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Trade and Synchronization in a Multi-Country Economy*

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Abstract

Substantial evidence suggests that countries with stronger trade linkages have more synchronized business cycles. The standard international business cycle framework cannot replicate this finding, uncovering the trade-comovement puzzle. In this paper we investigate the extent to which more sophisticated trade models can sort out this puzzle. We show that under certain macro-level conditions but irrespective of the micro-level assumptions concerning trade (within a large class of trade models) synchronization is explained by three factors: (i) the correlation between each country's productivity shocks, (ii) the correlation between each country's share of expenditure on domestic goods, and (iii) the correlation between each country's productivity and the partner's share of expenditure on domestic goods. An empirical investigation of the link between trade and each of the three factors shows that the trade-comovement relation is explained by the first and second factors.

Keywords: Business Cycle Synchronization, International Trade.

JEL Classification: F15; F41; E30.

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1 Introduction

Substantial empirical evidence suggests that countries or regions with stronger trade linkages have more correlated business cycles. Frankel and Rose (1998), Clark and van Wincoop (2001), Calderon et al. (2007), Baxter and Kouparitsas (2004), and Imbs (2004), among others, show that pairs of countries that trade with each other exhibit a high degree of business cycle comovement. These findings have been interpreted as evidence that trade integration leads to business cycle synchronization. However, from a theoretical perspective the standard international real business cycle (IRBC) model, based on Backus et al. (1994), has difficulties in replicating this empirical fact (see Kose and Yi, 2001 and 2006). In the latter paper, the authors' baseline model explains only one-tenth of the responsiveness of comovement to trade intensity. This has given rise to the so-called trade-comovement puzzle: Standard models are unable to generate high output correlations arising from high bilateral trade intensity.

In the conventional IRBC framework, trade is modeled using the Armington specification, which imposes an exogenous trade specialization pattern. In the Armington framework trade adjustments are only at the intensive margin. By contrast, in a large class of trade models, trade shares also adjust at the extensive margin: when a country's relative efficiency declines it exports a narrower range of goods. In this paper, we investigate the extent to which the trade-comovement puzzle can be solved by modeling the trade linkages allowing for more sophisticated micro-level assumptions.

The main contribution of this paper is to show that, under certain macro-level conditions but irrespective of the micro-level assumptions concerning trade (within a large class of trade models), business cycle synchronization (measured by the output correlation) is explained by three factors: (i) the correlation between the two countries' productivity shocks, (ii) the correlation between the two countries' share of expenditure on domestic goods, and (iii) the correlation between each country's productivity and the partner's share of expenditure on domestic goods. Therefore, the ability of a model to generate higher output synchronization arising from increased bilateral trade depends on the extent to which trade integration affects each of these three factors.

This result relates to recent work by Arkolakis et al. (2008) and Arkolakis et al. (2012) concerning the welfare gains from trade. These authors show that the real wage (which determines the welfare gains from trade) can be represented as a function of the import penetration ratio and

an elasticity parameter that, depending on the particular micro-level assumptions, relates either to preferences or technology. In particular, Arkolakis et al. (2012) show that the gains from trade have the same form in a large class of trade models that includes the Armington model, Eaton and Kortum (2002), Bernard et al. (2003), Krugman (1980), and multiple versions of Melitz (2003). In turn, in the context of the IRBC model that concerns us, the labor supply responds to changes in the real wage (a function of the import penetration ratio). It follows that, in the absence of short-run wealth effects on the labor supply, the import penetration ratio and a parameter relating to the labor supply elasticity and the trade elasticity are the only determinants of employment and output fluctuations in response to foreign shocks.

To illustrate the quantitative implications of this result, our starting point is a multi-country model of international trade with endogenous specialization inspired by Eaton and Kortum (2002). We embed it in a real business cycle framework by including country specific technology shocks and allowing for variable labor supply. We calibrate the model's trade costs to match each country-pair's bilateral trade shares and assess the model's ability to generate high business cycle correlations between countries with strong trade linkages. We show that in this framework, the trade-comovement puzzle arises because trade counterfactually reduces the correlation between each country's share of expenditure on domestic goods and fails to substantially increase the correlation between each country's import penetration ratio and the trade partner's technology shocks. As a result, within a large class of trade models, the trade-comovement puzzle can be resolved only if productivity shocks are more correlated for country-pairs that trade more.

Using data on bilateral trade in manufacturing for a panel of 21 OECD countries, we estimate each country's technology levels between 1988 and 2007 extending the procedure developed in Eaton and Kortum (2002) to panel data. Based on these estimates we show that the two factors that explain the trade-comovement relation empirically are the correlation between each country-pair's technology levels and the correlation between each country-pair's share of expenditure on domestic goods. In particular, the second factor is the most important: for countries with strong trade linkages, the correlation of the share of expenditure on domestic goods is large. Thus, we argue that this should constitute a *litmus test* for theoretical models: stronger trade linkages should lead to synchronization in the share of expenditure on domestic goods.

Equipped with the estimated technology levels from our panel of countries, we examine what

happens once we relax the assumption that shocks are uncorrelated. In particular, we examine if by feeding the estimated technology shocks into the theoretical model we are able to reproduce the relation between trade and business cycle synchronization. With the estimated shocks we explain up to 83.9% of the trade-comovement relation. However, we show that even allowing for correlated shocks, the model still implies counterfactually that higher bilateral trade is associated with lower correlation between each country's share of expenditure on domestic goods. Thus, what emerges is an additional challenge: How to break the negative relation between trade integration and the correlation in the share of expenditure on domestic goods.

A second result of our analysis concerns the importance of the calibration assumptions about the number of countries that constitute the world economy. The models typically analyzed in the literature are either a two-country or three-country framework. However, it is likely that pairs of countries with higher bilateral trade intensity also share substantial trade linkages with common trading partners. A two-country or three-country model may not capture this feature of the data and lead to an attenuated link between trade and business cycle synchronization.¹ Instead, a multi-country model captures both the bilateral trade linkages and the trade linkages with common trading partners. Therefore, in a multi-country world, country-pair's import penetration ratios may comove positively provided both countries share the same trading partners, implying higher synchronization. This finding is related to work by Zimmermann (1997), Ishise (2011), and Johnson (2011). These papers note that third-country effects may be important in driving comovement.

Our paper is also related to a strand of the literature that tries to extend the IRBC model by changing the micro-level assumption about trade to improve the model's ability to explain the empirical association between trade and business cycle synchronization. Burstein et al. (2008) highlight the role of vertical specialization and show that countries with tighter links in the chain of production exhibit higher bilateral manufacturing output correlations.² Arkolakis and Ramanarayanan (2009) develop a two-country international business cycle model augmented with vertical specialization and consider, alternatively, the cases of perfect competition and Bertrand

¹We show that in a two-country world the correlation between each country's share of expenditure on domestic goods is -1 irrespective of the level of trade integration, whereas in the data countries with strong trade linkages exhibit more synchronized import penetration ratios.

²In a recent paper, di Giovanni and Levchenko (2010) emphasize the empirical relevance of vertical linkages in production to explain the effect of bilateral trade on business cycle synchronization.

competition. They conclude that vertical specialization alone is insufficient to solve the trade-comovement puzzle and suggest that allowing for variable markups may be helpful. Finally, Drozd and Nosal (2008) and Cacciatore (2012) propose search and matching frictions as a possible solution to the trade comovement puzzle. The latter considers these frictions in the labor market while the former introduces them in the goods market.

The remainder of the paper is organized as follows. Section 2 presents our equilibrium model of trade and the business cycle used to analyze the relation between trade integration and business cycle synchronization. Section 3 presents a simple two-country example that illustrates the model's predictions concerning the relation between trade and comovement. In Section 4 we assess the potential for the baseline model (with uncorrelated technology shocks) to quantitatively replicate the empirical relation between trade and comovement. Section 5, contains the most important contribution of the paper. We examine in depth the empirical channels through which trade integration is associated with business cycle synchronization and confront the data with the theoretical predictions. We also extend the baseline model to allow for correlated shocks. Finally, Section 6 concludes.

