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National Financial Frictions and International Business Cycle Synchronization

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Abstract

A two-country real business cycle model with national endogenous borrowing constraints and frictionless international financial markets can account for the high level of international co-movements. The borrowing mechanism brings about a wedge between the real interest rate and the expected marginal product of capital, which plays a key role in the international transmission of technology shocks. Moreover, terms of trade are amplified by the effects of these shocks on real interest rates which ultimately lead to greater synchronization of economic activities across countries. Finally, the signs of international co-movements are not sensitive to the structure of international asset markets (incomplete markets or financial autarky). Therefore, in the presence of national financial frictions, international efficiency cannot be assessed from looking at the behavior of aggregate variables.

JEL identification: E44, F34, F44
Keywords: borrowing constraints, working capital, international co-movements, terms of trade

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1 Introduction

In this paper, I examine the role of national borrowing constraints in accounting for *international business cycle synchronization*. Backus, Kehoe, and Kydland's (1992) model (hereafter BKK), which stands as a benchmark in the international real business cycle (IRBC) literature, fails to replicate highly positive cross-country correlations in output, investment, and hours worked. In contrast to BKK's results, I show that interest rates can decrease in response to positive technology shocks in an environment where firms face working capital requirements. Internationally, this mechanism leads workers of the country hit by the technology shock to initially lend to the workers of the other country. A simple and parsimonious baseline model augmented with terms of trade dynamics allows for significant levels of business cycle synchronization. The mechanism at work does not require financial intermediaries, international portfolios, nor monetary policy interventions.

Table 1 presents cross-country correlations in real GDP, consumption, investment, and hours worked for pairings of the US and OECD countries from 1971Q1 to 2010Q4. At a business cycle frequency, almost all international correlations are positive and the correlations with an aggregate of OECD countries are strong. It is important to understand how international transmission works and through which channels shocks propagate from one country to another. There are also some implications for international risk-sharing; as outputs and factors of production evolve in the same direction, this leaves little room for countries to smooth out consumption fluctuations. One major finding of this paper is that studying international co-movements of macroeconomic aggregates is not informative of the level of international efficiency. Specifically, the predictions of incomplete markets and financial autarky are undistinguishable when two-country models feature national financial frictions. I argue that there are welfare gains to be made on an international basis due to dampening

Table 1: International correlations

	International correlations			
	GDP	Consumption	Investment	Hours worked
Country:				
Australia	0.44	-0.01	0.36	0.44
Austria	0.39	0.22	0.36	0.18
Belgium	0.43	0.2	0.34	-
Canada	0.74	0.56	0.29	0.64
Denmark	0.66	0.54	0.59	-
Finland	0.35	0.22	0.01	0.28
France	0.5	0.42	0.33	0.45
Germany	0.5	0.44	0.53	0.56
Greece	0.42	0.17	0.35	-
Iceland	0.32	0.27	0.35	-
Ireland	0.38	0.57	0.47	0.57
Italy	0.47	0.09	0.29	0.02
Japan	0.51	0.37	0.48	0.52
Korea	0.3	0.1	0.27	-0.01
Luxembourg	0.52	-0.06	0.05	-
Mexico	0.23	0.05	0.11	-
Netherlands	0.5	0.41	0.45	-
New Zealand	0.1	0.19	0.12	-
Norway	0.38	0.31	0.1	0.16
Portugal	0.32	-0.24	0.07	-
Spain	0.32	0.31	0.15	0.81
Sweden	0.37	0.16	0.26	0.54
Switzerland	0.48	0.38	0.45	-
Turkey	0.26	0.43	-0.01	-
United Kingdom	0.68	0.51	0.49	0.74
Aggregate	0.67	0.56	0.54	0.71
Mean	0.42	0.26	0.29	0.42
Median	0.42	0.27	0.33	0.49

The cross-country correlations reported for GDP, consumption, and investment are between the United States and OECD countries in national currency at constant prices (OECD countries) from 1971:1 to 2010:4. As for the aggregate measure, country-specific series are transformed PPP US dollars of 2005. Hours worked are from Ohanian and Raffo (2012) also from 1971:1 to 2010:4, except for Sweden (1974:1-2010:4), Korea (1982:3-2009:4), and Spain (1995:1-2010:4). I exclude these three countries of the hours worked aggregate measure. All series are logged and de-trended with the H-P filter ($\lambda = 1,600$).

Table 2: Correlations between real GDP and real interest rates

Country:			
Australia	0.18	Italy	-0.12
Canada	0.42	Japan	0
France	0.37	U.K.	0.46
Germany	0.15	U.S.	0.18
Mean	0.21	**Median**	0.18

The correlations reported are between the logarithm of real GDP and the real interest rate, from which trends are removed using the H-P filter ($\lambda = 1,600$). I construct ex-post real interest rates by subtracting the quarterly growth rate of the CPI from a 90-days Treasury Bills rate of return. The data spans from 1971:1 to 2010:4 for all countries with the exception of Germany (1975:3-2010:4) and Italy (1977:1-2010:4). I refer the reader to Appendix A.1 for a description of the data.

national financial frictions, which ultimately create distortions.

The mechanism that I put forward breaks the link between the expected marginal product of capital and the real interest rate, which contrasts with the standard RBC or IRBC models, where firms equate these two variables. From the estimation of the RBC models, Beaudry and Guay (1996) find a correlation between output and real interest rates that is almost perfect, whereas when estimated empirically this correlation is close to zero. Table 2 presents the correlation between the logarithm of real GDP and real interest rate; the trends are removed using the H-P filter for Australia and G-7 countries between 1971Q1 and 2010Q4. Despite much variation in the correlations across countries, the estimates generally suggest a low positive value. This paper proposes that the introduction of national financial frictions and working capital requirements can bring this correlation closer to its empirical counterpart and plays an important role in *business cycle synchronization*.

The borrowing mechanism is similar to the ones examined by Jermann and Quadrini (2012) and Neumeyer and Perri (2005). However, the focus of their work differs from mine. Jermann and Quadrini (2012) study the role of financial shocks in a closed-economy environment, whereas Neumeyer and Perri (2005) investigate the characteristics of emerging market business cycles and stress the role of interest rate shocks. In my baseline model, the two countries (Home and Foreign) are linked internationally via two markets: the goods and the assets markets. I follow Backus, Kehoe, and Kydland's (1994) approach so that each country specializes in the production of one intermediate good but the final consumption good is an aggregate of these two goods. This structure creates important terms of trade effects. I also assume that financial markets are incomplete or that countries can only trade assets that are risk-free, *i.e.* non-contingent international bonds.

