Explaining International Business Cycle Synchronization

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The business cycles of major advanced economies are synchronized. Standard macro models fail to explain that fact. This paper presents a *simple* two-country, two-good, complete-markets dynamic general equilibrium model in which country-specific productivity shocks generate highly correlated business cycles. The structure here differs from standard open economy macro models by assuming recursive intertemporal preferences, and a weak wealth effect on labor supply. Recursive preferences magnify the terms of trade response to shocks. In the model here, a persistent productivity (and GDP) increase in a given country triggers a strong improvement of the *foreign* country's terms of trade. When the wealth effect on labor supply is weak, this induces a *rise* in foreign hours worked and GDP, i.e. domestic and foreign real activity comove positively.

Key words: international business cycles, terms of trade, real exchange rate, wealth effect on labor supply, GHH preferences, wage rigidity.

JEL codes: F31, F32, F36, F41, F43.

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1. Introduction

GDP, employment and investment are highly positively correlated across advanced economies. Standard macro models fail to explain that key fact--in those models, shocks that originate in one country have a weak effect on foreign GDP, and predicted cross-country correlations of real activity are markedly smaller than empirical correlations. Explaining international business cycle synchronization is thus one of the main challenges for macroeconomics (e.g., Backus et al. (1992, 1994)). The present paper provides a possible resolution of the "international correlation puzzle". It develops a *simple* dynamic general equilibrium model in which country-specific productivity shocks induce fluctuations of real activity that are highly correlated across countries.

A two-country world with two traded goods is considered. The specification of technologies and markets follows standard International Real Business Cycle models.[1] Each country is inhabited by a representative household who produces one traded good using domestic capital and labor. Households use domestic and imported traded goods for consumption and physical investment, but each household has a spending bias towards the domestic good. The global financial market is complete. Economic fluctuations are driven by persistent productivity shocks.

The model *differs* from standard open economy macro models by making two key assumptions—we show that these assumptions jointly allow to generate high cross-country business cycle correlations: (i) Recursive intertemporal preferences (Epstein and Zin (1989), Weil (1989, 1990)) are considered here, while standard open economy models assume time-separable preferences. (ii) A muted effect of wealth changes on labor supply is assumed. I consider a period utility function of the Greenwood, Hercowitz and Huffman (1988) [GHH] type that entails a zero wealth effect on desired labor supply. By contrast, standard open economy macro models mostly assume the King, Plosser and Rebelo (1989) [KPR] period utility function that implies a strong negative response of desired labor supply to a wealth increase. I also consider a setting in which the real (consumption) wage rate is rigid in the short-run, and hours worked are determined by

[1]E.g., Dellas (1986), Cantor and Mark (1988), Crucini (1989), Backus et al. (1994), Kollmann (1991,1996), Devereux (1992), Heathcote and Perri (2002).

firms' labor demand (workers can be off their labor supply schedule); this mechanism also eliminates the effect of wealth shocks on labor.

Consider the effect of a persistent exogenous productivity increase in one of the countries, named 'Home'. That supply shock induces a persistent rise in Home GDP, employment, consumption, investment and welfare; it lowers the relative price of the Home output good (compared to the Foreign output good), and thus, the Home terms of trade deteriorate. Due to consumption home bias, the relative price of the Home consumption basket falls, i.e. the Home (consumption-based) real exchange rate depreciates. Conversely, the other country's ('Foreign') terms of trade *improve*. This raises the Foreign marginal product of labor, expressed in units of Foreign consumption, which increases Foreign firms' labor demand. The effect of the shock on the Foreign labor supply depends on opposing substitution and wealth effects of the Foreign terms of trade improvement, with the former increasing and the latter reducing the Foreign labor supply. In the short run, the Home productivity increase raises Foreign output *if* Foreign hours worked rise.

In standard macro models, the terms of trade (and real exchange rate) response to a productivity shock is weak, and the substitution and wealth effects of terms of trade changes on labor supply largely offset each other. As a result, standard models predict a muted response of Foreign output to a Home productivity increase.

Recursive preferences (considered here) magnify the terms of trade responses to persistent shocks. Under these preferences, the coefficient of risk aversion, CRA, can differ from the inverse of the intertemporal elasticity of substitution, IES (standard time-separable preferences imply that CRA=1/IES). When CRA≠1/IES, then a household's intertemporal marginal rate of substitution (IMRS) depends on her (future) lifetime utility. Under the common assumption that the coefficient of risk aversion exceeds the inverse of the intertemporal elasticity of substitution (CRA>1/IES), a rise in future life-time utility *reduces* the IMRS.[2] Financial market completeness implies that, in equilibrium, the ratio of the Home IMRS to the Foreign IMRS is equated to the (gross) rate of appreciation of the Home real exchange rate. With recursive preferences, a persistent rise in Home productivity (that increases Home life-time utility, and thus

[2] CRA>1/IES implies a preference for the early resolution of uncertainty over future consumption (Weil, 1990).

lowers the Home IMRS) triggers thus a sharper depreciation of the Home real exchange rate (compared to the depreciation predicted by a model with time-separable utility, in which the IMRS does *not* depend on life-time utility); this implies a stronger deterioration of the Home terms of trade, and a stronger improvement of the *Foreign* terms of trade.

When the wealth effect on labor supply is weak, the stronger Foreign trade improvement induces a noticeable *rise* in Foreign hours worked. This explains why, in the model here, country-specific productivity shocks can generate highly correlated fluctuations of Home and Foreign GDP. Importantly, recursive preferences and a weak wealth effects on labor are *both* needed for this result. Thus, GHH utility or a rigid real wage rate are crucial ingredients of the mechanism described here (in flex-wage model variants with KPR utility, the predicted cross-country output correlations are *lower* under recursive preferences than under time-separable preferences, i.e. the correlation puzzle worsens). The structure here also matches other key business cycle facts better than conventional open economy models. In particular, the setup here generates a more volatile real exchange rate.