2 The Theoretical Economy

In this Section, we develop a simple model of the world economy to study the link between trade integration and business cycle synchronization. The setup of the model builds on Eaton and Kortum (EK, 2002). The world economy consists of M countries, each represented by a continuum of unit measure of identical and infinitely lived households. In each period of time t , the world economy experiences one of finitely many states, or events, $s_t \in \mathcal{S}$. We denote by $s^t = (s_0, \dots, s_t)$ the history of events through period t . The probability of any particular event s_{t+1} conditional on history s^t is $\pi(s_{t+1}|s^t)$. The initial realization s_0 is given.

2.1 Technology and Market Structure

Each country consumes a non-traded final good that is produced competitively by domestic final-good firms. The representative final-good firm in country i makes use of a continuum of differenti-

ated manufactured intermediate commodities indexed by $n \in [0, 1]$ that are combined as follows:

$$Y_i(s^t) = \left[\int_0^1 Q_i(n, s^t)^\phi dn \right]^{1/\phi}, \quad (1)$$

where $Q_i(n, s^t)$ is the input of the differentiated intermediate commodity of type n . The parameter $\phi \in (0, 1)$ relates to the elasticity of substitution across differentiated intermediate commodities, given by $\sigma = 1/(1 - \phi)$. Hence, the demand in country i for intermediate variety n satisfies the relation

$$Q_i(n, s^t) = \left[\frac{p_i(n, s^t)}{P_i(s^t)} \right]^{-\sigma} Y_i(s^t), \quad (2)$$

where $p_i(n, s^t)$ is the price of intermediate variety n in country i and

$$P_i(s^t) = \left[\int_0^1 p_i(n, s^t)^{1-\sigma} dn \right]^{1/(1-\sigma)},$$

is the *ideal price index* in country i of the composite of intermediate commodities.

Trade barriers.— The differentiated intermediate commodities are subject to trade barriers taking the form of an *iceberg cost*: To successfully deliver in country j one unit of any differentiated intermediate commodity produced in country i , $\tau_{ji} \geq 1$ units need to be shipped, with $\tau_{ii} = 1$.

Intermediate-good sector.— The structure of the intermediate-good sector is as in EK; in particular, we adopt a probabilistic formulation of technology differences. Countries have differential access to technology, so efficiency varies across commodities and countries. Producing one unit of the intermediate commodity n in country i requires $[\varphi_i^n(s^t)]^{-1}$ units of labor. Therefore, the cost for intermediate firms in country i to deliver one unit of intermediate commodity n to country j is

$$p_{ji}(n, s^t) = \left[\frac{W_i(s^t)}{\varphi_i^n(s^t)} \right] \tau_{ji}, \quad (3)$$

where $W_i(s^t)$ is the wage rate in country i . There is perfect competition, so country i firms potentially sell the commodity n to country j at price $p_{ji}(n, s^t)$. The commodity is purchased from the lowest-cost supplier; hence, the price of commodity n in country j is given by

$$p_j(n, s^t) = \min_{i=1, \dots, M} [p_{ji}(n, s^t)]. \quad (4)$$

Complete characterization of the equilibrium prices requires the specification of how the efficiencies

are distributed across firms and countries. We follow EK and model firms' efficiency using a probabilistic approach: It is assumed that country i 's efficiency in producing commodity n is the realization of a random variable φ , which is drawn independently for each n . We assume that country i 's efficiency follows a Fréchet distribution:

$$\begin{aligned} F_i(\varphi; s^t) &= \text{Prob}[\varphi_i^n \leq \varphi \mid s^t] \\ &= \exp\left[-T_i(s^t) \varphi^{-\theta}\right], \end{aligned} \tag{5}$$

where $\varphi \geq 0$. The parameter $\theta > 1$ controls the degree of heterogeneity across firms, with higher θ implying less heterogeneity. Given θ , the parameter $T_i(s^t) > 0$ determines aggregate productivity and is both stochastic and country specific. By combining (3) and (5), it follows that the distribution of $p_{ji}(n, s^t)$ —the cost for country i firms to supply commodity n in country j —is given by the following cumulative distribution function:

$$\begin{aligned} G_{ji}(p; s^t) &= \text{Prob}[p_{ji}(n, s^t) \leq p \mid s^t] \\ &= 1 - \exp\left\{-T_i(s^t) [W_i(s^t) \tau_{ji}]^{-\theta} p^\theta\right\}. \end{aligned} \tag{6}$$

The resulting distribution of $p_j(n, s^t)$, the price of commodity n in country j , is found by noticing that the price of the lowest cost supplier of commodity n in country j will be less than p unless each source's cost is greater than p . Thus, the distribution $G_j(p; s^t) = \text{Prob}[p_j(n, s^t) \leq p \mid s^t]$ is given by

$$\begin{aligned} G_j(p; s^t) &= 1 - \prod_{i=1}^M [1 - G_{ji}(p; s^t)] \\ &= 1 - \exp\left[-\Phi_j(s^t) p^\theta\right], \end{aligned} \tag{7}$$

where the aggregate stochastic variable $\Phi_j(s^t) = \sum_{i=1}^M T_i(s^t) [W_i(s^t) \tau_{ji}]^{-\theta}$ determines the distribution of prices. The upshot is that aggregate fluctuations in country j are determined by the behavior of this variable. In particular, in equilibrium the *ideal price index* in country j of the final good is given by

$$P_j(s^t) = \kappa \Phi_j(s^t)^{-1/\theta}, \tag{8}$$

where κ is a positive constant.³

Bilateral trade flows.— The probability λ_{ji} that country i is the lowest-cost supplier to j for any particular intermediate commodity is given by⁴

$$\lambda_{ji}(s^t) = \frac{T_i(s^t) [W_i(s^t) \tau_{ji}]^{-\theta}}{\Phi_j(s^t)}. \quad (9)$$

Since there are a continuum of intermediate goods, the probability λ_{ji} also corresponds to country j 's expenditure on country i 's differentiated intermediate goods (X_{ji}) as a fraction of country j 's total expenditure on differentiated intermediate goods (X_j), $\lambda_{ji}(s^t) = X_{ji}(s^t)/X_j(s^t)$. The bilateral trade intensity measure used in our study is closely linked to one of the measures proposed by Frankel and Rose (FR, 1998), which is the sum of a country's bilateral exports divided by the sum of each country's aggregate net income. In our theoretical economy, this is given by

$$\left(\text{Bilateral Trade}\right)_{ji} \equiv \left[\frac{\lambda_{ji}(s^t) X_j(s^t) + \lambda_{ij}(s^t) X_i(s^t)}{X_j(s^t) + X_i(s^t)} \right]. \quad (10)$$

Stochastic technology shocks.— In each period $t = 0, 1, \dots$, the event s_t yields a realization for the stochastic technology level in each country, $T_i(s^t)$. In particular, it is assumed that the technology level in each country can be represented as the product of a deterministic component and a stochastic component, as follows:

$$T_i(s^t) = \mathcal{T}_i \exp[a_i(s^t)], \quad (11)$$

where the deterministic component \mathcal{T}_i governs the average technological advantage of country i . In turn, for each period t , the event s_t yields a realization for the stochastic component in each country $a_i(s^t)$; this component follows a serially correlated discrete Markov process and is independent across countries.

³ $\kappa = [\Gamma(\frac{1-\sigma+\theta}{\theta})]^{1/(1-\sigma)}$, where $\Gamma(\cdot)$ is the Gamma function and it is assumed that $\theta > \sigma - 1$.

⁴This probability is obtained by calculating

$$\lambda_{ji}(s^t) = \Pr[p_{ji}(n, s^t) \leq \min\{p_{js}(n, s^t); s \neq i\}] = \int_0^\infty \prod_{s \neq i} [1 - G_{js}(p; s^t)] dG_{ji}(p; s^t).$$

2.2 Preferences

The stand-in household in country i has preferences represented by a utility function of the form introduced by Greenwood et al. (1988), given by

$$u(C_i, N_i; s^t) = \ln \left[C_i(s^t) - \xi \frac{N_i(s^t)^{1+\nu}}{1+\nu} \right] \quad (12)$$

where $C_i(s^t)$ and $N_i(s^t)$ are, respectively, consumption and time spent working by the stand-in household. The parameter ν is the inverse of the Frisch elasticity of labor supply and $\xi > 0$. The choice of preferences excludes wealth effects and therefore excludes intertemporal substitution in the labor choice.⁵ The Bellman equation characterizing the stand-in household optimal behavior reads as

$$V_i(B_{i,t}, s^t) = \max_{C_i, N_i} \left[u(C_i, N_i; s^t) + \beta \sum_{s^{t+1} \in \mathcal{S}} \pi(s^{t+1}|s^t) V_i(B_{i,t+1}, s^{t+1}) \right], \quad 0 < \beta < 1 \quad (13)$$

and is subject to the budget constraint

$$P_i(s^t) C_i(s^t) + q_i(s^t) B_i(s^t) = W_i(s^t) N_i(s^t) + B_i(s^{t-1}), \quad (14)$$

where $B_i(s^{t-1}) \equiv B_{i,t}$ denotes the holdings of domestic, risk-free, one-period-lived bonds by the stand-in household, and $q_i(s^t)$ denotes the price of domestic bonds. In the quantitative investigation that follows we assume there are no international financial markets and impose the equilibrium conditions under financial autarky $B_i(s^t) = 0$ for all s^t .⁶

⁵In a recent paper, Jaimovich and Rebelo (2009) find evidence of a weak wealth effect in labor supply choices.

