suuply shock and the negative sunspot shock on the terms of trade is more muted, so that the net effect is still positive (i.e. the terms of trade depreciates above its steady state level in the short-run). Therefore, in our indeterminacy model, the asymmetric responses to Home and Foreign technology shocks, combined with the sunspot shocks, can generate a negative correlation between relative consumption and

[21] The time it takes for Foreign output to become positive depends on the bond adjustment cost parameter. In our baseline calibration, with a bond adjustment cost of 0.001, Foreign output stays negative for 25 quarters. With a higher bond adjustment cost, e.g. 0.05, the time is reduced to 9 quarters.

the real exchange rate, provided the variances and correlations are chosen with this goal in mind.

4.2.3 ......

Since sunspot shocks are transmitted negatively across countries, this implies that the indeterminacy model cannot replicate the observed behavior for relative prices, or solve the Backus-Smith puzzle, using sunspot shocks alone. In the indeterminacy model a sunspot-induced increase in output is associated with a depreciation of the terms of trade and the real exchange rate, whereas in the data positive output changes are associated with an appreciation of these relative prices. Rather, the ability of the indeterminacy model to replicate the data more realistically depends on the inclusion of both sunspot and productivity shocks. In particular, the shock specification that we found can help solve the puzzles required: (a) a negative correlation between the sunspot shock and the productivity shock; and (b) the standard deviation of the sunspot shock to be sufficiently greater than the standard deviation of the productivity shock. In the baseline calibration it is assumed that the sunspot shock has a standard deviation that is 3.0835 times larger than the technology shock. As discussed by Xiao (2004), estimates of the standard deviation of sunspot shocks are found to be 0.049, which is seven times the estimate of the standard deviation of productivity shocks 0.007 found by Burnside *et al.* (1996). For the two shocks, we require significantly less relative variance than these estimates, in order to generate our results.

5 Conclusion

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Table 5: Second moments of the indeterminacy model: Sensitivity Analysis 1

	Data		$\alpha + \gamma = 1.19$		
			Indet.	Low trade	High trade
	Gao	Kar	baseline	elasticity	elasticity‡
Standard deviations					
Consumption	0.62	0.83	0.90	0.91	0.90
Investment	2.92	2.84	2.47	1.88	2.89
Employment	0.68	0.93	1.01	1.01	1.01
Terms of Trade	1.77	1.71	1.69	1.80	1.64
Real Ex. Rate	2.38	-	1.29	1.37	1.25
Real Net Exports	0.38	0.38	0.67	0.39	0.81
Correlations with output					
Consumption	0.82	0.86	0.99	0.98	0.99
Investment	0.94	0.95	0.87	0.93	0.80
Employment	0.85	0.87	0.99	0.99	0.99
Terms of Trade	-0.16	-0.17	-0.19	-0.20	-0.20
Real Net Exports	-0.47	-0.45	-0.42	-0.44	-0.41
Cross-country correlations					
Output	0.58	0.37	0.36	0.51	0.31
Consumption	0.43	0.24	0.38	0.51	0.33
Investment	0.41	0.25	-0.50	-0.14	-0.64
Employment	0.45	0.32	0.38	0.51	0.32
Correlation with the real exchange rate					
Rel. consumption	-0.17	-0.19	-0.06	-0.17	0.00