The asset pricing literature has for many years studied models with recursive preferences, as the flexibility afforded by the separation between the IES and CRA parameters helps to capture the joint dynamics of consumption and asset returns (e.g., Rudebusch and Swanson (2012)). By contrast, the international macroeconomics literature has only recently begun to consider models with recursive preferences. See, e.g., Colacito and Croce (2011, 2013), Benigno et al. (2012), Gourio et al. (2013), Caporale et al. (2014), Kollmann (2015, 2016), Lewis and Liu (2015) and Sauzet (2015). These studies show that models with recursive preferences can generate higher real exchange rate volatility than standard models (with time-separable preferences). However, these papers consider endowment economies, and thus they cannot explain why output, employment and investment are synchronized across countries, the focus of the paper here. The present paper updates and extends Kollmann (2009), the first analysis of a two-country *production* economy with recursive preferences. Benigno et al. (2012), Colacito et al. (2014), Mumtaz and Theodoridis (2015), Backus et al. (2016) and Tretvoll (2016) also study open economy *production* economies with recursive preferences, but the focus of those papers is different; the quantitative models in these papers do not explain the high empirical cross-country correlations of output, employment and investment. [3]

Section 2 describes the baseline two-country model with production and recursive preferences. Section 3 discusses stylized facts about international business cycles. Section 4 presents simulation results and Section 5 concludes.

2. A two-country model

2.1. Preferences, technologies, shock process, risk sharing

A world with two symmetric countries, Home (*H*) and Foreign (*F*) is assumed. Each country is inhabited by a representative infinitely-lived household.

At date *t*, perfectly competitive firms in country *i* produce $Y_{i,t}$ units of a perishable tradable intermediate good *i*, using the technology

$$Y_{i,t}=(L_{i,t}\theta_{i,t})^{\omega}(K_{i,t})^{1-\omega},\ \ 0<\omega<1,$$

where $L_{i,t}$ and $K_{i,t}$ are hours worked and capital, respectively. The country *i* capital stock is owned by the local household and rented to competitive domestic firms. Labor and capital are immobile internationally. $\theta_{i,t}>0$ is exogenous stochastic labor augmenting productivity. Productivity is non-stationary (see below).

The country *i* household combines local and imported intermediates into a non-tradable final good, $Z_{i,t}$:

$$Z_{i,t}\equiv(y^{i}_{i,t}/(1-\alpha))^{1-\alpha}(y^{j}_{i,t}/\alpha)^{\alpha},\ j\neq i, \tag{1}$$

where $y^{j}_{i,t}$ is the amount of intermediate good *j* used by country *i*. There is a bias towards using the local input: $0<\alpha<0.5$. The final good is used for consumption, $C_{i,t}$, and gross

[3] Those models do not feature the muted wealth effect on labor assumed in the present paper, the key condition for international synchronization highlighted here. Benigno et al. (2012) and Mumtaz and Theodoridis (2015) use two-country New Keynesian model to study the effect of volatility shocks. Colacito et al. (2014) explore differential effects of permanent and transitory productivity shocks on international capital flows. Backus et al. (2016) analyze the dynamics of Pareto weights in a two-country world with volatility shocks. Tretvoll (2016) focuses on real exchange rate variability.

investment, $I_{i,t}$: $Z_{i,t}=C_{i,t}+I_{i,t}$. The law of motion of the capital stock is $K_{i,t+1}=(1-\delta)K_{i,t}+I_{i,t}$, where $0<\delta<1$ is the capital depreciation rate.

At date t, the price of country i's final good equals its marginal cost: $P_{i,t}=(p_{i,t})^{1-\alpha}(p_{j,t})^{\alpha}$, $j\neq i$, where $p_{j,t}$ is the price of intermediate good j. Input demands are: $y^i_{i,t}=(1-\alpha)P_{i,t}Z_{i,t}/p_{i,t}$, $y^j_{i,t}=\alpha P_{i,t}Z_{i,t}/p_{j,t}$ for $j\neq i$. Market clearing for tradable goods requires $y^i_{H,t}+y^i_{F,t}=Y_{i,t}$ for $i=H,F$. Country i's terms of trade and real exchange rate are defined as

$$q_{i,t}\equiv p_{i,t}/p_{j,t} \text{ and } RER_{i,t}\equiv P_{i,t}/P_{j,t}, \text{ with } i\neq j,$$

respectively. Thus, increases in $q_{i,t}$ and $RER_{i,t}$ represent an improvement in the country i terms of trade, and an *appreciation* of its real exchange rate, respectively. Note that $RER_{i,t}=(q_{i,t})^{1-2\alpha}$; due to home bias, an improvement of a country's terms of trade induces an appreciation of its real exchange rate, as $1\text{-}2\alpha>0$ (the logged real exchange rate and terms of trade are perfectly positively correlated).

The country i household has a concave period utility function that is increasing in consumption and decreasing in hours worked:

$$u_{i,t}(C_{i,t},L_{i,t})=\tfrac{1}{1-\sigma}[\psi_{i,t}(C_{i,t},L_{i,t})]^{1-\sigma},\ \ \sigma>0,\ \ \sigma\neq 0, \tag{2}$$

where $\psi_{i,t}(C_{i,t},L_{i,t})>0$ is an affine function of $C_{i,t}$ (see below).

Intertemporal household preferences are described by a recursive life-time utility function inspired by Epstein and Zin (1989), and Weil (1989, 1990):

$$U_{i,t}=\{(1-\beta_{i,t})\cdot[\psi_{i,t}(C_{i,t},L_{i,t})]^{1-\sigma}+\beta_{i,t}\cdot[E_tU^{1-\gamma}_{i,t+1}]^{(1-\sigma)/(1-\gamma)}\}^{1/(1-\sigma)},$$

where $U_{i,t}>0$ is country i life-time utility at date t. (Epstein, Zin and Weil assume that utility only depends on consumption. The specification of recursive preferences used here, that also depends on labor, follows Rudebusch and Swanson (2012).) $0<\beta_{i,t}<1$ is i's subjective discount factor between periods t and t+1, $1/\sigma$ is the intertemporal elasticity of substitution (IES). γ indexes the household's aversion against uncertainty in future life-time utility. Standard time-separable preferences obtain when $\gamma=\sigma$, i.e. when γ=1/IES. Epstein, Zin and Weil assume that the subjective discount factor is constant. To ensure that the model has a unique deterministic steady state, and an equilibrium in which the consumption/GDP ratio is stationary, I posit that the subjective discount factor of household i is a decreasing function of its period utility, normalized by productivity: $\beta_{i,t}=\overline{\beta}-b\cdot\ln(\widetilde{u_{i,t}}/\widetilde{u})$ for σ<1 and $\beta_{i,t}=\overline{\beta}+b\cdot\ln(-\widetilde{u_{i,t}}/\widetilde{u_i})$ for σ>1, with b>0. Here $\widetilde{u_{i,t}}\equiv u_{i,t}/X_t^{1-\sigma}$ and $\widetilde{u_i}$ is the steady state value of $\widetilde{u_{i,t}}$; $X_{i,t}>0$ is a geometric moving average of past productivity:

$$X_{i,t}=(X_{i,t-1})^{1-\eta}(\theta_{i,t-1})^{\eta}, \text{ with } 0\leq\eta<1. \tag{3}$$