In both countries, there are two types of agents: investors and workers. Investors own national firms and workers lend to these firms. Since firms need to pay their factors of production and dividends to shareholders before receiving their revenues, they also contract an *intra-period loan* from the workers. The debt renegotiation problem emerges as firms can default on their obligations of that loan, although in equilibrium it would not be optimal. In the event of a default, workers would be able to repossess a fraction of the firm's capital collateral. Moreover, since investors have a lower discount factor than workers, firms also incur some *inter-period debt*. Their total liabilities, consisting of the sum of the *intra-period loan* and *inter-period debt*, cannot be greater than some fraction of the capital. Hence, the dual function of capital goods introduces a wedge between the sum of the real interest rate and the depreciation rate ($r_t + \delta$) and the expected marginal product of capital ($E_t Y_{kt+1}$).

If national financial frictions are removed, my baseline model corresponds to Heathcote and Perri's (2002) *bond economy*. They examine various international asset market structures and find that movements obtained from the simulation of financial autarky are clearly closest to their equivalents in the data. Contrary to their results, the difference in volatilities and international co-movements generated by different asset market structures is small. This suggests that assessing international efficiency from examining the behavior of international aggregate variables might not be informative when national frictions are important.

Consider the impact of a temporary positive shock to the Home country's production technology. This effectively increases firms' production and their *intra-period loans* directly from the Solow residual. Hence, their total liabilities - which also corresponds to a fraction of the value of their collateralized assets - increase, since their borrowing constraint is relaxed. In fact, the need for increase in working capital is so important that firms cut down their demand for *inter-period debt*, which leads to a lower interest rate. Internationally, partially-integrated financial markets ensure that uncovered interest parity holds, so that when facing a lower interest rate, Home workers prefer to lend to Foreign workers. This results in Foreign firms borrowing more to increase output, as well as investing and accumulating capital in a similar fashion to Home firms. The presence of borrowing-constrained firms allows for the emergence of an *investment wedge*. In fact, contrary to the benchmark two-country model of Backus, Kehoe, and Kydland (1992), a greater expected marginal product of capital does not lead to a greater real interest rate. Therefore, technology shocks contribute to explaining the synchronization of economic activities across countries.

The rest of this paper is organized as follows. In section 2, I show how some features of my baseline model are related to previous work. In section 3, I present the baseline model that features endogenous borrowing constraints for firms. In section 4, I characterize the persistence and volatility of the technology shocks that are based on the United States and an aggregate of the rest of the world. In this section, I also calibrate the rest of the parameters. In section 5, I evaluate the effects of those shocks and present my results. Section 6 concludes and offers some new potential paths for further research.

2 Related literature

Within the literature, there are numerous studies that focus on international business cycles. I highlight some previous work that aim to explain the degree of *synchronization of business cycles* and that examine the implications of different international asset market structures. I also compare my framework to other studies that feature national financial frictions in an international environment.

On the international linkages of the goods market, Ambler, Cardia, and Zimmermann (2002) build a model in which countries have multiple sectors and sector-specific shocks in order to generate greater positive co-movement in outputs. The two-good market structure embedded in my model also increases output co-movements across countries through terms of trade effects. However, they find negative cross-country correlations in investment and in hours worked from the estimation of their baseline model. Terms of trade effects are also amplified by credit constraints in the model of Paasche (2001). On that note, his framework differs from mine in that it features two small open economies that export to a large country. Moreover, he examines the effects of the terms of trade shocks that are, in contrast, endogenously determined in my model.

Another approach has been to introduce non-separable preferences between consumption and leisure that are based on the work of Greenwood, Hercowitz, and Huffman (1988). With these type of preferences, stochastic discount factors depend not only on consumption levels, as is the case for separable preferences, but also on leisure decisions. Devereux, Gregory, and Smith (1992) find that this category of preferences can lead to cross-country correlations in consumption that are more in line with the data. Raffo (2010) introduces investment-specific technology shocks in a model where households have GHH preferences. Through a mechanism that emphasizes the role of these shocks, he successfully replicates the dynamics of international prices and quantities. However, Mandelman, Rabanal, Rubio-Ramírez, and Vílan (2011) find that these shock processes are co-integrated across countries. Results from the estimation of a vector error correction model (VECM) lead them to reject the hypothesis that this type of shocks can replicate international co-movements.

Karabarbounis's (2014) work features a home production structure from which a *labor wedge* emanates and is crucial to explain international co-movements. The mechanism that he emphasizes differs from mine, since it involves the consumption of non-market goods and its effects on the marginal rate of substitution. His structural approach to estimate some parameters is questionable, since it relies on matching movements of a *labor wedge* that is constructed from first order conditions of a standard RBC model. Hence, movements in the *labor wedge* may be resulting from a misspecification of this latter model.

Much work has focused on augmenting BKK's workhorse model with non-tradable goods. Stockman and Tesar (1995) show that this extension generates positive cross-country correlations in consumption and investment; the correlation of the trade balance with output generated by the model is closer to the data. Corsetti, Dedola, and Leduc's (2008) model features non-tradable goods that are considered as final goods as well as distribution services for tradable goods. They have some success in replicating the behavior of international prices, *i.e.* the *Backus-Smith puzzle* (the correlation between relative consumptions and the real exchange rate), and international co-movements. However, from their calibration, the implied trade price elasticity is lower than one half—much lower than microeconomic estimates. Contrary to my results, their findings are not robust to greater elasticity values.

Heathcote and Perri (2014) also stress the role of a low elasticity of substitution. This feature, coupled with low persistence and the absence of international spill-overs of shocks under complete markets, is necessary to bring up international co-movements. However, they set the correlation of technology shocks innovations so that it matches the empirical cross-country correlation in outputs. This correlation is much higher than the one that previous studies have estimated. In contrast to their work, I propose a mechanism from which the high level of co-movements arises endogenously.

As mentioned in the introduction, Heathcote and Perri (2002) examine different international asset market structures. In the absence of nationally-based frictions, one of their major findings is that these structures have very different implications for international business cycles. In fact, they find that output, consumption, investment, and hours worked behave similarly under complete and incomplete market structures.[1] However, under financial autarky, international co-movements are significantly greater, as are volatilities in terms of trade and in real exchange rates. From a model that features a non-tradable sector, Bengui, Mendoza, and Quadrini (2013) also find that, compared to other asset market structures, financial autarky is the only one able to generate tradable consumption dynamics close to the data for almost all of the 21 countries in their sample.

On the introduction of distortions to national economies, Kocherlakota and Pistaferri (2007) proceed to an investigation of the *Backus-Smith puzzle*. Specifically, their framework is constructed so that heterogeneous households are fully insured against country-specific aggregate shocks, but are partially insured against idiosyncratic shocks. Similar to my work, Perri and Quadrini (2011) rely on working capital requirements. However, the international transmission of the recent financial crisis is accounted for by financial shocks, so that their channels of propagation are different from mine. They assume that investors are shareholders of both Home and Foreign firms, and that since liquidation costs are the same across countries, this would be equivalent to having one international investor that faces identical financial shocks–whether or not they emanate from the Home or the Foreign economies.