5.1 Sensitivity Analysis

With indivisible labor, a higher mark-up χ implies a steeper labor demand curve

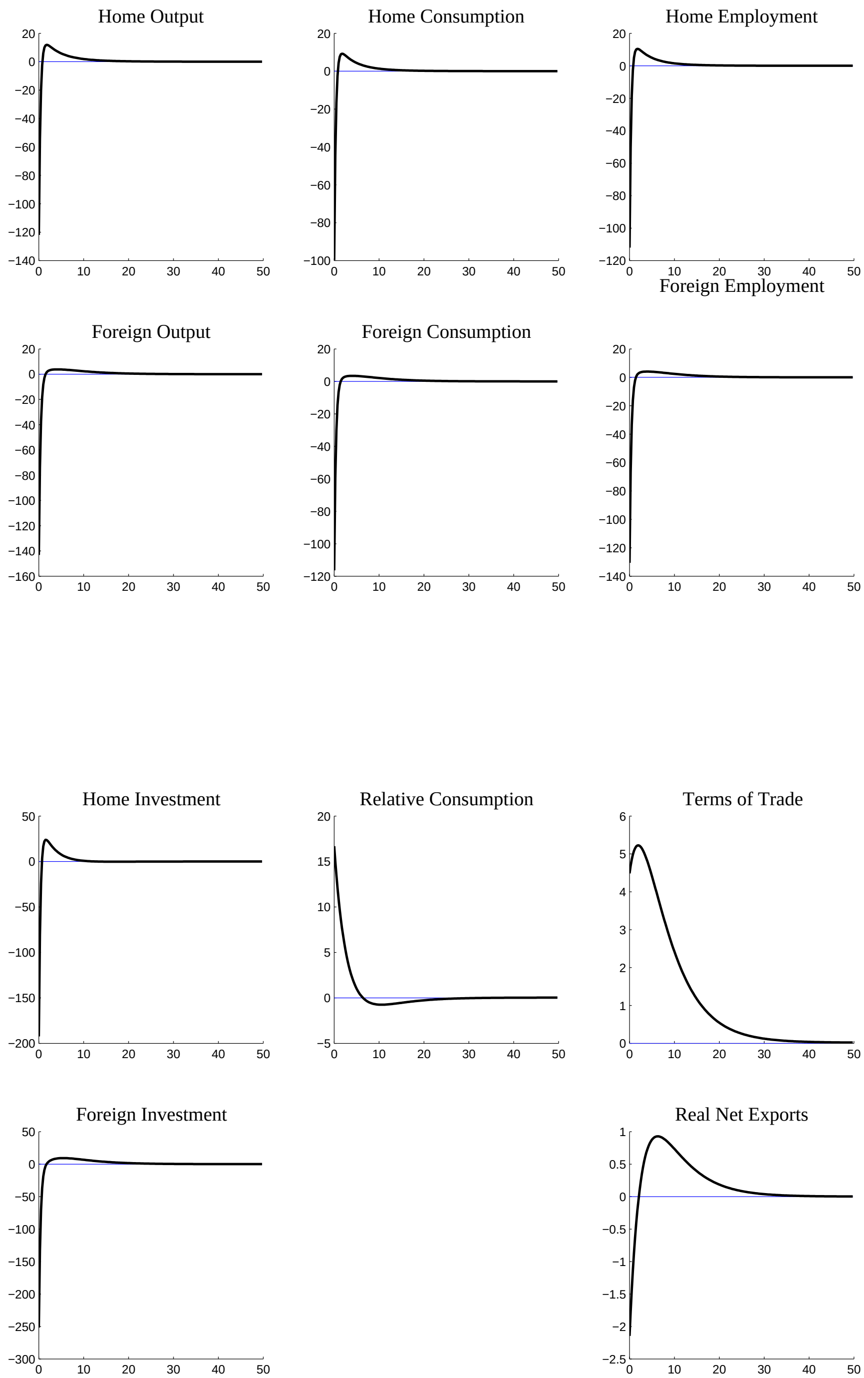

Figure 6: Dynamic responses for the decreasing marginal costs model without indeterminacy to a positive 1% Home productivity shock: $\alpha + \gamma = 1.099$ and $\theta = 1$

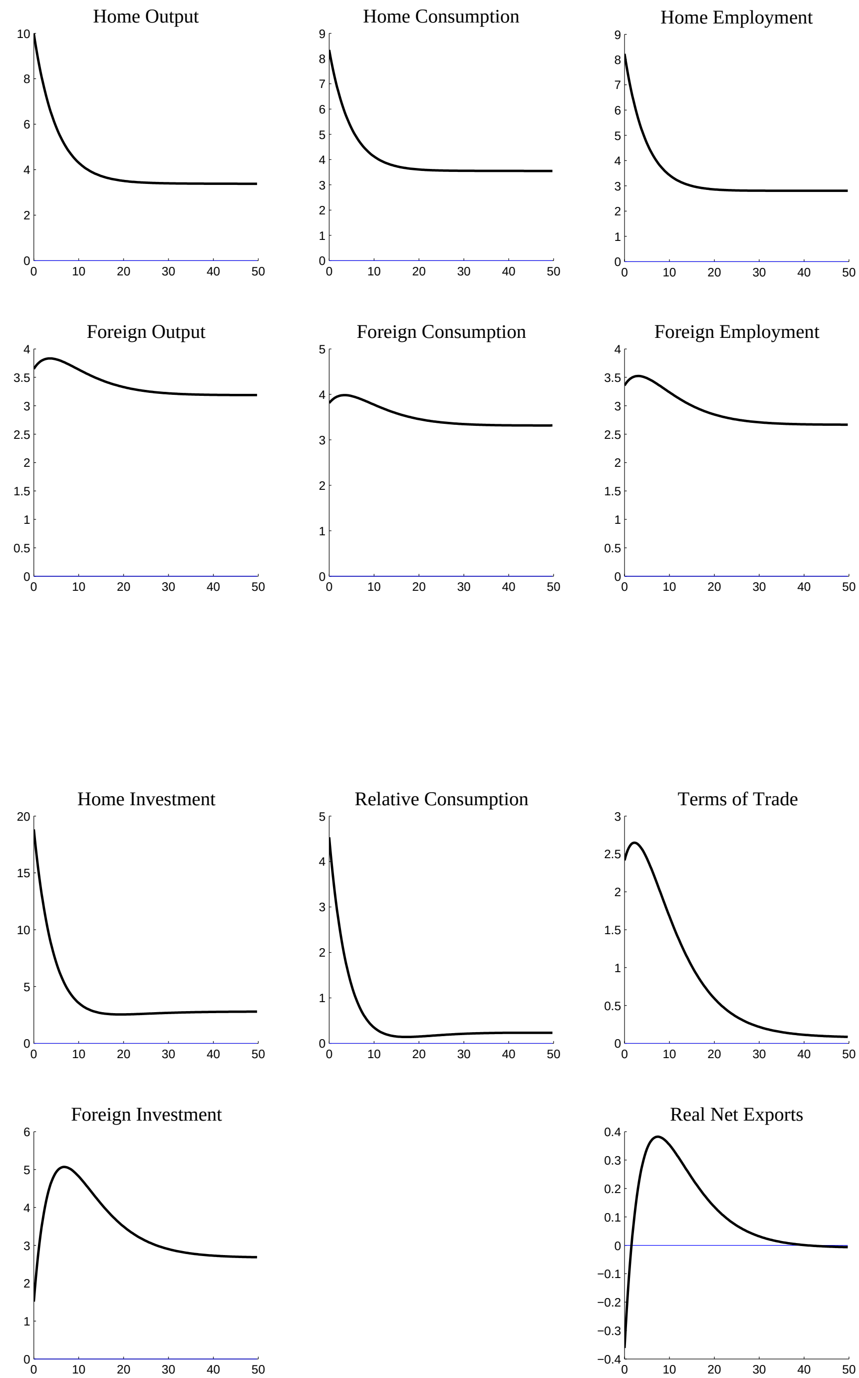

Figure 7: Dynamic responses for the determinacy model with dynamic capacity utilization to a positive 1% Home productivity shock ($\theta = 1$)