Country i's intertemporal marginal rate of substitution (IMRS) between aggregate consumption at dates t and t+1 is:

$$\rho_{i,t+1}\equiv\beta_{i,t}\frac{\Psi_{i,t+1}}{\Psi_{i,t}}\frac{\partial u_{i,t+1}/\partial C_{i,t+1}}{\partial u_{i,t}/\partial C_{i,t}}\left(\frac{U_{i,t+1}}{(E_t U_{i,t+1}^{1-\gamma})^{1/(1-\gamma)}}\right)^{\sigma-\gamma}, \tag{4}$$

with $\Psi_{i,t}\equiv 1-\beta_{i,t}-(b/\beta_{i,t})\cdot[(U_{i,t}/\psi_{i,t})^{1-\sigma}-1]$.[4] Note that when $\gamma=\sigma$ and b=0 is assumed, then $\rho_{i,t+1}=\overline{\beta}\cdot(\partial u_{i,t+1}/\partial C_{i,t+1})/(\partial u_{i,t}/\partial C_{i,t})$, i.e. the IMRS only depends on consumption and hours at t and t+1. When $\gamma\neq\sigma$, then the IMRS depends also on life-time utility $U_{i,t+1}$. When $\gamma>\sigma$, then an unexpected rise in $U_{i,t+1}$ induces a *fall* in the IMRS.

The model assumes complete international financial markets. In equilibrium, the Home/Foreign IMRS ratio is thus equated to the growth factor of the real exchange rate (Kollmann (1991, 1995), Backus and Smith (1993)):

$$\rho_{H,t+1}/\rho_{F,t+1}=RER_{t+1}/RER_t. \tag{5}$$

The market value of country i's net foreign assets at the end of period t, $NFA_{i,t+1}$, equals the present value of i's future net imports: $NFA_{i,t+1}=E_t\sum_{k=1}^{\infty}\rho_{i,t,t+k}\cdot(P_{i,t}/P_{i,t+k})\cdot(-NX_{i,t+k})$, where $NX_{i,\tau}\equiv p_{i,\tau}Y_{i,\tau}-P_{i,\tau}(C_{i,\tau}+I_{i,\tau})$ are net exports at date τ and $\rho_{i,t,t+k}\equiv\prod_{v=1}^{v=k}\rho_{i,t+v}$.

Optimal country i capital investment decisions are described by the Euler equation

$$1=E_t\rho_{i,t+1}\{(p_{i,t+1}/P_{i,t+1})\cdot MPK_{i,t+1}+1-\delta\},$$

[4]In the numerical simulations, b is set at a very small value, which implies that the term $\beta_{i,t}\Psi_{i,t+1}/\Psi_{i,t}$ in (4) makes a negligible contribution to high-frequency fluctuations of $\rho_{i,t+1}$.

where $MPK_{i,t+1} \equiv (1-\omega) Y_{i,t+1}/K_{i,t+1}$ is the date t+1 physical marginal product of capital in the country; $(p_{i,t+1}/P_{i,t+1}) \cdot MPK_{i,t+1}$ is the marginal product of capital expressed in units of country i consumption. Let $w_{i,t}$ denote the wage rate, in final consumption units. Intermediate good producing firms equate the marginal product of labor, in consumption units, to the wage rate:

$$(p_{i,t}/P_{i,t}) \cdot MPL_{i,t} = w_{i,t}, \tag{6}$$

where $MPL_{i,t+1} \equiv \omega Y_{i,t}/L_{i,t}$ is the physical marginal product of labor. Note that $p_{i,t}/P_{i,t} = (q_{i,t})^{\alpha} = (RER_{i,t})^{\alpha/(1-2\alpha)}$; thus, an improvement of the country i terms of trade $q_{i,t}$ (and an appreciation of its real exchange rate) raise the marginal products of capital and of labor, in consumption units. This increases the demand for capital (investment) and labor in country *i*.

As shown below, a positive shock to Home productivity improves the Foreign terms of trade. Under standard period utility functions, this induces opposing substitution and wealth effects on Foreign hours worked, with the former increasing and the latter decreasing Foreign labor supply. To highlight the role of the wealth effect on labor supply for international shock transmission, I compare model variants with the King, Plosser and Rebelo (1989) [KPR] period utility function that is widely used in the international macro literature (e.g. Backus et al. (1994)) to model variants with period utility à la Greenwood, Hercowitz and Huffman (1988) [GHH].[5] Under KPR utility, a wealth increase reduces desired labor supply. By contrast, the wealth effect on labor supply is zero under GHH utility.

KPR utility obtains when $\psi_{i,t} = C_{i,t} \cdot \zeta(L_{i,t})$, with $\zeta' < 0$ (see (2)).[6] The model variants with GHH utility below assume $\psi_{i,t}(C_{i,t}, L_{i,t}) = C_{i,t} + X_{i,t} \nu(L_{i,t})$, with ν',ν''<0,

[5]Some studies that have explored open economy models with GHH period utility, but without considering recursive intertemporal preferences, and without discussing implications for cross-country real activity correlations; e.g., Devereux et al. (1992), Correia and Rebelo (1995), Jaimovich and Rebelo (2008) and Raffo (2010).

[6]Concavity of the KPR period utility function requires $\zeta'' < (2-1/\sigma)(\zeta')^2/\zeta$.

where $X_{i,t}$ is the moving average of past productivity defined in (3).[7] The simulations below use these functional forms of labor disutility:

$$\zeta(L_{i,t})\equiv 1+\nu(L_{i,t}), \text{ with } \nu(L_{i,t})\equiv -\tfrac{1}{1+1/\eta}\cdot\{(L_{i,t})^{1+1/\eta}-L^{1+1/\eta}\}, \tag{7}$$

where L denotes steady state hours.

The household determines her desired labor supply by equating the marginal rate of substitution between consumption and leisure to the consumption wage: $mrs_{i,t}=w_{i,t}$, where $mrs_{i,t}\equiv-(\partial\psi_{i,t}/\partial L_{i,t})/(\partial\psi_{i,t}/\partial C_{i,t})$. Under KPR utility, $mrs_{i,t}=-C_{i,t}\cdot\zeta'(L_{i,t})/\zeta(L_{i,t})$ holds; thus, a rise in consumption increases the marginal rate of substitution, which raises the household's asking wage. The effect of a wage increase, that also raises consumption, on desired labor supply is ambiguous under KPR utility: the positive substitution effect of the wage increase is counteracted by a negative wealth effect.[8] Under GHH utility, by contrast, $mrs_{i,t}=-X_{i,t}\nu'(L_{i,t})$, i.e. the marginal rate of substitution does not depend on consumption: given the exogenous quantity $X_{i,t}$, a wage increase raises labor supply unambiguously (zero wealth effect).