⁶Our theoretical model considers a setting with balanced trade (i.e., financial autarky). Heathcote and Perri (2002) show that the financial autarky economy is closest to the data along most dimensions compared with the complete markets economy and the bonds-only economy. In particular, the financial autarky model better accounts for the observed cross-country output, consumption and employment correlations. Kose and Yi (2006) find that financial autarky helps to resolve the trade-comovement puzzle.

2.3 Equilibrium Conditions

The first-order conditions that characterize the solution to the problem of the stand-in household in country i are as follows:

$$q_i(s^t) \left[C_i(s^t) - \xi \frac{N_i(s^t)^{1+\nu}}{1+\nu} \right]^{-1} = \beta \sum_{s_{t+1} \in \mathcal{S}} \pi(s_{t+1}|s^t) \left[C_i(s^{t+1}) - \xi \frac{N_i(s^{t+1})^{1+\nu}}{1+\nu} \right]^{-1} \quad (15)$$

$$\xi N_i(s^t)^\nu = \frac{W_i(s^t)}{P_i(s^t)}. \quad (16)$$

Using the stand-in household budget constraint (14) and the first-order condition (16), and imposing the equilibrium conditions under financial autarky, yields the solution

$$\begin{aligned} Y_i(s^t) &= C_i(s^t) \\ &= \left[\left(\frac{1}{\xi} \right)^{1/\nu} \left(\frac{W_i(s^t)}{P_i(s^t)} \right)^{1+\frac{1}{\nu}} \right]. \end{aligned} \quad (17)$$

Note that by combining equations (8) and (9), the real wage in country i can be expressed in terms of the domestic technology advantage T_i and the share of domestic purchases λ_{ii} as follows:

$$\frac{W_i(s^t)}{P_i(s^t)} = \frac{1}{\kappa} \left(\frac{T_i(s^t)}{\lambda_{ii}(s^t)} \right)^{1/\theta}, \quad (18)$$

where λ_{ii} is one minus the import penetration ratio. It follows that hours worked and output can be expressed as follows

$$N_i(s^t) = \left[\left(\frac{1}{\xi \kappa} \right) \left(\frac{T_i(s^t)}{\lambda_{ii}(s^t)} \right)^{1/\theta} \right]^{1/\nu}, \quad (19)$$

$$Y_i(s^t) = \left[\kappa^{-\theta} \left(\frac{1}{\xi \kappa} \right)^{\theta/\nu} \left(\frac{T_i(s^t)}{\lambda_{ii}(s^t)} \right)^{1+\frac{1}{\nu}} \right]^{1/\theta}. \quad (20)$$

Finally, equilibrium in the market for produced goods in each country i requires total domestic labor income $W_i(s^t) N_i(s^t)$ to equal world spending on domestically produced goods, so that

$$W_i(s^t) N_i(s^t) = \sum_{j=1}^M \lambda_{ji}(s^t) W_j(s^t) N_j(s^t). \quad (21)$$

Combining this condition with (9) and (19) yields an expression for the excess demand for labor in each country, given by

$$Z_i(s^t) = \left(\frac{1}{\xi\kappa}\right)^{1/\nu} \left[\sum_{j=1}^M \frac{T_i(s^t) W_j(s^t)^{1+\frac{1}{\nu}} \Phi_j(s^t)^{\frac{1-\nu\theta}{\nu\theta}}}{W_i(s^t)^{1+\theta} \tau_{ji}^\theta} \right] - \left[\frac{\Phi_i(s^t)^{1/\theta} W_i(s^t)}{\xi\kappa} \right]^{1/\nu}. \quad (22)$$

An equilibrium is a wage vector $W(s^t) \in \mathbf{R}_{++}^M$ such that $Z_i(s^t) = 0$ for all $i = 1, \dots, M$, for a choice of numéraire wage. Given the wage vector, all other equilibrium prices and quantities obtain.

3 A Two-Country Example

Before turning to the quantitative evaluation of the multi-country model, it is instructive to consider a two-country example that delivers simple analytical solutions. The main purpose of this analysis is to understand qualitatively the relation between trade and business cycle synchronization implied by our model.

We consider a symmetric two-country world (*home* and *foreign*) with transport cost $\tau \geq 1$, and denote *foreign* variables by $*$. The numéraire is the *home* wage rate. The equilibrium dynamics in *home* are represented by the following two equations

$$\tilde{y} = \left[(1 + \sigma_n) \theta^{-1} \right] (a - \tilde{\lambda}), \quad (23)$$

$$\tilde{\lambda} = \vartheta (a - a^*) \quad (24)$$

with $\sigma_n = 1/\nu \geq 0$ the labor supply elasticity and

$$\vartheta = \left[\frac{1 + \sigma_n}{1 + 2\sigma_n + (1 + 2\theta) \tau^\theta} \right] \in (0, 1).$$

The variables a and a^* are, respectively, the *home* and *foreign* stochastic technology shocks (for

now assumed to be uncorrelated). A variable X in log-deviation from steady state is denoted by \tilde{x} and, in particular, $\tilde{\lambda}$ is the log-deviation from steady state of *home*'s share of expenditure in domestic goods.⁷

From equation (23), the elasticity of output to changes in the share of expenditure on domestic goods is given by

$$\frac{\partial \tilde{y}}{\partial \tilde{\lambda}} = - \left[(1 + \sigma_n) \theta^{-1} \right] < 0. \quad (25)$$

The parameter θ reflects the importance of the extensive margin adjustment of trade. A lower value of θ means that comparative advantage exerts a stronger force for trade against the resistance imposed by the trade costs. If θ is small, the set of intermediate goods that *home* imports increases substantially following a positive *foreign* shock. Thus, when θ is small *home* benefits substantially from a positive *foreign* shock, raising the real wage. An increase in the real wage at *home* raises employment and output. This increase is larger, the larger the labor supply elasticity σ_n .

It follows that a positive *foreign* shock is transmitted to *home* by lowering the latter's share of expenditure on domestic goods. From equation (24), we see that the elasticity of the share of expenditure on domestic goods to *foreign shocks* is given by

$$\begin{aligned} \frac{\partial \tilde{\lambda}}{\partial a^*} &= -\vartheta \\ &= - \left[\frac{1 + \sigma_n}{1 + 2\sigma_n + (1 + 2\theta) \tau^\theta} \right]. \end{aligned} \quad (26)$$

Thus, increased trade leads to higher business cycle synchronization if and only if $\frac{\partial \vartheta}{\partial \tau} < 0$. This condition is satisfied and, hence, the model is at least qualitatively consistent with trade leading to business cycle synchronization.

To understand better the transmission mechanism of *foreign* shocks it is helpful to inspect Figure 1. The Figure illustrates the impulse response (IRF) of *home*'s share of expenditure on domestic goods (top panels), employment (middle panels) and output (bottom panels) to a *foreign* technology shock. The left-hand side panels consider the model with endogenous labor supply ($\sigma_n > 0$) and the right-hand side panels consider the model with fixed labor supply ($\sigma_n = 0$). The red dotted IRF correspond to the model with trade costs ($\tau > 1$) while the blue IRF correspond to the model with free trade ($\tau = 1$).

⁷See Appendix B for detailed derivations.