[1] Baxter and Crucini (1995) show that these similarities vanish when shocks are either persistent or not transmitted internationally.

Iacoviello and Minetti (2006) embed real estate into a two-country framework in which a fraction of agents are also borrowing-constrained. They show that they can raise the co-movement of output by introducing different liquidation costs that depend on the lender's origin. In contrast, I do not allow for any international borrowing, with the exception of the international bond. Hence, this specific channel does not exist in my framework. My results are also closer to the data for international cross-country correlations. Their work belongs to the category of papers that examine financial frictions in a two-country environment, which makes use of Kiyotaki and Moore's (1997) enforcement constraint. Devereux and Yetman (2010) also introduce a similar enforcement constraint and study the international transmission when debt and equity markets are financially integrated. Another category consists of papers that make use of Bernanke, Gertler, and Gilchrist's (1999) financial accelerator in an international context. See *e.g.*, Faia (2007) and Ueda (2012) that show the importance of international portfolio and banking globalization.

3 The business-cycle model

The baseline model augments the *bond economy* of Heathcote and Perri (2002) in allowing for national financial frictions in a similar fashion to Perri and Quadrini (2011). The world is populated by investors and workers that live either in the Home (H) country or in the Foreign (F) country. A fraction $\varpi \in (0, 1)$ of households are investors and the remaining $1-\varpi$ are workers. Optimization problems of both types of agents are expressed in per-capita terms in the following section. Investors have a lower discount factor, and therefore borrow from workers. I assume that both type of agents consume a final good that is a composite of the differentiated intermediate goods produced locally and abroad and can also be used for investment purposes. The factors of production for the intermediate good consist of labor provided by workers and physical capital. Agents of the two countries are linked in two ways:

trade and finance. First, intermediate goods can be imported in order to produce the final good. Second, I adopt an incomplete financial market structure, so that workers trade an international non-contingent bond.

3.1 Firms

Intermediate goods are produced according to a Cobb-Douglas production function (where $i = \{H, F\}$):

$$y_{it} = A_{it} k_{it-1}^{\mu} n_{it}^{1-\mu} \tag{1}$$

where factor shares for capital k_{it-1} and labor n_{it} correspond respectively to μ and $1-\mu$, since the production function exhibits constant return to scale. Total factor productivity A_{it} is an exogenous shock to the production function. Home specializes in the production of intermediate good a and Foreign in the production of intermediate good b.

The final good in each country is a composite of these two intermediate goods and they are aggregated à la Armington by final good firms:

$$G(a_{Ht}, b_{Ht}) = \left[\omega^{\epsilon+1} a_{Ht}^{-\epsilon} + (1-\omega)^{\epsilon+1} b_{Ht}^{-\epsilon}\right]^{-\frac{1}{\epsilon}}, \tag{2}$$

$$G(a_{Ft}, b_{Ft}) = \left[(1-\omega)^{\epsilon+1} a_{Ft}^{-\epsilon} + \omega^{\epsilon+1} b_{Ft}^{-\epsilon}\right]^{-\frac{1}{\epsilon}} \tag{3}$$

where a_i and b_i denote, respectively, the quantity of intermediate good a and b used in the production of country i's final goods. Here, $\omega > 0.5$ represents home bias in the production intensity of the local intermediate good. Note that intermediate goods market clearing implies that

$$a_{Ht} + a_{Ft} = y_{Ht}, \tag{4}$$

$$b_{Ht} + b_{Ft} = y_{Ft}. \tag{5}$$

The elasticity of substitution between Foreign and Home intermediate goods is given by $\sigma = 1/(1+\epsilon)$. Final good firms generate important terms of trade effects for output synchronization, but the focus here is really on the optimization problem of intermediate good firms.[2]

At the beginning of each period, firms have an inter-temporal debt $R_{it-1}e^P_{it-1}$ contracted from workers, capital k_{it-1}. The choice of labor input n_{it}, investment x_{it}, dividends d_{it}, and the next period debt level e^P_{it} are made before production. The representative firm's budget constraint is given by:

$$p_{iit}y_{it} + e^P_{it} = d_{it} + x_{it} + R_{it-1}e^P_{it-1} + w_{it}n_{it}. \tag{6}$$

All variables are expressed in terms of the final good, so that the price of the intermediate good is p_{iit}. Since payments of the wage bill $w_{it}n_{it}$ to workers, of dividends d_{it} to investors, investment expenses x_{it} are all made before the revenues are realized, the firm contracts an *intra-period loan* l_{it}:

$$l_{it} = R_{it-1}e^P_{it-1} - e^P_{it} + d_{it} + x_{it} + w_{it}n_{it}. \tag{7}$$

From the budget constraint this loan must be equal to output. However, the contract is not perfectly enforceable, and defaulting can occur with some positive probability. In the

[2]In the rest of this section, I use firms to implicitly refer to intermediate good firms.

case of a default, the lender can liquidate the firm's capital and commercial real estate for a fraction λ of the value of its capital holdings. Hence, the recovery value if a default occurs is λk_{it}. Since the total liabilities of the firm are $l_{it} + e_{it}$, in order to prevent any defaults the borrowing constraint is as follows:[3]

$$\lambda k_{it} \geq l_{it} + e^{P}_{it}. \tag{8}$$

The firms' optimization problem is essentially to maximize the discounted sum of dividends. I refer the reader to Appendix B.1 for a complete recursive formulation of the problem and the corresponding first order conditions. One wedge that is particularly crucial for the results can be derived from these conditions. Specifically, the introduction of a borrowing constraint for firms results in a wedge between the real interest rate and the expected marginal product of capital. From the first order conditions with respect to the *inter-period debt* and capital and in absence of capital adjustment costs, the next period's expected real interest rate can be expressed as follows:

$$R_{it} = E_t \left(Y_{k_{it+1}} (1 - \vartheta_{it+1}) + 1 - \delta \right) - \frac{(1 - \lambda)\, \vartheta_{it}}{E_t m_{it+1}} \tag{9}$$

where $E_t \left(Y_{k_{it+1}} \right)$ corresponds to the expected marginal product of capital, ϑ_{it} to the Lagrange multiplier on the borrowing constraint, and $E_t m_{it+1}$ to the stochastic discount factor. If that constraint does not bind ($\vartheta_{it} = 0$), then the real interest rate minus the depreciation rate coincides with the expected marginal product of capital.

[3] This problem is based on Hart and Moore (1994) and I assume that the borrower has all the bargaining power. I refer the reader to Appendix A of Perri and Quadrini (2011) for a complete derivation of the debt renegotiation problem.