I compare model variants with a flexible consumption wage rate, in which firm labor demand equals household labor supply ($p_{i,t}MPL_{i,t+1}/P_{i,t+1}=w_{i,t}=mrs_{i,t}$), to model variants with wage rigidity, in which the real consumption wage rate is set one period in advance, at the expected future marginal rate of substitution between consumption and leisure: $w_{i,t}=E_{t-1}mrs_{i,t}$. Under a predetermined wage rate, labor hours are determined by firms' labor demand (6);[9] thus, households can (temporarily) be off their labor supply schedule ($w_{i,t}\neq mrs_{i,t}$), which mutes the wealth effect on hours.

[7]Under GHH utility, the disutility of labor is scaled by $X_{i,t}$ to permit balanced growth, and to ensure that equilibrium hours worked are stationary; the $X_{i,t}$ term can be rationalized by assuming that there is home production by households (e.g., Rudebusch and Swanson (2012)). KPR utility is consistent with balanced growth and stationary hours when the disutility of work is not scaled by productivity.

[8]Total differentiation of the KPR labor supply condition gives $\widehat{w_{i,t}}=\widehat{C_{i,t}}+\Xi\widehat{L_{i,t}}$, with $\hat{x}\equiv dx/x$ and $\Xi\equiv(\zeta''\cdot L/\zeta'-\zeta'\cdot L/\zeta)$. The Frisch labor supply elasticity (computed at constant consumption), LSE, is: LSE=1/Ξ. At a given wage rate, a rise in consumption reduces hours worked when LSE>0.

[9]Rigid-wage models usually assume that hours are demand-determined (e.g. Blanchard and Gali (2007), Kollmann et al. (2016)).

Empirical fluctuations of productivity, and of relative (domestic/foreign) productivity, are highly persistent. The model assumes that log productivity has a unit root, and that log productivity is co-integrated across countries:

$$\ln(\theta_{i,t+1})-\ln(\theta_{i,t})=-\kappa\cdot[\ln(\theta_{i,t})-\ln(\theta_{j,t})]+\varepsilon^{\theta}_{i,t+1}\text{, with } \kappa>0, \text{ for } i=H,F \text{ and } j\neq i, \tag{8}$$

where $\varepsilon^{\theta}_{i,t+1}$ is a Gaussian white noise.

2.2. Numerical solution method

As productivity is assumed non-stationary, but cointegrated across countries, I reformulate the model by normalizing country *i* GDP, consumption, investment, net exports and utility by *i*'s productivity. The model has a stationary equilibrium, in terms of the normalized variables. I solve the reformulated model with the Dynare toolbox (Adjemian et al. (2014)) using a third-order approximation around the symmetric deterministic steady state.

2.3. Calibration

2.3.1. Preference and technology parameters

One period represents one quarter. The steady state subjective discount factor and the slope parameter of the endogenous discount factor are set at $\overline{\beta}=0.99$ and $b=0.001$, respectively.[10] The intertemporal elasticity of substitution (IES) $1/\sigma$ is set at 1.5, in line with standard values used in the macro literature. Following the macro-finance literature (e.g. Swanson (2014)), I consider high risk aversion coefficients: $\gamma=10$ and $\gamma=50$, but I also discuss a case with $\gamma=1/\text{IES}=0.66$ (standard time-separable preferences). The Frisch labor supply elasticity in set at 2, a standard value used in macro models; that elasticity generates hours volatility broadly in line with the data.[11]

The model will be evaluated by comparing model-predicted business cycle statistics to empirical statistics of 1973-2013 quarterly data for the US and for an

[10]The small value of b implies that short term model dynamics are similar to those generated by a (non-stationary) model variant with a constant subjective discount factor ($b=0$).

[11] Under KPR utility, the Frisch labor supply elasticity, LSE, at the steady state is LSE=$1/(1/\eta+\omega/s_C)$, where η is the curvature of labor disutility (see (7)) and s_C is the steady state consumption/GDP ratio. s_C depends solely on ω,δ and $\overline{\beta}$. Under GHH utility, LSE=η.

aggregate of 13 other OECD economies (hereafter named 'rest of the world', ROW) for which quarterly aggregate hours worked series were constructed by Ohanian and Raffo (2012, 2014).[12] Long historical quarterly times on hours worked are only available for these 13 countries and for the US (the US hours data used here is the BLS series 'hours of wage and salary worked on nonfarm payrolls'). The choice of 13 ROW countries is thus dictated by the availability of quarterly hours data (that are needed for estimating quarterly productivity series, the driving force of economic fluctuations in the model).

The labor share is calibrated at ω=0.65, consistent with US and ROW data.[13] The depreciation rate of capital is set at δ=0.025, as in standard quarterly macro models. In 1973-2013, the mean US trade share (0.5*(exports+imports)/GDP) was 10%. Hence, the import share parameter in the model is set at α=0.10 (see (1)).

2.3.2. Exogenous process

I estimate the parameters of the productivity process (8) using quarterly US and ROW productivity series (1973-2013). Empirical log labor augmenting productivity for country i is constructed as $\ln(\theta_{i,t})=(\ln(GDP_{i,t})-\omega_i \ln(L_{i,t})-(1-\omega_i)\ln(K_{i,t}))/\omega_i$, where ω_i is the sample average of country *i's* wage share. Quarterly capital series are obtained by cubic spline interpolation of annual capital stocks from the Penn World Table. Aggregate ROW productivity is a GDP-weighted index of productivity in the 13 individual ROW countries.[14] The standard deviations of first differenced quarterly US and (aggregate) ROW log productivity are 0.88% and 0.68%, respectively, i.e. the average standard deviation (across the two regions) is 0.78%. The empirical correlation between US and ROW productivity growth is 0.13. In the calibrated model, I thus set the standard

[12] The 13 ROW countries are: Australia, Austria, Canada, Finland, France, Germany, Ireland, Italy, Japan, Korea, Norway, Sweden, UK. The Ohanian-Raffo quarterly hours data (available until 2013) are estimated from time series on employment and hours worked per employee (ILO, OECD).