[Figure 1 about here]

Consider first the top panels of Figure 1, which show the response of *home*'s share of expenditure on domestic goods ($\tilde{\lambda}$). Following a positive *foreign* technology shock, foreign intermediate goods become less expensive. Thus, *home*'s final good producers increase production by purchasing more of each *foreign* variety (intensive margin), and also by sourcing from more efficient *foreign* intermediate good suppliers (extensive margin). The upshot is that *home*'s share of expenditure on domestic intermediate goods decreases. This decrease is partially offset by a rise in foreign's relative wage implied by the trade balance condition. However, with endogenous labor supply the relative wage adjustment needed to restore trade balance is small. Hence, a foreign shock lowers *home*'s share of expenditure on domestic goods by more if the labor supply elasticity is large.

As discussed earlier, the elasticity of *home*'s share of expenditure in domestic goods to a foreign shock is given by $-\vartheta$. Since ϑ is low at high values of τ , the implication is that trade integration (a lower τ) implies a larger fall in *home*'s share of expenditure on domestic goods following a positive *foreign* shock. This is illustrated by contrasting the blue IRF (model with free trade) and the red dotted IRF (model with trade barriers).

Turning to the middle panels of Figure 1, we see that with endogenous labor supply a positive *foreign* shock raises *home*'s employment. This happens because the decrease in $\tilde{\lambda}$ implies that *home*'s final good producer benefits from the foreign shock by sourcing from more efficient *foreign* intermediate good suppliers. The upshot is that the domestic price level falls, which raises the real wage. In the absence of trade costs, *home*'s final good producer is able to benefit more from the increased efficiency of *foreign*'s intermediate good producers. With free trade *home*'s real wage increases by more following a *foreign* shock and in this way trade integration leads to more synchronized employment fluctuations.

Finally, the bottom panels of Figure 1 show the response of *home*'s output following a positive *foreign* shock. The interpretation of these IRF is the same as before. A positive foreign technology shock implies that foreign intermediate goods cost less, raising the import penetration ratio; as the expenditure share on imported intermediate commodities increases the aggregate price level falls, raising the real income. In addition, with flexible labor supply *home*'s real income increases by more because the higher real wages raise employment, allowing *home*'s intermediate good production and

final good production also to increase by more.

We have seen that the model is able to qualitatively obtain the positive relation between trade intensity and business cycle synchronization. To judge if the model can resolve the trade-comovement puzzle, it is necessary to determine whether we are able to reproduce quantitatively the empirical relation between bilateral trade intensity and business cycle synchronization. We do this in the next Section in the setting of the multi-country world economy.

4 Quantitative Evaluation: Multi-Country Model

We use a simulation approach to determine whether our model quantitatively reproduces the trade-comovement relation. We simulate several sets of time series for the world economy, reproduce the FR regression and compare the implied relation between trade and comovement with the empirical relation. This Section describes the calibration used to evaluate the model and the main findings.

4.1 Calibration

Before turning to the quantitative findings, we first describe the targets informing the choice of parameter values used to evaluate the theoretical economy. The number of countries M is set equal to 21 to replicate the empirical analysis that follows—implying 210 distinct country-pairs.

The list of technology parameters that have to be determined includes the following: the elasticity of substitution between intermediate inputs σ ; the parameter that controls the level of heterogeneity in productive efficiencies θ ; the parameters controlling each country's technology level in steady-state \mathcal{T}_i ; and the 420 trade-cost parameters τ_{ij} for each $i, j = 1, \dots, 21$, with $i \neq j$. The first two parameters are chosen based on evidence in Bernard et al. (2003), who choose the parameters θ and σ matching the productivity and size advantage of exporters in the U.S. plant-level data. The parameter θ is chosen to match the productivity advantage of exporters, and the parameter σ corresponds to the price elasticity of demand for differentiated intermediate commodities and therefore relates to the size advantage of exporting establishments. The values estimated by Bernard et al. (2003) for θ and σ are, respectively, 3.60 and 3.79.

The trade-cost parameters τ_{ij} are chosen based on the bilateral trade shares from the OECD Structural Analysis (STAN) database. In particular, from equation (9) we derive the following

relationship:

$$\frac{\lambda_{ji}}{\lambda_{jj}} = \frac{\mathcal{T}_i}{\mathcal{T}_j} \left(\frac{W_i \tau_{ji}}{W_j} \right)^{-\theta}, \quad (27)$$

where λ_{ji} is country j 's expenditure in country i commodities as a share of total expenditure by country j and can be directly measured in the data (it is country j 's bilateral import penetration from partner i). The calibration is simplified substantially by assuming symmetric iceberg costs, $\tau_{ji} = \tau_{ij}$, so that the bilateral trade cost τ_{ji} is given by

$$\tau_{ji} = \left(\frac{\lambda_{ji} \lambda_{ij}}{\lambda_{jj} \lambda_{ii}} \right)^{-\frac{1}{2\theta}}. \quad (28)$$

The upshot is that, by making use of the symmetry assumption, the bilateral trade costs are easily identified using the data on trade shares described in the Appendix A. Figure 2 illustrates the relation between the bilateral import penetration ratios from the STAN database and the model's counterpart. As the figure shows, the fit is very good despite the symmetry assumption made to calibrate the iceberg trade costs. The scatter points are located near the 45-degree line, and the correlation between the simulated bilateral trade intensities and the data's counterpart is 95%. The median bilateral trade intensity in the data is 1.02% while in the simulation it is 0.9%.

[Figure 2 about here]

Figure 3 illustrates the distribution of the calibrated iceberg costs. Table 1 shows the relation between the calibrated values of the iceberg trade costs and the empirical proxies used for trade frictions in the next subsection: log distance, border dummy and language dummy. The relation between each of these variables and the iceberg costs has the expected sign, and the R^2 of the regression is very high: 58%. These results suggest that our calibrated values of iceberg costs adequately capture the empirical trade barriers.

[Figure 3 about here]

[Table 1 about here]

Turning to the calibration of the technology level in each country \mathcal{T}_i , we use equation (20) to obtain the following relation:

$$\mathcal{T}_i = \kappa^\theta \lambda_{ii} \xi^{\theta/(1+\nu)} Y_i^{\theta\nu/(1+\nu)}. \quad (29)$$

The value of each \mathcal{T}_i is determined by replacing Y_i with the real GDP per capita in constant PPP averaged between 1970 and 2007 for each of the 21 countries in our sample and using the STAN bilateral trade share to recover each λ_{ii} (given by one minus the import penetration ratio in the respective country).

The remaining technology parameters that need to be chosen are the parameters of the stochastic process for the technology shocks, $a_i(s^t)$, which follows a correlated discrete Markov process. In particular, we use a finite-state Markov process with states and transition probabilities set to approximate the continuous autoregressive model given by (up to a constant)

$$a(s^t) = \rho a(s^{t-1}) + \epsilon(s_t),$$

where $\epsilon(s_t)$ is a normally distributed and zero-mean *i.i.d.* shock with standard deviation σ_ϵ . We choose values for σ_ϵ and ρ to match the standard deviation and the autocorrelation of output fluctuations in the US. Note that the technology shocks are independent across countries.

Given the values for the technology parameters, we explore the relation between trade integration and business cycle synchronization for values of the labor supply elasticity $1/\nu$ ranging between 1 and 3. However, in our baseline calibration we set $1/\nu = 2.33$ so that the ratio between the standard deviation of employment and output is consistent with the US time series.

4.2 Quantitative Evaluation

This Section examines the ability of our model to replicate the trade-comovement relation. In order to compare the model with the data we estimate using ordinary least squares (OLS) the following regression in the spirit of FR using both empirical and simulated data:

$$\text{cor}(\tilde{y}_j, \tilde{y}_i) = \alpha + \beta \left(\text{Bilateral Trade} \right)_{ji} + \varepsilon_{ji}, \quad (30)$$

where $\text{cor}(\tilde{y}_j, \tilde{y}_i)$ is the correlation between (log) output in country j and in country i , and $\left(\text{Bilateral Trade} \right)_{ji}$ is the country-pair's bilateral trade intensity as defined in (10).

We are interested in the sign and magnitude of the regression coefficient β . A positive β indicates that increased trade integration generates more synchronized business cycles. We consider the level of bilateral trade intensity in addition to the logarithm, as suggested by Kose and Yi (2006).

They recommend the level specification because they judge that the relation between business cycle synchronization and trade is not a semi-log relation. As they state, the semi-log specification implies that an increase in trade intensity from 0.1 percent to 0.2 percent would have the same impact on GDP correlation as an increase in trade intensity from 20 percent to 40 percent, which is counterfactual and inconsistent with the IRBC model.