3.2 Investors

The description of the firm's problem is not sufficient, because investors own the firms from which they receive dividends d_{it} and have the following utility function: $E_0 \sum_{t=0}^{\infty} \gamma^t \ln c_{it}^P$. As shareholders of the firms, their budget constraint is as follows:

$$s_{it}(d_{it} + p_{it}^s) = c_{it}^P + p_{it}^s s_{it+1} \tag{10}$$

where s_{it} corresponds to the equity shares and p_{it}^s to the market price of those shares. Hence, the effective stochastic discount factor that is consistent with the firms' problem is: $m_{it+1} = \gamma E_t u_c(d_{it+1})/u_c(d_{it})$. I refer the reader to Appendix B.2 for the investors' first order conditions.

3.3 Workers

Workers maximize the discounted sum of period-specific Cobb-Douglas utilities, as follows:

$$E_0 \sum_{t=0}^{\infty} \beta_{it}^t U(c_{it}^W, n_{it})$$

where

$$U(c_{it}^W, n_{it}) = \alpha \ln c_{it}^W + (1-\alpha) \ln (1 - n_{it}), \tag{11}$$

so that c_{it}^W corresponds to the consumption of the final good and n_{it} to the hours worked. In order to ensure stationarity in an incomplete financial market, I adopt Mendoza's (1991) approach and render the discount factor endogenous as follows:

$$\beta_{it} = \left(1 + \exp(U(c_{it}^W, n_{it}))\right)^{-\varsigma_W}.$$

At the beginning of each period, workers have bond holdings reaching maturity. After production occurs, they receive their loan plus the interest on that loan back for the ones made to firms $R_{Ht-1}e^{W}_{Ht-1}$ and the ones made internationally to Foreign workers $Z_t R_{t-1} f_{Ht-1}$. They are also paid for the hours they work $w_{it}n_{it}$ over the time period. They allocate their revenues by either buying more bonds or they can modify their consumption. Hence, the budget constraint for Home-country workers is as follows:[4]

$$R_{Ht-1}e^{W}_{Ht-1} + Z_t R_{t-1} f_{Ht-1} + w_{Ht}n_{Ht} = c^{W}_{Ht} + e^{W}_{Ht} + Z_t f_{Ht}. \tag{12}$$

I refer the reader to Appendix B.3 for first order conditions of the workers' optimization problem.

3.4 Shocks

There are two technology shocks (Home and Foreign) that follow a multivariate autoregressive process as follows:

$$\Omega_t = \Gamma\Omega_{t-1} + \varepsilon_t,\ \varepsilon_t \sim N(0, \Sigma) \tag{13}$$

where $\Omega_t = [A_{Ht}, A_{Ft}]'$ and $\varepsilon_t = [\varepsilon_{A_{Ht}}, \varepsilon_{A_{Ft}}]'$. Elements of the diagonal in matrix Γ are defined as spill-overs. The variance-covariance matrix is given by: $E(\varepsilon_t \varepsilon_t') = \Sigma$.

[4]The budget constraint for Foreign workers is similar, but since their pricing of the currency is in terms of their own final good, the real exchange rate term does not show up.

3.5 Market clearing

For the final goods' market, the production of the goods is equal to the domestic absorption:

$$c_{it}^P + c_{it}^W + x_{it} = G(a_{it}, b_{it}) \text{ where } i = \{H, F\}. \tag{14}$$

The market for *inter-period debt* clears:

$$(1-\varpi)e_{it}^P + \varpi e_{it}^W = 0. \tag{15}$$

The international bonds market clearing condition is:

$$Z_t f_{Ht} + f_{Ft} = 0. \tag{16}$$

3.6 Recursive competitive equilibrium

Definition 1. *In each country (where $i = \{H, F\}$ and $j = H, F$, but $i \neq j$), a recursive competitive equilibrium is defined as a set of functions for*

(i) workers' policies $c_i^W(\boldsymbol{s})$, $n_i(\boldsymbol{s})$, $f_i(\boldsymbol{s})$, $e_i^W(\boldsymbol{s})$;
(ii) investors' policies $c_i^P(\boldsymbol{s})$
(iii) firms' policies $d_i(\boldsymbol{s}; k_i, e_i^P)$, $n_i(\boldsymbol{s}; k_i, e_i^P)$, $k_i(\boldsymbol{s}; k_i, e_i^P)$ and $e_i^P(\boldsymbol{s}; k_i, e_i^P)$;
(iv) firms' value $V_i(\boldsymbol{s}; k_i, e_i^P)$;
(v) aggregate prices for each country $w_i(\boldsymbol{s})$, $R(\boldsymbol{s})$, $R_i(\boldsymbol{s})$, $p_{ii}(\boldsymbol{s})$, $p_{ij}(\boldsymbol{s})$, $P_i(\boldsymbol{s})$ and $m(\boldsymbol{s}, \boldsymbol{s}')$;
(vi) law of motion for the aggregate state $s' = \Psi(s)$.

Such that:

(i) workers' policies satisfy conditions (27-29);
(ii) investors' policies satisfy conditions (26);
(iii) firms' policies are optimal and $V_i(\boldsymbol{s}; k_i, e_i^P)$ satisfies the Bellman's equation (22);

(iv) the wage, interest rates, and prices clear the labor, bond markets, goods markets(4) and (5), and $m(\boldsymbol{s}, \boldsymbol{s'}) = \gamma U_{c^{P'}}/U_{c^P}$*;*

(v) the resource constraint (14) is satisfied;

(vi) the law of motion in each country $\Psi(s)$ *is consistent with individual decisions and the stochastic process for* A_i*.*

3.7 Prices, terms of trade and real exchange rate

Under the assumption of perfect competition for firms, the equilibrium prices of goods a and b in terms of the Home final good correspond to the marginal products of these two goods. For prices, the first position of the subscript determines the production location of the intermediate good and the second position of the subscript indicates where it is used for the production of the final good. Hence, p_{HHt} corresponds to the price of good a in the Home country with $i = \{H, F\}$

$$p_{Hit} = \partial G(a_{it}, b_{it})/\partial a_{it}, \quad p_{Fit} = \partial G(a_{it}, b_{it})/\partial b_{it}. \tag{17}$$

The price level of the final good is an aggregate of the Home and the Foreign country intermediate good, so that

$$P_{Ht} = \left(\omega p_{HHt}^{\frac{\epsilon}{1+\epsilon}} + (1-\omega) p_{FHt}^{\frac{\epsilon}{1+\epsilon}}\right)^{\frac{1+\epsilon}{\epsilon}}. \tag{18}$$

Terms of trade are defined as the price of good b in terms of the price of good a and also correspond to the marginal rate of substitution:

$$\begin{aligned} TOT_t &= \frac{p_{FHt}}{p_{HHt}} = \frac{1-\omega}{\omega}\left(\frac{a_{Ht}}{b_{Ht}}\right)^{1+\epsilon} \\ &= \frac{p_{FFt}}{p_{HFt}} = \frac{\omega}{1-\omega}\left(\frac{a_{Ft}}{b_{Ft}}\right)^{1+\epsilon} \end{aligned} \tag{19}$$

The real exchange rate is defined as the ratio of the price of final goods in the Foreign country over the price of the same final goods in the Home country:

$$Z_t = \frac{P_{Ft}}{P_{Ht}} = \frac{\left(\omega p_{FHt}^{\frac{\epsilon}{1+\epsilon}} + (1-\omega) p_{HHt}^{\frac{\epsilon}{1+\epsilon}}\right)^{\frac{1+\epsilon}{\epsilon}}}{\left(\omega p_{HHt}^{\frac{\epsilon}{1+\epsilon}} + (1-\omega) p_{FHt}^{\frac{\epsilon}{1+\epsilon}}\right)^{\frac{1+\epsilon}{\epsilon}}}.$$

4 Calibration

There are two different groups of parameters that are calibrated in this section. Specifically, parameters that govern the shock processes (*i.e.* persistence and covariance parameters) and fixed parameters that are calibrated to match steady state targets.