[13] In the model, the share of GDP going to labor equals ω; the sample average of the labor share (compensation of employees/(GDP net of indirect taxes)) is 0.64 (0.66) in the US (ROW).

[14] ROW aggregates of productivity are Törnqvist indices, and so are the ROW aggregates for *GDP*, *C*, *I* and *L* discussed in Sect. 3 below. For variable 'X', the ROW aggregate $X_{ROW,t}$ obeys $\Delta\ln X_{ROW,t}=\sum_{j=1}^{13} s_{j,t}\Delta\ln X_{j,t}$ where $X_{j,t}$ is the country *j* observation, and $s_{j,t}$ the weight of country *j* at date *t*, with $\sum_j s_{j,t}=1$. Weights equal countries' smoothed nominal GDP shares in aggregate ROW nominal US$ GDP, at current exchange rates; to reduce the effect of nominal exchange rate volatility, exponential time trends are fitted to raw GDP shares, and fitted trend shares are used as weights.

deviation of $\Delta\ln(\theta_{i,t})$ at 0.78% (for i=H,F); the correlation between $\Delta\ln(\theta_{H,t})$ and $\Delta\ln(\theta_{F,t})$ is set at 0.13. An Augmented Dickey-Fuller test fails to reject the hypothesis that relative US/ROW productivity has a unit root. To ensure stationarity of the normalized model, the productivity error correction parameter (see (8)) is set at a small positive value, κ=0.001. The partial adjustment parameter of the preference shifter $X_{i,t}$ (see (3)) is set at η=0.001, which ensures that a productivity shock has a negligible short-run effect on preferences.

3. Stylized facts about international business cycles

Table 1 reports historical business cycle statistics (1973-2013) for US and ROW quarterly GDP, consumption, gross investment, hours worked, net exports (NX) and the US real effective exchange rate (CPI-based). The empirical consumption measure is the sum of private and government consumption. Net exports are normalized by domestic GDP.[15] The statistics shown in Table 1 pertain to first differenced quarterly data. GDP, consumption, investment, hours and the real exchange rate are logged before first differencing.

The historical standard deviation of GDP growth is 0.81% in the US, and 0.59% in the ROW; thus US GDP is more volatile than ROW GDP. The Table reports 'relative standard deviations' of other variables, i.e. standard deviations divided by the standard deviation of GDP. Relative standard deviations are broadly similar across the US and the ROW. Consumption, net exports and hours worked are less volatile than GDP, while investment and the real exchange rate are 3-4 times more volatile than GDP. Consumption, investment and hours worked are positively correlated with domestic GDP. US net exports are negatively correlated with domestic GDP; the real exchange rate is weakly countercyclical.

This paper is mainly motivated by the fact that cross-country (US-ROW) correlations of GDP and hours worked are sizable (about 0.45). Cross-country correlations of consumption and investment too are positive (about 0.35) but slightly lower. Importantly, the cross-country correlations of GDP, consumption, investment and hours are noticeably *higher* than the cross-country correlation of productivity (0.13).

[15]The NX/GDP series for the ROW is a GDP-weighted average of individual countries' NX/GDP.

Thus the model here will only produce realistic cross-country correlations if it generates synchronized responses to country-specific productivity shocks.

4. Model predictions

Table 2 reports predicted standard deviations and cross-correlations of key variables generated by different model variants. Predicted moments of GDP, consumption, investment, hours worked and the real exchange rate pertain to log first differenced variables, while moments for 'net exports' pertain to the first differenced net exports/GDP ratio. The Table also reports the Hansen-Jagannathan (1991) bound ['HJ bound'] generated by the model, i.e. the ratio of the standard deviation of the intertemporal marginal rate of substitution (IMRS) divided by the mean IMRS. That statistic allows to evaluate whether the model has the potential to generate realistic risk premia on financial assets. In equilibrium, the Sharpe ratio of any traded risky asset is bounded above by the HJ bound. The historical quarterly Sharpe ratio of US equity returns was 0.22 in 1973-2013.[16] Thus, a model-generated HJ bound below 0.22 indicates that the model cannot generate a realistic equity premium.

Cols. (1)-(6) of Table 2 report predicted moments generated by model variants with a flexible consumption wage rate ('flex-wage'), while Cols. (7)-(12) show moments for predetermined-wage model variants. For each of these model variants, I report predicted moments generated under KPR utility and under GHH utility, and that for three values of the risk aversion coefficient: γ=1/IES, γ=10 and γ=50. Historical US moments (from Table 1) are shown in Col. (13) of Table 2.

Table 3 report dynamic effects of a one-standard deviation (0.78%) positive innovation to Home productivity, for the flex-wage model variant (Panel (a)), and for the predetermined-wage model variant (Panel (b)).

4.1. Flex-wage model variants (Table 2, Cols. (1)-(6); Table 3, Panel (a))

Consider first the predicted moments generated by the flex-wage model variant. That variant matches well the historical volatility of US GDP; it also capture the fact that

[16] That Sharpe ratio is based on returns data from Ken French's web page. The Sharpe ratio of an asset is the ratio of the mean of its excess return (relative to a risk-free asset) divided by its standard deviation.

investment is much more volatile than GDP, while consumption, hours and net exports are less volatile than GDP. Under all model specifications (KPR/GHH, time separable/recursive), investment and hours worked are pro-cyclical (positively correlated with domestic output), and the real exchange rate is countercyclical. Consumption is pro-cyclical in all model variants with GHH utility.[17] The following discussion focuses on model predictions for the real exchange rate and for international correlations.

Flex-wage model variants with time-separable preferences (γ=1/IES) show well-known shortcomings of standard international macro models (e.g., Backus et al. (1994)); in particular, the predicted cross-country correlations of GDP, investment and hours worked are smaller than empirical cross-country correlations; this is the case under *both* KPR and GHH period utility (see Cols. (1) and (4)). The predicted cross-country GDP correlations with γ=1/IES is 0.23 (0.14) under KPR (GHH) utility, while the empirical correlation is 0.45. Furthermore, the predicted relative standard deviation of the real exchange rate (0.37 [0.16] under KPR [GHH] utility) is much smaller than the empirical relative standard deviation (3.03). In addition, the HJ bounds generated by the model variants with γ=1/IES are close to zero, i.e. those variants cannot generate a realistic equity premium.