We first estimate Equation (30) using our data, obtained from the OECD STAN database over the 1988–2007 period (see Appendix A for details). We define $\text{cor}(\tilde{y}_j, \tilde{y}_i)$ as the correlation in manufacturing output between country j and country i .⁸ $\left(\text{Bilateral Trade}\right)_{ji}$ is the average bilateral trade intensity measure calculated as the sum of bilateral manufacturing imports from country i to country j and from country j to country i , as a fraction of the two countries' total manufacturing output. The OLS estimates of β are reported in Table 2. The results indicate that there is a positive association between trade integration and comovement. The specification (in levels) is shown in column 1 and the semi-log specification in column 2. The β coefficient takes the value 8.362 in the levels regression and 0.093 in the semi-log regression.

[Table 2 about here]

As a second step, we use our model of the world economy (composed of 21 countries) to simulate 500 replications of time series for output for each country and the bilateral trade intensities for each country-pair. In order to assess our model's potential to generate high business cycle correlations between countries with stronger trade linkages we estimate by OLS equation (30), for each replication. Table 3 reports the median and the 95% confidence intervals (CIs) for the estimated coefficient β . We report the results obtained with four alternative values for the labor supply elasticity, and using the bilateral trade intensity measure in levels (Panel A) and logs (Panel B). We consider alternative values for the labor supply elasticity because, as illustrated in Section 3, the response of the import penetration ratio to foreign shocks increases as the labor supply elasticity is raised. The tables show that the β coefficients are positive, indicating that the model qualitatively replicates the trade-comovement relation but fall short quantitatively compared with the data. We

⁸We use manufacturing output instead of total output because the empirical work in Section 5 requires panel data on bilateral trade flows and the use of manufacturing output allows us to extend the time-series length of the panel substantially. The FR result concerning trade and business cycle synchronization is robust across alternative measures of output.

assess the ability of the model to replicate the empirical relation by calculating the ratio between the OLS β coefficient obtained using the simulated data and its empirical counterpart. In our baseline calibration ($1/\nu = 2.33$) the model explains 12.4% of the empirical relation in levels and 10.8% of the semi-log relation. This implies that the baseline model with uncorrelated shocks is not more successful than the IRBC and, thus, the puzzle remains.

[Table 3 about here]

Our next step is to investigate theoretically and empirically the channels through which trade leads to business cycle synchronization. This will allow us to identify the elements that are missing from our baseline model and that are required to be successful in addressing the link between trade and comovement in a way that is consistent with the data but at the same time disciplined by the theory.

5 Trade and the Channels of Synchronization

In the previous Section we established that if technology shocks are uncorrelated across countries, the trade-comovement puzzle persists when trade linkages are modelled within the EK framework. In this Section we use the relation between a country's output and the fluctuation in that country's import penetration ratio to better understand the nature of the trade-comovement puzzle. From equation (20) it follows that output fluctuations in country i (in log deviations from steady state) are given by

$$\tilde{y}_i(s^t) = \left(1 + \frac{1}{\nu}\right) \frac{1}{\theta} \left[a_i(s^t) - \tilde{\lambda}_{ii}(s^t) \right]. \quad (31)$$

Expression (31) implies that the degree of comovement between any country-pair depends on the correlation between each country's productivity shock $a_i(s^t)$ and on the correlation between each country's share of expenditures on domestic goods $\tilde{\lambda}_{ii}(s^t)$ (which, in log-deviation from steady state, is equal to the negative of the import penetration ratio). It turns out that expression (31) holds for a large class of trade models, as we establish in Result 1:

Result 1 *Suppose the following macro-level assumptions are satisfied:*

A1. Balanced trade, so that for any country j , $\sum_{i=1}^M X_{ji} = \sum_{i=1}^M X_{ij}$;

A2. Aggregate profits are a constant share of revenue;

A3. The import demand system exhibits constant elasticity of substitution (CES);

A4. Labor supply choices are independent of wealth.

It follows that, irrespectively of the micro level assumptions about trade, output fluctuations are given by equation (31).

See appendix C for proof.

This result builds on the work of Arkolakis et al. (2012), who show that the predictions of a large class of trade models concerning the change in real income associated with any foreign shock only depend on the import penetration ratio and the trade elasticity. The relevant class of models is large and includes many well-known trade models such as the Armington model, Eaton and Kortum (2002), Bernard et al. (2003) extension of EK to imperfect competition, Krugman (1980), and multiple versions of Melitz (2003).

From equation (31), we see that the covariance between the log output fluctuations in country i and in country j around the steady state can be written as

$$\text{cov}(\tilde{y}_i, \tilde{y}_j) = \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \left[\text{cov}(a_i, a_j) + \text{cov}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) - \text{cov}(a_i, \tilde{\lambda}_{jj}) - \text{cov}(\tilde{\lambda}_{ii}, a_j) \right], \quad (32)$$

where $\text{cov}(x, z)$ denotes the covariance between two variables x and z . Given that our measure of business cycle synchronization is the correlation of log output fluctuations around the steady state, it is convenient to express (32) in terms of correlations. If we assume that (i) the technology shocks in each country all have the same standard deviation and (ii) the world economy is symmetric in the sense that the standard deviations of $\tilde{\lambda}_{ii}$ and \tilde{y}_i are the same across countries, by manipulating (32) we obtain the following three-factor model for the output correlation between countries i and j

$$\text{cor}(\tilde{y}_i, \tilde{y}_j) = \beta_1 \text{cor}(a_i, a_j) + \beta_2 \text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) + \beta_3 \left[\text{cor}(a_i, \tilde{\lambda}_{jj}) + \text{cor}(\tilde{\lambda}_{ii}, a_j) \right], \quad (33)$$

where $\text{cor}(x, z)$ denotes the correlation between two variables x and z .⁹ Equation (33) is our basic empirical specification. It implies three channels through which trade can increase business cycle synchronization, summarized in the following result:

Result 2 *The output correlation for each country-pair may be expressed as the sum of three factors, as in equation (33). It follows that there are three channels through which an increase in bilateral trade may increase business cycle synchronization: (i) Increased bilateral trade resulting in a higher correlation between each country's technology shocks; (ii) increased bilateral trade resulting in a higher correlation between each country's share of expenditure on domestic goods; and (iii) increased bilateral trade raising the correlation between the domestic import penetration ratio and foreign technology shocks.*

See appendix D for proof.

Equation (33) and Result 2 provide the basis for the empirical analysis that follows. The share of expenditure on domestic goods λ_{ii} (equivalently, one minus the import penetration ratio) can be obtained from the bilateral trade data. Moreover, by using these data for a panel of 21 OECD countries, we estimate each country's technology level a_i between 1988 and 2007, following the procedure developed in EK. This allows us to evaluate the model based on the estimation of the regression equation

$$\text{cor}(\tilde{y}_i, \tilde{y}_j) = \alpha + \beta_1 \text{cor}(a_i, a_j) + \beta_2 \text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) + \beta_3 \left(\text{cor}(a, \tilde{\lambda}) \right)_{ij} + e_{ij}, \quad (34)$$

where

$$\left(\text{cor}(a, \tilde{\lambda}) \right)_{ij} \equiv \text{cor}(a_i, \tilde{\lambda}_{jj}) + \text{cor}(\tilde{\lambda}_{ii}, a_j).$$

⁹The factor loadings are given by

$$\begin{aligned} \beta_1 &\equiv \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_a^2}{\sigma_y^2}, \\ \beta_2 &\equiv \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_\lambda^2}{\sigma_y^2}, \\ \beta_3 &\equiv - \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_a \sigma_\lambda}{\sigma_y^2}, \end{aligned}$$

where σ_x denotes the standard deviation of a variable x . See Appendix D for detailed derivations.

We evaluate the model by testing if the factor loadings have the expected sign and are statistically significant, and by judging the model’s goodness of fit.¹⁰ If the fit of the model is judged to be good, we can examine carefully the channels through which trade leads to business cycle synchronization. In particular, by inspecting how each of the three factors is related to the country-pair’s bilateral trade intensity we are able to identify if country-pairs that trade more have higher output correlations because of: (i) Higher correlation between each country’s technology shocks; (ii) higher correlation between each country’s share of expenditure on domestic goods; or (iii) higher correlation between the domestic import penetration ratio and the foreign technology shock. Finally, notice that the three factors are not independent. In particular, an increased correlation between each country’s technology shocks may imply an increased correlation between each country’s share of expenditure on domestic goods.