4.1 Technology shocks

Since I study business cycle synchronization and international risk sharing at a business cycle frequency, the first step is to de-trend the data to retrieve the shocks. I follow Jermann and Quadrini's (2012) approach of log-linearizing the shocks, and work with deviations rather than levels. I remove a linear trend from the logarithm of all series where the deviations from the steady state are required. I use US data and construct an aggregate for "the rest of the world". All variables and their construction are described in Appendix A.2.

From the model's two-good structure, final-good output can be rewritten as:

$$Y_{it} = \frac{A_{it} k_{it-1}^{\mu} n_{it}^{1-\mu}}{\left(\omega + (1-\omega) TOT_{it}^{\frac{\epsilon}{1+\epsilon}}\right)^{\frac{1+\epsilon}{\epsilon}}}, \tag{20}$$

so that the technology shock or Solow residual $\widehat{A_{it}}$ takes the following form:

$$\widehat{A_{it}} = \widehat{Y_{it}} - (1-\mu)\widehat{n_{it}} - (1-\omega)\widehat{TOT_{it}} \tag{21}$$

where $\widehat{Y_{it}}$, $\widehat{n_{it}}$, and $\widehat{TOT_{it}}$ are log-deviations from a linear trend of their respective variables. For example, $\widehat{Y_{it}} = \log(Y_{it}) - \widehat{\beta}_0 - \widehat{\beta}_1 t$ where $\widehat{\beta}_0$ and $\widehat{\beta}_1$ are estimated from an OLS regression. I exclude deviations of the capital stock, since quarterly data is not available for all countries. Note that variations in terms of trade only contribute a very small fraction to the estimated Solow residual.

In Table 3, I report the results of the maximum likelihood estimation of equation (13) from which shocks are derived from equation (21). The shocks' processes are specified so that there are no contemporaneous effects from the other shocks. I present the results of the estimation for which I impose symmetry on both shock processes, *i.e.* equal persistence, spill-over parameters and equal standard deviations of both types of innovations. Contrary to BKK's estimation of technology shocks, spill-over effects are not significant.

4.2 Preferences and technology parameters

In Table 3, I also report the parameterization of preferences and technology. I assume that they are the same in the two countries, and that steady-state targets match US data. The fraction of investors in each economy is set to half, following Campbell and Mankiw's (1990) findings that half of the households face borrowing constraints.[5] As for the parameters that control labor, α is set so that working hours correspond to 30 percent of the total time. The discount factor for workers is standard in the literature and ς_W is set so that β is equal to

[5]This assumption is standard in two-country models for which a fraction are borrowing-constrained, see *e.g.* Devereux and Yetman (2010) and Iacoviello and Minetti (2006).

Table 3: Parameterization

Symbol	Value	Definition
ϖ	0.5	share of investors in the economy
ς_W	0.015	workers discount factor equals 0.99
γ	0.97	investors discount factor
α	0.31	consumption weight in the utility function
μ	0.36	capital share
δ	0.025	capital depreciation
λ	0.52	enforcement parameter
ω	0.85	weight on domestic good
$\sigma=1/(1+\epsilon)$	0.85	elasticity of substitution between traded goods
Shocks		
Γ	$\begin{bmatrix} 0.981 & -0.0001 \\ (0.011) & (0.012) \\ & \\ -0.0001 & 0.981 \\ (0.012) & (0.011) \end{bmatrix}$	persistence and spill-over (std. err. are in parentheses)
σ_{US}	0.00595	standard deviation of innovations (US)
σ_{ROW}	0.0053	standard deviation of innovations (ROW)
ρ	0.211	correlation of innovations

0.99 in the steady state, corresponding to an annual real interest rate of 4 percent. The discount factor for investors γ is set to 0.97 so that there is a quarterly interest premium of two percentage points, following the calibration of Bernanke, Gertler, and Gilchrist (1999). Since I construct the shocks from quarterly data, I assume a depreciation rate δ of 2.5 percent corresponding to an annual depreciation rate of 10 percent. For the elasticity of the different input factors in the Cobb-Douglas production function, the share of labor is 0.64. The enforcement parameter λ is set in order to replicate the average of the ratio of debt over quarterly output, 3.07, in the U.S. from 1971 to 2010. Debt corresponds to credit market instruments in the nonfarm nonfinancial business sector (Flow of Funds: Table B.102 and B.103) and output to gross value added business GDP (NIPA: Table 1.3.4).

International parameters are set in accordance with Heathcote and Perri (2002). I set the parameter that controls for home bias ω to 0.85, so that imports correspond to 15 percent of output, a value that corresponds to the average ratio for the United States between 1984 and 2010. The other international parameter, the elasticity of substitution between Home and Foreign goods, appears to be disputed in the literature. In fact, the range of values are rather vast, depending on whether the model has non-traded goods, a distribution sector, or price stickiness.[6] For the benchmark calibration, I use the value of 0.85, which seems to be an intermediate value and the same value reported by Bodenstein (2011). In the sensitivity analysis, I test the model with different values for that parameter.

5 Results of the business cycle estimation

I linearize the business-cycle model described in section 3, so that the dynamics around the steady state are studied. The standard deviations of the calibrated shocks are not large

[6] See Bodenstein (2011) for a discussion on the different values this parameter has taken in the literature.

enough to qualify situations for which borrowing constraints would not be binding.

5.1 Impulse responses

In this section, I examine the responses of key variables to technology shocks. Specifically, I introduce a one percent temporary shock on the Home economy as illustrated in Figure 1. In order to have a better understanding of the borrowing mechanism, I start by presenting the effects in a closed-economy environment. As a result of a Home positive temporary shock, output grows directly from the Solow residual. In this case, firms must pay their factors of production and dividends to their shareholders before receiving their revenues. As such, a greater technology shock entails that they contract greater *intra-period loans*.