The flex-wage model variants with recursive preferences (γ=10 and γ=50; see Cols. (2)-(3) and (5)-(6)) generate greater real exchange rate volatility and greater HJ bounds (i.e. higher IMRS volatility) than the flex-wage model variants with time-separable preferences (γ=1/IES). Persistent productivity shocks have a sizable effect on life-time utility; with recursive preferences ($\gamma\neq$1/IES), the IMRS is affected by fluctuations in life-time utility, which triggers strong real exchange rate responses under efficient risk sharing (see (4),(5)). The greater the risk aversion coefficient γ, the greater the predicted volatility of the IMRS and of the real exchange rate. The KPR and GHH flex-wage model variants with γ=10 (γ=50) generate HJ bounds of about 0.05 (0.24), respectively, and a relative standard deviation for the real exchange rate of about 1.2 (1.5). Hence, recursive preferences with substantial risk aversion are needed to generate a realistic HJ bound, and a volatile real exchange rate.

[17] Consumption is countercyclical in KPR model variants with recursive preferences.

Recursive preferences have an effect on predicted cross-country correlations; that effect depends on the period utility function. In the flex-wage model with KPR period utility, the assumption of recursive preferences *lowers* the predicted cross-country correlations (compared to time-separable preferences), i.e. the correlation puzzle *worsens*. By contrast, under GHH utility, recursive preferences produce *higher* cross-country correlations. When γ=50, the predicted cross-country correlations of GDP, consumption, investment and hours are, 0.14, -0.02, 0.34 and 0.15, respectively under KPR utility (in the flex-wage structure); see Col. (3). The corresponding predicted correlations under GHH utility are 0.35, 0.65, 0.64 and 0.62, respectively (Col. (6)). In the flex-wage GHH model variant with high risk aversion (γ=50), the predicted cross-country correlation of GDP remains thus below the empirical correlation (0.45), but the predicted cross-country correlations of consumption, investment and hours *exceed* the empirical correlations.

The dynamic responses to a one-standard Home productivity innovation (0.78%) reported in Table 3 (Panel (a)) help to understand these properties if the flex-wage model. The Home productivity shock triggers a persistent rise in Home GDP, consumption and investment; it also deteriorates the Home terms of trade, and depreciates the Home real exchange rate. Under time-separable preferences (γ=1/IES), the terms of trade (and real exchange rate) response is modest, and Home net exports fall persistently (see Cols. (9) and (10) of Panels (a1) and (a3)). Home net foreign assets (the present value of Home net imports) increase thus, on impact, and remain persistently above their unshocked path (Col. (11)). Under time-separable preferences, the Home country *receives* thus a wealth transfer from the Foreign country, in response to the positive Home productivity shock. Home hours worked rise—the rise is more persistent under GHH utility than under KPR utility. Under time-separable preferences (KPR and GHH), Foreign consumption falls initially, because of the appreciation of the Foreign real exchange rate; Foreign hours and GDP rise very slightly, which reflects the modest improvement in the Foreign terms of trade.[18] That muted Foreign response explains the low predicted cross-country correlations generated by the flex-wage model variants with time-separable preferences.

[18]The Home productivity increase raises Home hours. Under KPR utility (with σ<1) a rise in hours reduces the marginal (period) utility of consumption, while the opposite is the case under GHH. This helps to

The effect of the Home productivity increase on Foreign real activity changes when recursive preferences (γ>1/IES) are assumed. The productivity shock raises Home lifetime utility. When γ>1/IES, this *lowers* the Home country's IMRS (between the period preceding the shock and the date of the shock); see (4). Foreign life-time utility rises less, because of consumption home bias, and hence the relative Home/Foreign IMRS falls. Efficient risk sharing with recursive preferences then implies that Home consumption rises less than under time-separable preferences, while Foreign consumption rises more.[19] Also, the Home real exchange rate depreciates more strongly, and thus the Home terms of trade deteriorate more sharply. (Recall that the gross rate of appreciation of the Home real exchange rate is equated in equilibrium to the relative Home/Foreign IMRS; see (5)). For example, under GHH utility, the Home real exchange rate depreciates by 0.99% on impact, with recursive preferences (γ=50), compared to a 0.010% depreciation with time-separable preferences (the corresponding changes of the Home terms of trade are -1.23% and -0.012%, respectively). The greater deterioration of the Home terms of trade (with recursive preferences) dampens the rise in Home investment induced by the Home productivity shock, and it strengthens the rise in Foreign investment.

The more muted rise in Home consumption and investment, under recursive preferences, implies that Home net exports rise persistently, in response to the Home productivity increase. Thus, Home net foreign assets fall, on impact. This shows that efficient risk sharing with recursive preferences implies that the Home household makes a wealth transfer **to** the Foreign household. This transfer contributes to the stronger depreciation of the Home real exchange rate.

The stronger rise in Foreign consumption under recursive preferences explains why, in the flex-wage structure, Foreign hours worked rise *less* when households have KPR period utility (negative wealth effect on labor supply). This is why, in a flex-wage world with KPR utility, the assumption of recursive preferences *lowers* the predicted cross-country correlations of hours and output (as discussed above). By contrast, under

understand why Home consumption rises less and the Home real exchange rate depreciates more, with KPR utility than with GHH utility.

[19]With recursive preferences and KPR period utility, Home consumption actually *falls* on impact, and thus consumption is countercyclical, as mentioned above (with GHH utility, Home consumption rises on impact).

GHH utility (zero wealth effect on labor supply), Foreign hours and GDP rise more strongly when recursive preferences are assumed (compared to time-separable preferences)--the stronger improvement in the Foreign terms of trade, under recursive preferences, implies a stronger rise in Foreign hours, due to a stronger positive substitution effect on labor supply, as well as a stronger rise in Foreign labor demand. This highlights that recursive preferences and a weak wealth effects on labor are *jointly* needed for generating synchronized responses of Home and Foreign real activity to country-specific productivity shocks.