5.1 Estimation of the Technology Shocks

Eaton and Kortum (2002) estimate the state of technology T_i using bilateral trade in manufactures for a cross-section of 19 OECD countries in 1990. We adapt their procedure to estimate a panel of technology shocks $a_i(s^t)$ for 21 countries using data on bilateral trade in manufactures among OECD countries over the period 1988–2007.¹¹ The procedure is based on equation (9) which, like the theoretical gravity equation of Anderson and van Wincoop (2003), relates trade flows to characteristic of the trading partners and trade barriers. Normalizing equation (9) by the country j expenditure on domestic goods X_{jjt} , we obtain

$$\frac{X_{jit}}{X_{jjt}} = \frac{T_{it}}{T_{jt}} \left(\frac{W_{it}}{W_{jt}} \right)^{-\theta} \tau_{jit}^{-\theta}, \quad (35)$$

¹⁰Relaxing the symmetry assumption leads to the following random coefficient model

$$\text{cor}(\tilde{y}_i, \tilde{y}_j) = \alpha + \beta_1^{ij} \text{cor}(a_i, a_j) + \beta_2^{ij} \text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) + \beta_3^{ij} \left(\text{cor}(a, \tilde{\lambda}) \right)_{ij} + e_{ij}.$$

We estimate the model in which coefficients may be correlated with the regressors using the instrumental variable method proposed in Heckman and Vytlačil (1998) and our findings are robust. See footnote 15.

¹¹See Appendix A for a complete description of the data used.

where the cross-sectional unit of observation is the country-pair indexed by ij (where i is the source and j is the destination country) and time is indexed by t . Taking logs of (35) gives

$$\begin{aligned}\ln \frac{X_{j it}}{X_{j jt}} &= -\theta \ln \tau_{j it} + \ln \frac{T_{it}}{T_{jt}} - \theta \ln \frac{W_{it}}{W_{jt}} \\ &= -\theta \ln \tau_{j it} + S_{it} - S_{jt},\end{aligned}\tag{36}$$

where

$$S_{it} \equiv \ln T_{it} - \theta \ln W_{it}\tag{37}$$

is a measure of country's i state of technology adjusted by labor costs.

The left-hand side of (36) is calculated using bilateral trade data for 21 countries. In terms of the right-hand side, we proceed as follows. The effect of S_{it} is given by the coefficient on the respective source-country time effect. The trade costs are captured by the proxies for geographic barriers suggested by the gravity literature, as follows:

$$\ln \tau_{j it} = d_k + b + l + e + m_j - \delta_{ji} - \eta_{j it},\tag{38}$$

where the dummy variables associated with each component are omitted to simplify the notation.¹² The term d_k ($k = 1, \dots, 6$) captures the effect of the distance between j and i lying in the k th interval, b is the effect of j and i sharing a common border, l is the effect of j and i sharing a common language, e is the effect of j and i belonging to the European Union (EU), and m_j ($j = 1, \dots, 21$) is a destination fixed effect. The error terms δ_{ji} and $\eta_{j it}$ are orthogonal to each other and to all the other regressors. The potential reciprocity in geographical trade barriers is captured by assuming that the error term δ_{ji} consists of two components

$$\delta_{ji} = \delta_{ji}^2 + \delta_{ji}^1.$$

The component δ_{ji}^2 has variance σ_2^2 and is meant to capture the country-pair specific component affecting two-way trade so that $\delta_{ji}^2 = \delta_{ij}^2$. The second component δ_{ji}^1 affects one-way trade and has variance σ_1^2 . Finally, the error term $\eta_{j it}$ is a classical disturbance with variance σ_η^2 .¹³

¹²In the empirical specification it is important to allow the trade costs $\tau_{j it}$ to be indexed by time since some of the empirical proxies for trade barriers (in particular, EU membership of the country-pair) are time specific.

¹³This error structure gives a variance-covariance matrix of $\delta + \eta$ with diagonal elements $\sigma_1^2 + \sigma_2^2 + \sigma_\eta^2$ and certain non zero off-diagonal elements $E(\delta_{ij}\delta_{ji}) = \sigma_2^2$.

Using the previous results in (36) yields the regression equation

$$\ln \frac{X_{jit}}{X_{jjt}} = S_{it} - S_{jt} - \theta m_j - \theta d_k - \theta b - \theta l - \theta e + \theta \delta_{ji}^2 + \theta \delta_{ji}^1 + \theta \eta_{jit}, \quad (39)$$

which is estimated by generalized least squares (GLS) and using panel data from 1988 to 2007. We use the estimates of the S_{it} to obtain the technology levels estimates \widehat{T}_{it} 's by using equation (37) and setting θ equal to 3.60 as in Section 4.1.¹⁴ Once we have the technology levels, the estimated technology shocks $\widehat{a}_i(s^t)$ are given by

$$\widehat{a}_i(s^t) = \ln \left(\frac{\widehat{T}_{it}}{\text{avg } \widehat{T}_{it}} \right), \quad (40)$$

where $\text{avg } \widehat{T}_{it}$ is the time-series average of \widehat{T}_{it} .

5.2 Channels of Synchronization

Once we have obtained a panel for the technology shocks $\widehat{a}_i(s^t)$, we can compute the three factors in equation (34). This allows us to test the predictions of our model by judging the goodness of fit of the regression equation and verifying if the factor loadings are statistically significant and have the expected sign. Specifically, β_1 and β_2 are predicted to be positive while β_3 should be negative. Table 4 shows the results of the OLS regression. Three aspects of the results support our model. First, the coefficients on each of the three factors have the predicted signs and are highly significant. Second, the coefficients are jointly statistically significant as implied by the F -statistic. Third, the three factors account for an important fraction of the variation in output correlation across country-pairs, and the largest Adjusted R^2 is obtained for the model that includes all three factors.¹⁵

[Table 4 about here]

Thus, although the model is not completely successful (in particular the intercept α should be zero but instead it is statistically significant), overall Result 2 is strongly supported by the

¹⁴The implied state of technology is $\widehat{T}_{it} = W_{it}^\theta e^{\widehat{S}_{it}}$.

¹⁵We also estimated equation (34) using the instrumental variable method proposed in Heckman and Vytlačil (1998) that allows for the factor loadings to be correlated with the regressors. The estimated factor loadings (average effects) are not statistically different from the OLS estimates and have the same sign as predicted by the theory.

model's estimates. First, higher productivity correlation between pairs of countries is associated with higher output comovement. Second, when the correlation between each country's share of expenditure on domestic goods is higher, countries exhibit higher output correlation. Lastly, we also find that a higher correlation between the domestic share of expenditure on domestic goods and foreign technology is negatively associated with output comovement, which is consistent with the model's prediction that the transmission of foreign shocks requires a high elasticity of the import penetration ratio to foreign shocks.

Having established that the fit of the three-factor model is good and consistent with theory, the next step is to study how each factor responds to changes in the bilateral trade intensity. This allows us to study empirically the channels through which trade leads to higher business cycle synchronization, and contrast these results with the theoretical predictions (within the framework of Result 2). To do this, we estimate by OLS the following three equations

$$\text{cor}(a_i, a_j) = \alpha_1 + \gamma_1 \left(\text{Bilateral Trade} \right)_{ij} + \varepsilon_{ij}^1 \quad (41)$$

$$\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) = \alpha_2 + \gamma_2 \left(\text{Bilateral Trade} \right)_{ij} + \varepsilon_{ij}^2 \quad (42)$$

$$\left(\text{cor}(a, \tilde{\lambda}) \right)_{ij} = \alpha_3 + \gamma_3 \left(\text{Bilateral Trade} \right)_{ij} + \varepsilon_{ij}^3 \quad (43)$$

Table 5 shows the estimation with the empirical data. The results suggest that greater bilateral trade intensity is associated with (i) a higher correlation between each country's technology shocks, and (ii) higher correlation between each country's share of expenditure on domestic goods. By contrast, there is no significant relation between trade and the correlation between the domestic import penetration ratio and the foreign technology shocks. Therefore, we conclude that empirically the first and second factors are responsible for the positive association between trade and business cycle comovement. In particular, the second factor is the most important: countries with strong trade linkages exhibit a higher correlation of the share of expenditures on domestic goods.