From equation (8), liabilities on the right hand side cannot exceed the value of capital that can be repossessed on the left hand side. In the event of rapid capital accumulation, the borrowing constraint would be relaxed. However, this is too costly for firms. Hence, their borrowing constraint is more binding, as shown by the impulse response of the Lagrange multiplier displayed in Figure 1. The log-linearization of equation (9), which features the real interest rate and the marginal product of capital, is instructive. The sources of these dynamics can be decomposed as follows:

$$\widehat{R_{it}} \approx \phi^{-1} \left[\mu\bar{y}/\bar{k} \left((1-\bar{\vartheta})E_t\hat{y}_{kit+1} - \bar{\vartheta}E_t\hat{\vartheta}_{it+1}\right) - (1-\lambda)\bar{\vartheta}/\gamma \left(\hat{\vartheta}_{it} - E_t\hat{m}_{it+1}\right)\right].$$

where $\phi = \mu\bar{y}/\bar{k}(1-\bar{\vartheta}) + 1 - \delta - (1-\lambda)\bar{\vartheta}/\gamma > 0$. Following a positive technology shock, $\hat{\vartheta}_{it}$ is the term that contributes the most to lower the real interest rate, so that the *investment wedge* decreases. In the absence of borrowing constraints, firms would increase their *inter-*

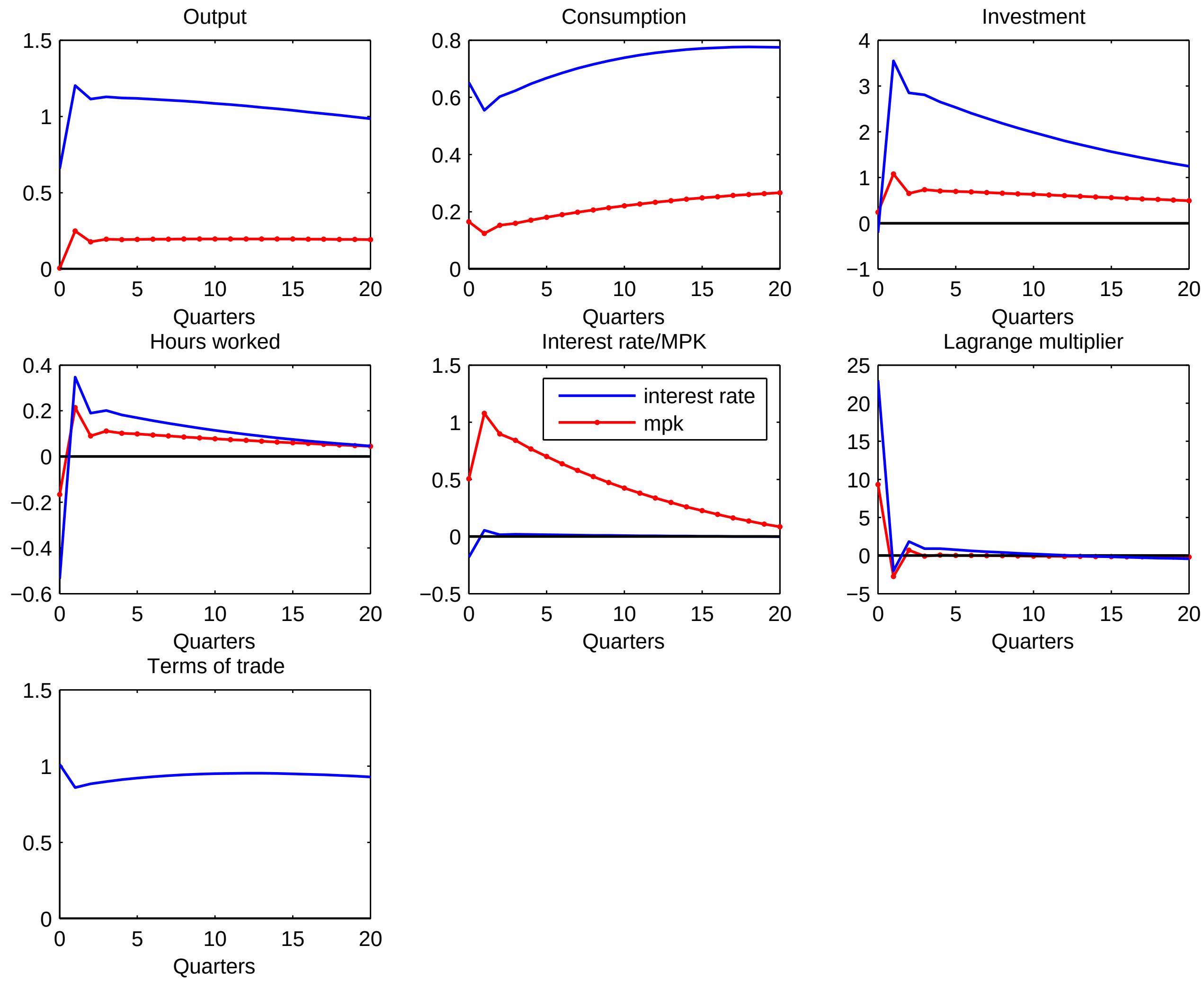

Figure 1: Impulse responses to a one percent temporary Home technology shock

The solid blue lines correspond to the Home economy and the dotted red lines to Foreign economy.

period debt. However, in this framework, they cannot do so since they have greater working capital requirements. Consequently, a lower demand for this type of debt leads to a decline in the real interest rate.

How do these effects matter in an open-economy? The answer is through the uncovered interest rate parity. Movements in the real exchange rate are not large enough to reverse the fall in the Foreign interest rate below its steady state value. Yet the Foreign real interest rate is higher than the Home one, so that Home workers lend to Foreign workers. This result is a stark contrast to BKK's model, which predicts that Home workers borrow from Foreign workers, since the expected marginal product of capital is equal to the interest rate. Consequently, the Foreign trade balance is in surplus as can be shown from the combination of equations (6) and (12):

$$NX_{Ft} = f_{Ft} - R_{t-1} f_{Ft-1}.$$

This increase in net exports that stems from real interest rate dynamics is an important contributor to the positive cross-country correlation in outputs. Terms of trade amplify the real interest rate effects. Following a positive technology shock, the Home economy exports more of good a, so that its price decreases in the Foreign economy. Moreover, the Home economy's demand for good b increases, so that the price of its imports increase. This implies favorable terms of trade for the Foreign economy, so that Foreign firms produce more of good b. Therefore, international positive co-movements of investment and hours worked are also the results of the real interest rate dynamics and terms of trade effects.