4.2. Predetermined-wage model variants (Table 2, Cols. (7)-(12); Table 3, Panel (b))

When the consumption wage rate is set one period in advance, then a positive innovation to Home productivity induces, on impact, a stronger rise in Home labor hours, GDP and investment, than in the flex-wage model. This holds for all preferences specifications and is due to the fact that, in the period of the shock, workers are off their labor supply schedule and hours worked are solely demand-determined. However, after one period, workers are again on their labor supply schedule, and responses to the shock are similar to the ones predicted by the flex-wage model.[20] The impact effect of a productivity shock on the real exchange rate remain similar to the effect in the flex-wage world; thus the Home real exchange rate (and terms of trade) depreciation is again much stronger under recursive preferences than under time-separable preferences (see Table 3, Panel (b)). Importantly, the recursive-preferences model variants with a predetermined wage rate predicts that the Home productivity shock triggers a strong initial rise in *Foreign* hours worked and GDP (see Table 3, Panels (b2),(b4)). With risk aversion γ=50, a one-standard deviation innovation to Home productivity raises Home and Foreign GDP by about 1.2% and 0.2%, respectively, on impact, under both KPR and GHH period utility. Intuitively, the sizable Foreign terms of trade improvement under recursive preferences boosts Foreign firms' labor demand—which raises Foreign hours worked and GDP, on impact,

[20]The stronger short-run rise in Home GDP explains why the predicted standard deviation of output (about 1.4%) is higher than in the flex-wage structures. Also, the predicted relative standard deviation of hours worked is now slightly larger than the empirical relative standard deviation (by contrast the flex-wage model variants yields a relative volatility of hours that is slightly below the empirical relative volatility).

at the predetermined consumption wage rate.[21] The KPR and GHH predetermined-wage model variants with recursive preferences and high risk aversion (γ=50) match closely the empirical cross-country GDP correlations (0.45). These model variants also generate sizable predicted cross-country correlations of consumption, investment and hours worked (in the range 0.5-0.7). By contrast, under time-separable preferences, the assumption of a predetermined wage rate does not raise the cross-country GDP correlation (compared to the flex-wages structure), as the terms of trade response to productivity shocks remains muted. This confirms that recursive preferences and a weak wealth effects on labor are *jointly* necessary for international business cycle synchronization, in response to productivity shocks.

5. Conclusion

This paper has shown that a simple two-country business cycle model can generate sizable cross-country correlations of real activity if two key assumptions are made: (i) households have recursive preferences; (ii) the wealth effect on labor supply is muted. With recursive preferences, a persistent productivity (and GDP) increase in a given country triggers a strong improvement of the foreign country's terms of trade. This induces a rise in foreign hours worked and GDP, when the wealth effect on the foreign labor supply is weak. In the model here, country-specific productivity shocks can thus generate highly correlated domestic and foreign business cycles, and a volatile real exchange rate.

[21] With wage flexibility, the rise in Foreign labor demand increases the Foreign wage rate, which dampens the rise in hours worked. When the wage rate is predetermined, the labor input rises more strongly, as the wage rate does not increase immediately.

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Table 1. Historical statistics (1973-2013)

	US	ROW
Standard deviations (in %)		
GDP	0.81	0.59
Standard deviations relative to GDP		
Consumption	0.66	0.74
Investment	4.09	3.53
Hours worked	0.89	0.71
Net exports/GDP	0.40	0.48
Real exchange rate	3.03	n.a.
Correlations with domestic GDP		
Consumption	0.63	0.67
Investment	0.84	0.73
Hours worked	0.71	0.43
Net exports/GDP	-0.23	0.04
Real exchange rate	-0.07	n.a.
Cross-country correlations		
GDP	0.45	
Consumption	0.35	
Investment	0.34	
Hours worked	0.43	

Note: Empirical statistics (1973q1-2013q4) are shown for quarterly macroeconomic variables in the US and in an aggregate of 13 other OECD economies ('ROW'); see text for list of countries. The statistics pertain to first differenced quarterly data. 'Consumption' is the sum of private and government consumption. 'Investment' is gross investment (private and public).

GDP, consumption, investment, hours worked and the real exchange rate are logged before first differencing. ROW aggregates of GDP, consumption, investment and hours worked are GDP-weighted Törnqvist indices of variables in individual ROW countries. ROW net exports/GDP is a GDP-weighted average of NX/GDP in individual countries. The GDP weights (used for the construction of ROW aggregates) are smoothed GDP shares in aggregate ROW GDP (see main text).

The real exchange rate is the US (trade weighted) real effective exchange rate (CPI based). A rise in RER represents an appreciation. Due to limited data availability, statistics for the real effective exchange rate are only shown for the US.

Data sources—Hours worked: US Bureau of Labor Statistics; Ohanian and Raffo (2012, 2014). All other data are from the OECD statistics database.

Table 2. Predicted moments: role of flexible & predetermined wage, KPR & GHH utility, risk aversion coefficient (γ).

	Flexible wage rates						Predetermined wage rates						
	KPR utility			GHH utility			KPR utility			GHH utility			
	γ=1/IES	γ=10	γ=50	γ=1/IES	γ=10	γ=50	γ=1/IES	γ=10	γ=50	γ=1/IES	γ=10	γ=50	**Data**
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*
Standard deviations (in %)													
Y	0.82	0.84	0.85	0.90	0.85	0.84	1.52	1.38	1.36	1.54	1.39	1.36	0.81
Standard deviations relative to GDP													
C	0.22	0.22	0.25	0.48	0.36	0.39	0.49	0.48	0.48	0.81	0.72	0.72	0.66
I	3.95	3.62	3.49	3.58	3.37	3.37	5.58	5.07	4.92	2.27	2.14	2.13	4.09
L	0.61	0.63	0.63	0.67	0.62	0.61	1.12	1.07	1.07	1.08	1.04	1.03	0.89
NX	0.10	0.05	0.08	0.16	0.09	0.15	0.13	0.04	0.04	0.17	0.08	0.10	0.40
RER	0.37	1.32	1.51	0.16	1.21	1.53	0.22	0.82	0.95	0.09	0.75	0.95	3.03
Correlations with domestic GDP													
C	0.42	-0.18	-0.28	0.70	0.41	0.26	-0.81	-0.82	-0.83	0.95	0.92	0.89	0.63
I	0.98	0.98	0.98	0.96	0.94	0.94	0.98	0.98	0.98	0.94	0.94	0.93	0.84
L	0.97	0.98	0.98	0.99	0.99	0.98	0.97	0.97	0.97	0.98	0.98	0.97	0.71
NX	-0.62	0.57	0.61	-0.64	-0.04	0.11	-0.62	-0.09	0.27	-0.65	-0.49	-0.29	-0.23
RER	-0.60	-0.65	-0.66	-0.13	-0.55	-0.53	-0.55	-0.50	-0.48	-0.06	-0.48	-0.45	-0.07
Cross-country correlations													
Y	0.23	0.15	0.14	0.14	0.31	0.35	0.21	0.47	0.52	0.14	0.40	0.47	0.45
C	0.13	0.13	-0.02	-0.30	0.70	0.65	0.24	0.63	0.69	-0.09	0.55	0.69	0.35
I	0.19	0.31	0.34	0.21	0.56	0.64	0.11	0.60	0.70	0.04	0.44	0.54	0.34
L	0.38	0.19	0.15	0.15	0.53	0.62	0.23	0.65	0.73	0.14	0.52	0.61	0.43
Hansen-Jagannathan bound													
	0.002	0.050	0.257	0.002	0.047	0.225	0.003	0.050	0.257	0.002	0.047	0.225	