[Table 5 about here]

These results are in contrast to the regression performed with the simulated data, shown in Table 6. First, there is no association between trade and the technology shocks' correlation as we are considering uncorrelated shocks. Second, the link between trade and the correlation between each country's share of expenditure on domestic goods is (counterfactually) negative and insignificant. This happens because, with uncorrelated shocks, positive technology shocks in country i lead to an increase in both its share of expenditure on domestic goods (λ_{ii}) and the foreign country import penetration ratio (so that λ_{ji} falls). Hence, the positive association between trade and comovement is (counterfactually) driven by the third component: An increase in trade is associated with a lower correlation between a country's technology and the foreign country's share of domestic expenditures.

[Table 6 about here]

These findings have important implications. The empirical results provide some guidance on how to resolve the trade-comovement puzzle. This involves strengthening the mechanisms through which trade affects the channels represented by (41) and (42). Two ingredients are needed. Bilateral trade intensity should lead to: (i) a higher correlation of technology shocks, and (ii) a higher correlation of the share of expenditures on domestic goods. We note that the latter channel requires a multi-country framework.¹⁶ In what follows we use the estimated technology shocks to reexamine the relation between trade and comovement implied by the model.

5.3 Correlated Shocks

In this Section we undertake an experiment in which we feed the technology shocks estimated in Section 5.1 into our theoretical model of the world economy to examine the relation between trade and business cycle synchronization. As the evidence in Section 5.2 shows, this allows us to account for the fact that the correlation of technology shocks increases with bilateral trade intensity.¹⁷

¹⁶In the two-country model analyzed in Section 3, the correlation between *home's* and *foreign's* share of expenditure on domestic goods is -1 , irrespective of the trade cost τ (see Appendix B). Therefore, an empirically important channel to explain the trade-comovement relation is always absent in the two-country model.

¹⁷The exercise proposed in this Section is similar in spirit to one of the experiments conducted in the paper by Kose and Yi (2006). These authors estimate productivity shocks for each country based on data from the Penn World Tables by calculating the implied Solow residuals. They investigate if increased trade integration is associated with increased TFP correlation and find evidence in favor of this hypothesis. Next, they undertake an experiment in which, as transport costs decline, the correlation between the TFP shocks in the two countries increases by an amount consistent with their TFP regressions. We perform a similar exercise but instead of identifying the productivity shocks based on Solow residuals we use the structural relation implied by equation (40).

Table 7 summarizes the results of the quantitative experiment in which the labor supply elasticity, $1/\nu$, is set to 2.33. Panel A shows the level specification of the FR regressions. As expected, the ability of the model to account for the trade-comovement relation increases substantially when we allow for correlated shocks. The model now explains 55.5% of the empirical relation, which is in contrast to the 12.4% explained when shocks are uncorrelated. Panel B shows the results for the semi-log specification. In this case the results are even stronger. The model explains 83.9% of the empirical relation.

[Table 7 about here]

As a next step, we use the model with estimated shocks to investigate the relation between bilateral trade and each of the three factors explaining comovement. The results are shown in Table 8 and should be contrasted with the empirical counterpart shown in Table 5. When we feed the model with the estimated shocks, trade is positively associated with the correlation between each country's technology shocks. However, using the estimated shocks the model still implies a negative and insignificant association between bilateral trade and the correlation between each country's share of expenditure on domestic goods. This is counterfactual since in the data we find that for country-pairs with high bilateral trade intensity, the correlation between each country's share of expenditure on domestic goods is positive and large. Finally, with the estimated shocks the association between the third factor and trade becomes small and statistically insignificant.

[Table 8 about here]

Our findings suggest that both the empirical research and the models should examine further the positive association between trade and the comovement in the share of expenditure on domestic goods. Empirically, this channel is the most important to explain why trade leads to business cycle synchronization. Therefore, we argue that this should constitute a litmus test for theoretical models: stronger trade linkages should lead to synchronization in the share of expenditure on domestic goods.

6 Conclusion

Substantial empirical evidence suggests that countries or regions with stronger trade linkages have more correlated business cycles. However, from a theoretical perspective the IRBC model has difficulties in replicating this empirical fact. This has given rise to the so-called trade-comovement puzzle: Standard models are unable to generate high output correlations arising from high bilateral trade intensity.

In this paper, we examine the source of the puzzle. We show that within a large class of trade models, there are three channels through which bilateral trade may increase business cycle synchronization: (i) if trade increases the correlation between each country's technology shocks; (ii) if trade leads to higher correlation between each country's share of expenditure on domestic goods; and (iii) if trade raises the elasticity of the domestic import penetration ratio to foreign technology shocks. When technology shocks are assumed uncorrelated across countries the third channel is the only one that matters, implying that the trade-comovement puzzle arises because trade fails to substantially increase the correlation between each country's import penetration ratio and the trade partner's technology shocks. However, this mechanism is shown to be counterfactual.

We use bilateral trade data in manufactures for a panel of 21 OECD countries to estimate each country's technology shocks between 1988 and 2007 by extending the procedure developed in Eaton and Kortum (2002) to a panel data setting. Based on these estimates we find that the first and second channels are supported by the data: Higher bilateral trade intensity is associated with higher correlation between each country's technology and with a higher correlation between each country's share of expenditure on domestic goods.

We find that allowing for correlated shocks is part of the solution to the trade comovement puzzle. However, we show that even allowing for correlated shocks, the model still implies a counterfactual relation between bilateral trade and each country pair correlation of the import penetration ratios. Therefore, our findings suggest that both the empirical and theoretical research should examine the positive association between trade and the comovement in the share of expenditure on domestic goods. This invites further research to uncover new trade related transmission mechanisms of productivity shocks. This will require the development of richer micro foundations concerning the relation between trade and business cycle fluctuations.

References

- ANDERSON, J. E., AND E. VAN WINCOOP (2003): “Gravity with Gravitas: A Solution to the Border Puzzle,” *American Economic Review*, 93(1), 170–192.
- ARKOLAKIS, C., A. COSTINOT, AND A. RODRIGUEZ-CLARE (2012): “New Trade Models, Same Old Gains?,” *American Economic Review*, 102(1), 94–130.
- ARKOLAKIS, C., S. DEMIDOVA, P. J. KLENOW, AND A. RODRIGUEZ-CLARE (2008): “Endogenous Variety and the Gains from Trade,” *American Economic Review*, 98(2), 444–50.
- ARKOLAKIS, C., AND A. RAMANARAYANAN (2009): “Vertical Specialization and International Business Cycle Synchronization,” *Scandinavian Journal of Economics*, 111(4), 655–80.
- BACKUS, D. K., P. J. KEHOE, AND F. E. KYDLAND (1994): “Dynamics of the Trade Balance and the Terms of Trade: The J-Curve?,” *American Economic Review*, 84(1), 84–103.
- BAXTER, M., AND M. A. KOUPARITSAS (2004): “Determinants of Business Cycle Comovement: A Robust Analysis,” NBER Working Papers 10725, National Bureau of Economic Research.
- BERNARD, A. B., J. EATON, J. B. JENSEN, AND S. KORTUM (2003): “Plants and Productivity in International Trade,” *American Economic Review*, 93, 1268–290.
- BURSTEIN, A., C. KURZ, AND L. TESAR (2008): “Trade, Production Sharing, and the International Transmission of Business Cycles,” *Journal of Monetary Economics*, 55(4), 775–95.
- CACCIATORE, M. (2012): “International Trade and Macroeconomic Dynamics with Labor Market Frictions,” Mimeo.
- CALDERON, C., A. CHONG, AND E. STEIN (2007): “Trade Intensity and Business Cycle Synchronization: Are Developing Countries any Different?,” *Journal of International Economics*, 71(1), 2–21.
- CLARK, T. E., AND E. VAN WINCOOP (2001): “Borders and Business Cycles,” *Journal of International Economics*, 55(1), 59–85.