5.2 Quantitative analysis

5.2.1 Baseline model

Table 4 reports the moments generated by the baseline model for two different asset market structures: *bond economy* and financial autarky. I also compare my results to the ones generated by Heathcote and Perri's (2002) model. The impact of endogenous borrowing constraints and working capital requirements can be assessed in column 2, where it can be observed that the level of *business cycle synchronization* is higher. In order to assess the degree to which international correlations generated by various theoretical models match their empirical counterparts, I construct a metric. This metric consists of the sum of the squared deviations between theoretical $\tilde{\rho}(a_{US}, a_{ROW})$ and empirical $\hat{\rho}(a_{US}, a_{ROW})$ international correlations of four aggregate variables GDP, consumption, investment, and hours worked:

$$\text{metric} = \sum_{a=\text{GDP,C,X,N}} \left(\tilde{\rho}(a_{US}, a_{ROW}) - \hat{\rho}(a_{US}, a_{ROW})\right)^2 .$$

According to the metric, international correlations that are generated from the *bond economy* with national financial frictions replicate most closely their empirical counterparts out of the four theoretical models. These results, however, are specific to the calibrated parameters. For alternative parameterizations, financial autarky with national financial frictions replicates better international correlations. For this category of models, the signs of cross-country correlations in investment and in hours worked are the same, whereas they differ for models that do not embed national frictions.

The early IRBC literature has devoted much attention to international co-movements in

Table 4: Business cycle statistics

Model:		Baseline		HP (2002)	
International asset market structure:		B.E.	F.A.	B.E.	F.A.
	Data				
Volatility					
Standard deviations (in percent)					
GDP	**1.58**	0.8	0.83	1.21	1.18
Standard deviations relative to GDP					
Investment	**2.8**	3.09	2.82	2.73	2.04
Hours worked	**0.97**	0.54	0.6	0.32	0.28
Domestic Co-movement					
Real interest rate, GDP	**0.18**	0.17	0.25	-	-
Net Exports/GDP, GDP	**-0.52**	-0.5	-	-0.65	-
International Correlations					
GDP_{US}, GDP_{ROW}	**0.68**	0.32	0.21	0.17	0.24
C_{US}, C_{ROW}	**0.56**	0.44	0.67	0.68	0.85
X_{US}, X_{ROW}	**0.56**	0.44	0.55	0.29	0.35
N_{US}, N_{ROW}	**0.71**	0.69	0.22	0.17	0.14
Metric					
		0.16	0.47	0.64	0.65

Statistics in the first column for the *volatility* and *domestic co-movement* sections are calculated from US data and the *international correlations* statistics are calculated from US and "the rest-of-the-world" aggregate described in Appendix A.3 from 1971Q1 to 2010Q4. In the second and third columns, I present statistics generated from the baseline model for two different international asset market structures: a *bond economy* and financial autarky. In the fourth and fifth columns, I present statistics from Heathcote and Perri (2002). All series have been logged (except net exports and real interest rate) and Hodrick-Prescott filtered ($\lambda = 1,600$).

order to assess the level of international efficiency. In fact, one of BKK's main findings is the *quantity anomaly*: cross-country correlations in outputs are greater than cross-country correlations in consumption in the data, whereas their benchmark model and variants of that model generate the opposite when they assume complete markets. Moreover, cross-country correlations in investment and in hours worked are strongly positive in the data, while the ones generated by their model are negative. Some work has considered that this may reflect a lack of international risk-sharing (Heathcote and Perri (2002); Kollmann (1996)).

Heathcote and Perri (2014) show that a two-good model with low elasticity of substitution between Home and Foreign goods and complete asset markets can account for the quantity anomaly. They argue that this asset market structure is also better at capturing international co-movements. From my interpretation of the statistics in Table 4, my point of view differs from theirs in that international co-movements are not informative of the degree of international efficiency. From an empirical perspective, Fitzgerald (2012) estimates the importance of asset market frictions from a structural model that embeds trade costs. From 1970 to 2000, she cannot reject the hypothesis that industrialized countries' asset markets are perfect. However, she assumes that intermediate goods producers operate in a frictionless market. If national financial frictions were to be taken into account, then there would be an additional variable in her estimation that might affect the results.

5.2.2 Sensitivity analysis

I perform a sensitivity analysis of within-country and international business cycle statistics to changes in key parameters. Table 5 presents the moments from different specifications. This information is compared to the data (column 1) and the baseline model (column 2). In columns 3 and 4, I examine the sensitivity of the elasticity of substitution between Home and Foreign goods, σ, since in the literature, as mentioned earlier, a consensus has not been

Table 5: Sensitivity analysis statistics

Model:	Data	Baseline	$\sigma = 0.6$	$\sigma = 2.5$	GHH pref.	$\iota = 0.75$	HP (2002) shocks
Volatility							
Standard deviations, in percent							
GDP	**1.58**	0.8	0.78	0.82	1.17	0.8	0.79
Standard deviations relative to GDP							
Investment	**2.8**	3.09	2.86	3.51	2.11	3.12	3.19
Hours worked	**0.97**	0.54	0.52	0.55	0.8	0.53	0.53
Domestic Co-movement							
Real interest rate, GDP	**0.18**	0.17	0.16	0.17	0.35	0.18	0.15
Net Exports/GDP, GDP	**-0.52**	-0.5	-0.61	-0.17	-0.46	-0.56	-0.58
International Correlations							
GDP_{US}, GDP_{ROW}	**0.68**	0.32	0.37	0.26	0.43	0.3	0.24
C_{US}, C_{ROW}	**0.56**	0.44	0.65	0.33	0.66	0.41	0.54
X_{US}, X_{ROW}	**0.56**	0.44	0.74	0.06	0.38	0.39	0.09
N_{US}, N_{ROW}	**0.71**	0.69	0.85	0.52	0.74	0.7	0.53

Statistics in the first column for the *volatility* and *domestic co-movement* sections are calculated from US data and the *international correlations* statistics are calculated from US and "'the rest-of-the-world" aggregate described in Appendix A.3 from 1971Q1 to 2010Q4. Statistics of column 2 are generated from the estimation of the baseline model, and statistics of columns 3 to 7 are generated from variations of that model for some key parameters. Columns 3 and 4 correspond to lower and higher elasticities of substitution between Home and Foreign intermediate goods; column 5 to the baseline model where workers have GHH preferences; column 6 to a lower parameter of equity home bias; and column 8 to the baseline model where shocks are parameterized similarly to Heathcote and Perri (2002). All series have been logged (except net exports and real interest rate) and Hodrick-Prescott filtered with a smoothing parameter of 1,600.

reached on the value that this parameter should take. A greater level of complementarity (lower substitutability) leads to a greater need for imports, so that net exports' correlation with GDP goes down. Consequently, output, investment, and hours worked are more correlated across countries, the greater is the elasticity of substitution.