Note: This Table reports predicted moments generated by model variants with flexible wage rates (Cols. (1)-(6)) and by model variants with predetermined consumption wage rate (Cols. (7)-(12)). Cols. (1)-(3) and (7)-(9) assume a period utility function of the King, Plosser and Rebelo (1988) [KPR] type, while Cols. (4)-(6) and (10)-(12) assume a period utility function of the Greenwood, Hercowitz and Huffman (1988) [GHH] type. Cols. (1),(4),(7),(10) assume risk aversion of γ=1/IES(=0.66); Cols. (2),(5),(8),(11) assume risk aversion γ=10; Cols. (3),(6),(9),(12) assume risk aversion γ=50. Col. (13) shows empirical statistics for the US (from Table 1).

Variables are listed in the left-most column. Statistics for GDP (Y), consumption (C), investment (I), hours worked (L) and the real exchange rate (RER) pertain to log growth rates of these variables. Statistics for net exports (NX) pertain to the first difference of the net exports/GDP ratio. A rise in RER represents an appreciation.

The Hansen-Jagannathan bound is defined as the ratio of the unconditional standard deviation of the intertemporal marginal rate of substitution (IMRS), divided by the unconditional mean of the IMRS.

The Table reports *simulated* moments. For each model variant, a simulation run of 55000 periods was generated (initialized at the deterministic steady state); the first 5000 periods were discarded (to reduce influence of initial conditions); reported moments were computed using the remaining 50000 periods. Averaging moments across repeated shorter simulation runs (e.g. of length 164 periods, the number of periods in the historical sample) produces results close to the figures reported in the Table.

Table 3. Dynamic responses to a Home country productivity innovation (1 standard dev.)

Horizon	Y_H	Y_F	C_H	C_F	I_H	I_F	L_H	L_F	RER_H	NX_H	NFA_H
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*
(a) Flexible wage rate											
(a1) KPR utility; risk aversion γ=1/IES											
0	0.81	0.04	0.08	-0.03	3.09	0.11	0.46	0.06	-0.22	-0.06	1.98
4	0.78	0.05	0.33	-0.01	2.15	0.18	0.28	0.06	-0.29	-0.05	1.86
50	0.70	0.08	0.68	0.09	0.64	0.14	-0.02	0.02	-0.37	-0.02	1.47
(a2) KPR utility; risk aversion γ=50											
0	0.84	0.00	-0.07	0.12	2.46	0.33	0.51	0.00	-1.00	0.05	-7.91
4	0.81	0.01	0.16	0.16	1.82	0.33	0.34	-0.01	-1.06	0.07	-8.02
50	0.74	0.03	0.50	0.28	0.59	0.18	0.07	-0.07	-1.09	0.08	-8.03
(a3) GHH utility; risk aversion γ=1/IES											
0	0.89	0.00	0.31	-0.19	3.06	0.13	0.60	0.00	-0.01	-0.11	8.49
4	1.06	0.02	0.58	-0.16	2.86	0.20	0.69	0.03	-0.12	-0.11	8.38
50	1.75	0.27	1.75	0.16	1.88	0.47	1.10	0.22	-0.54	-0.10	7.09
(a4) GHH utility; risk aversion γ=50											
0	0.80	0.09	0.03	0.09	2.41	0.88	0.45	0.15	-0.99	0.07	-6.47
4	0.93	0.16	0.24	0.18	2.26	0.89	0.53	0.19	-1.04	0.07	-6.51
50	1.48	0.55	1.18	0.73	1.50	0.88	0.86	0.47	-1.20	0.07	-6.94
(b) Predetermined wage rate											
(b1) KPR utility; risk aversion γ=1/IES											
0	1.39	0.06	-0.38	-0.04	6.90	-0.02	1.36	0.09	-0.26	-0.13	1.93
4	0.77	0.05	0.39	-0.01	1.90	0.21	0.23	0.06	-0.31	-0.04	1.84
50	0.70	0.08	0.68	0.09	0.64	0.14	-0.02	0.02	-0.37	-0.02	1.47
(b2) KPR utility; risk aversion γ=50											
0	1.21	0.24	-0.36	-0.06	5.02	1.73	1.09	0.36	-1.01	0.04	-8.01
4	0.81	0.01	0.20	0.18	1.68	0.26	0.31	-0.03	-1.07	0.07	-8.02
50	0.74	0.03	0.50	0.28	0.59	0.18	0.07	-0.07	-1.09	0.08	-8.02
(b3) GHH utility; risk aversion γ=1/IES											
0	1.45	0.00	1.05	-0.19	3.31	-0.13	1.44	0.01	-0.02	-0.18	8.44
4	1.06	0.02	0.58	-0.17	2.86	0.21	0.69	0.03	-0.12	-0.11	8.38
50	1.75	0.27	1.75	0.16	1.88	0.47	1.10	0.22	-0.54	-0.10	7.09
(b4) GHH utility; risk aversion γ=50											
0	1.22	0.23	0.59	0.27	2.55	0.75	1.09	0.35	-0.99	0.03	-6.46
4	0.93	0.15	0.24	0.17	2.26	0.89	0.53	0.19	-1.04	0.07	-6.53
50	1.48	0.55	1.18	0.73	1.50	0.88	0.86	0.47	-1.20	0.07	-6.95

Note: The Table shows effect of an exogenous one-time innovation (1 std, 0.78%) to Home productivity on selected variables after 0, 4 and 50 quarters (see left-most Column labeled 'Horizon'). Cols. (1)-(8) show responses of Home and Foreign GDP (*Y*), consumption (*C*), investment (*I*), hours worked (*L*). Cols. (9)-(11) show responses of the Home real exchange rate (*RER*), net exports (*NX*) and net foreign assets (*NFA*). A rise in *RER* is an appreciation. Net exports and net foreign assets are normalized by quarterly Home GDP. Responses of GDP, consumption, investment and hours are expressed as % deviations from unshocked paths. Responses of net exports and net foreign assets (normalized by GDP) are expressed as percentage point differences from unshocked paths. All predetermined state variables are set at their unconditional mean, in the period of the shock (t=0).