In column 5, I consider preferences that are widely used in the IRBC literature: GHH preferences. Workers' utility function is non-separable in consumption and in leisure as follows:

$$U(c_{it}^{W}, n_{it}) = \log\left(c_{it}^{W} - \frac{\tau n_{it}^{\eta}}{\eta}\right)$$

where τ and η are calibrated so that hours worked correspond to 30% of total time and so that the inter-temporal elasticity of labor corresponds to 1.7, the value used by Greenwood, Hercowitz, and Huffman (1988). This elasticity of labor allows for greater movements in labor supply. Since the volatility of hours worked contribute to a larger share of output's volatility and cross-country correlation in hours worked is high, cross-country correlation in outputs is greater for GHH preferences.

So far, investors have been excluded from holding shares from firms that are abroad — the equity market is autarkic. In column 6, I relax that assumption, so that, in each country, local investors own a fraction $\iota \in (0, 1)$ of shares from local firms. Hence, the parameter ι corresponds to the degree of *home equity bias*. As such, in equilibrium, the consumption of Home investors corresponds to $c_{Ht}^{P} = \iota d_{Ht} + (1-\iota)Z_t d_{Ft}$, and the consumption of Foreign investors corresponds to $c_{Ft}^{P} = \iota d_{Ft} + \frac{(1-\iota)d_{Ht}}{Z_t}$. Volatilities and correlations are robust to a *home equity bias* that corresponds to 75%. This result differs from Devereux and Yetman's (2010) findings, since for their model greater financial integration of equity markets magnifies the international transmission of shocks. In column 7, I examine Heathcote and Perri's (2002) shocks specification. It appears that a greater value for spill-overs lowers cross-country correlations in output, investment, and hours worked; however they remain positive.

6 Conclusion and extensions

In this paper, I build a two-country, two-good model with endogenous national borrowing constraints in order to have a better understanding of the high level of *business cycle synchronization*. Specifically, international correlations between the United States and a fictional "rest-of-the-world" country are high for output, consumption, investment, and hours worked. I find that the combination of financial frictions, working capital requirements, and terms of trade dynamics contributes to a greater *business cycle synchronization* in the presence of technology shocks. Furthermore, I propose that national financial frictions can potentially lead to a biased estimation of the degree of international risk sharing. As such, more work should be carried out in the direction of disentangling the effects of national financial frictions, international asset market frictions, and trade costs.

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A Data sources and construction of variables

A.1 Data used in Table 2: Correlations between real GDP and real interest rates

Real GDP and the quarterly rate of return of 90-days Treasury Bills are from the IFS (International Financial Statistics) and the consumer price index is from the OECD Main Economic Indicators. The data spans from 1970:1 to 2014:3, except for Germany (1975:3-2014:3) and Italy (1980:1-2014:3).

A.2 Data used for the construction of technology shocks

For the US technology shock, I use real GDP and the export and import indices from the OECD Quarterly National Accounts (QNA). For hours worked, I use Ohanian and Raffo's (2012) estimates. The fictional "rest-of-the-world" country consists in an aggregation of data from 11 industrialized countries: Australia, Austria, Canada, Finland, France, Germany, Ireland, Italy, Japan, Norway, and the UK. Some data limitations on hours worked do not allow us to include more countries. Prior to aggregate real GDP, I transform each of the series in PPP U.S. dollars of 2005 (source: OECD-QNA). For hours worked, I also use Ohanian and Raffo's (2012) estimates and sum countries' series for every quarter. Finally, for the terms of trade, I construct these series from individual country indices (source: OECD-QNA). I weigh country indices by the share of the real GDP in the fictional "rest-of-the-world" country.

A.3 Data used in Tables 4 and 5

Real GDP, consumption, investment and hours worked are obtained from the OECD-QNA. The series of net exports over GDP is computed from NIPA data (Table 1.1.5). As for international correlations, the fictional "rest-of-the-world" country's series corresponds to the sum of the individual series that are transformed in PPP US dollars of 2005.

B Recursive formulation and first order conditions

B.1 Firms' Problem

The firm's problem can also be formulated recursively as follows:

$$
\begin{aligned}
V(\mathbf{s_i}; k_{i_{-1}}, e^P_{i_{-1}}) \quad = \quad & \max_{d_i, n_i, k_i, e^P_i} \left\{ d_i + E m'_i V(\mathbf{s'_i}; k_i, e^P_i) \right\} \\
& \text{subject to:} \\
& Y_i + e^P_i - w_i n_i = d_i + k_i - (1-\delta) k_{i_{-1}} + R_{i_{-1}} e^P_{i_{-1}}, \\
& \lambda k_i \geq e^P_i + Y_i.
\end{aligned}
\tag{22}
$$

The recursive formulation is instructive because it shows the value of the firm as the sum of the discounted stream of dividends. Y_i refers to output in terms of the final good price, so that $Y_i = \frac{p_{ii}}{P_i} y_i$. The first order conditions are with respect to n_i, e^P_i, and k_i. The variable ϑ_i corresponds to the Lagrange multiplier on the borrowing constraint and on the capital accumulation equation.

$$
Y_{ni} = \frac{w_i}{1 - \vartheta_i}, \tag{23}
$$

$$
1 = E m'_i R_i + \vartheta_i, \tag{24}
$$

$$
1 = \lambda \vartheta_i + E m'_i \left(Y'_{ki}(1 - \vartheta'_i) + (1 - \delta) \right). \tag{25}
$$

Equation (23) corresponds to the derivative with respect to labor. Equation (24) refers to a standard Euler equation for a borrowing-constrained model. The Lagrange multiplier ϑ_i also affects the inter-temporal substitution of consumption as the marginal utility of consumption decreases while the borrowing constraint is relaxed. Equation (25) shows capital dynamics and highlights the importance of capital as collateral.

B.2 Investors' Problem

As investors maximize over their consumption level and shares' quantity, combining first order conditions leads to:

$$\frac{p^s_{it}}{c^P_{it}} = \gamma \frac{E_t(d_{it+1} + p^s_{it+1})}{c^P_{it+1}}. \tag{26}$$

B.3 Workers' Problem

From the equilibrium conditions and the workers' optimization problem, combining first order conditions leads to:

$$\frac{U_{c^W_{Ht}}}{E_t(U_{c^W_{Ht+1}})} = \frac{\beta_{Ht}}{\beta_{Ft}} \frac{U_{c^W_{Ft}}}{E_t(U_{c^W_{Ft+1}})} \frac{E_t(Z_{t+1})}{Z_t}, \tag{27}$$

$$E_t\left(\frac{Z_t}{Z_{t+1}} R_{Ht}\right) = R_{Ft} = R_t, \tag{28}$$

$$\frac{1-\alpha}{1-n_{it}} = \frac{\alpha w_{it}}{c^W_{it}}. \tag{29}$$

The combination of first order conditions with respect to consumption and to the international bond for both Home and Foreign workers leads to equation (27). As for equation (28), it results from the combination of first order conditions for the international and *inter-period bonds* and consists of the uncovered interest rate parity. Equation (29) refers to labor supply.