- DI GIOVANNI, J., AND A. A. LEVCHENKO (2010): “Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement,” *American Economic Journal: Macroeconomics*, 2(2), 95–124.
- DROZD, L., AND J. B. NOSAL (2008): “Long-Run Price Elasticity of Trade and the Trade-Comovement Puzzle,” Mimeo.
- EATON, J., AND S. KORTUM (2002): “Technology, Geography, and Trade,” *Econometrica*, 70(5), 1741–779.
- FRANKEL, J. A., AND A. K. ROSE (1998): “The Endogeneity of the Optimum Currency Area Criteria,” *Economic Journal*, 108(449), 1009–025.
- GREENWOOD, J., Z. HERCOWITZ, AND G. W. HUFFMAN (1988): “Investment, Capacity Utilization, and the Real Business Cycle,” *American Economic Review*, 78(3), 402–17.
- HEATHCOTE, J., AND F. PERRI (2002): “Financial Autarky and International Business Cycles,” *Journal of Monetary Economics*, 49(3), 601–27.
- HECKMAN, J., AND E. VYTLACIL (1998): “Instrumental Variables Methods for the Correlated Random Coefficient Model: Estimating the Average Rate of Return to Schooling When the Return is Correlated with Schooling,” *Journal of Human Resources*, 33(4), 974–87.
- IMBS, J. (2004): “Trade, Finance, Specialization, and Synchronization,” *Review of Economics and Statistics*, 86(3), 723–34.
- ISHISE, H. (2011): “The World Has More Than Two Countries: Implications of Multi-Country International Real Business Cycle Models,” IMES Discussion Paper Series 11-E-11, Institute for Monetary and Economic Studies, Bank of Japan.
- JAIMOVICH, N., AND S. REBELO (2009): “Can News about the Future Drive the Business Cycle?,” *American Economic Review*, 99(4), 1097–118.
- JOHNSON, R. C. (2011): “Trade in Intermediate Inputs and Business Cycle Comovement,” Discussion paper, Dartmouth College.

- KOSE, M. A., AND K.-M. YI (2001): “International Trade and Business Cycles: Is Vertical Specialization the Missing Link?,” *American Economic Review*, 91, 371–75.
- (2006): “Can the Standard International Business Cycle Model Explain the Relation Between Trade and Comovement?,” *Journal of International Economics*, 68, 267–95.
- KRUGMAN, P. (1980): “Scale Economies, Product Differentiation, and the Pattern of Trade,” *American Economic Review*, 70(5), 950–59.
- MELITZ, M. J. (2003): “The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity,” *Econometrica*, 71(6), 1695–725.
- ZIMMERMANN, C. (1997): “International Real Business Cycles Among Heterogeneous Countries,” *European Economic Review*, 41(2), 319–56.

Appendix

A Data

We consider a sample of 21 OECD countries composed of the United States (US), United Kingdom (UK), Austria (AT), Belgium (BE), Denmark (DK), France (FR), Germany (DE), Italy (IT), Netherlands (NL), Norway (NO), Sweden (SW), Switzerland (CH), Canada (CA), Japan (JP), Finland (FI), Greece (GR), Ireland (IR), Korea (KO), Portugal (PT), Spain (SP), and New Zealand (NZ) over the period 1988–2007. The variable definitions and data sources are as follows:

Output

Output is measured using gross manufacturing output from the OECD STAN database. The original manufacturing data, expressed in current prices and local currencies, are transformed into a real series expressed in terms of 2005 USD using CPI and PPP data from the OECD. Bilateral correlations are calculated using the linearly detrended log real output.

Country's share of expenditure on domestic goods

The measure λ_{ii} captures the fraction of total expenditure on country i on goods made in country i . Expenditure on goods made at home is measured as gross manufacturing output (converted to dollars using current exchange rates) less total manufacturing exports. Total expenditure is measured as the sum of expenditure on goods made at home and expenditure on total imports. All data are from the OECD STAN database. Bilateral correlations between λ_{ii} and λ_{jj} are calculated from the raw series of λ 's.

Trade intensity

We measure trade intensity between each country pair i and j , labeled $\left(\text{Bilateral Trade}\right)_{ij}$, by normalizing bilateral trade—that is, the sum of each country's manufacturing imports from the other—by the sum of nominal manufacturing output in the two countries, averaged over the entire period. Manufacturing imports data, denominated in dollars, is taken from the OECD STAN database. We normalize trade by nominal gross manufacturing output, also from the STAN.

Gravity variables

For all country-pairs that do not include Korea the following variables are from Andrew Rose's

website: distance between business centers, common language dummy, and border dummy.¹⁸ Bilateral measures of distance between Korea and the other countries in the sample are taken from the CEPII database.¹⁹

Wages

Total annual compensation to employees in manufacturing is from the OECD STAN database (variable LABR, industry C15T37 (manufacturing)). These values are divided by total employment in manufacturing (STAN variable EMPN) to get total compensation per employee.

B Two-Country Example: Log-Linear Model

We consider a symmetric two-country model (*home* and *foreign*) with transport cost $\tau > 1$, and denote *foreign* variables by $*$. A variable X in log-deviation from steady state is denoted by \tilde{x} and, in particular, $\tilde{\lambda}$ is the share of expenditure on domestic goods in log-deviation from the deterministic equilibrium. The numéraire is the *home* wage rate. In the deterministic steady state

$$\begin{aligned}\Phi &= 1 + \tau^{-\theta} = \alpha^{-1}, \\ \lambda &= \Phi^{-1} = \alpha.\end{aligned}$$

where $\alpha = (1 + \tau^{-\theta})^{-1}$.

We consider a log-linear approximation around the deterministic steady state. The equilibrium dynamics in the *home* country are represented by the following two equations

$$\tilde{y} = \left[(1 + \sigma_n) \theta^{-1} \right] (a - \tilde{\lambda}), \tag{B.1}$$

$$\tilde{\lambda} = \vartheta (a - a^*) \tag{B.2}$$

with $\sigma_n = 1/\nu$ the labor supply elasticity and

$$\vartheta = \left[\frac{1 + \sigma_n}{1 + 2\sigma_n + (1 + 2\theta) \tau^\theta} \right] \in (0, 1).$$

¹⁸<http://faculty.haas.berkeley.edu/arose>

¹⁹<http://www.cepii.fr/anglaisgraph/bdd/distances.htm>

Equation (B.1) corresponds exactly to equation (20) in log-linear form. To obtain equation (B.2) we start from the trade balance equilibrium condition, given by

$$(1 - \lambda)N = (1 - \lambda^*)W^*N^*,$$

$$\Rightarrow \frac{\Phi^\varepsilon}{T} = \Phi^{\varepsilon-1} + \Phi^{*\varepsilon-1}W^{*1+\sigma_n}\tau^{-\theta}, \quad (\text{B.3})$$

with $\varepsilon = \sigma_n/\theta$ and where to derive (B.3) we use the fact that in the symmetric two country model with the *home* wage rate as the numéraire the following holds

$$\lambda = \frac{T}{\Phi},$$

$$(1 - \lambda^*) = 1 - \frac{T^*W^{*-\theta}}{\Phi^*} = \frac{T\tau^{-\theta}}{\Phi^*},$$

$$N = \Phi^\varepsilon,$$

$$N^* = \Phi^{*\varepsilon}W^{*\sigma_n},$$

$$\Phi = T + T^*(W\tau)^{-\theta},$$

$$\Phi^* = T\tau^{-\theta} + T^*W^{*-\theta}.$$

We consider a log-linear approximation around the deterministic steady state. Equation (B.3) can be expressed in log-linear form as

$$\varepsilon\tilde{\phi} = \alpha(\varepsilon - 1)\tilde{\phi} + (1 - \alpha)(\varepsilon - 1)\tilde{\phi}^* + (1 - \alpha)(1 + \sigma_n)\tilde{w}^* + a. \quad (\text{B.4})$$

Next, we use the following log-linear approximations

$$\tilde{\lambda} = (1 - \alpha) (a - a^*) + (1 - \alpha) \theta \tilde{w}^* \quad (\text{B.5})$$

$$\tilde{\lambda}^* = -(1 - \alpha) (a - a^*) - (1 - \alpha) \theta \tilde{w}^* \quad (\text{B.6})$$

$$\tilde{\phi} = -\tilde{\lambda} + a \quad (\text{B.7})$$

$$\tilde{\phi}^* = \left(\frac{\alpha}{1 - \alpha} \right) \tilde{\phi} \quad (\text{B.8})$$

By combining (B.4)|(B.5), we obtain equation (B.2). Also, notice that, no matter the trade costs, the two country's share of expenditure on domestic goods are perfectly negatively correlated, given that $\tilde{\lambda} = -\tilde{\lambda}^*$.

C Proof of Result 1

If assumptions A1—A3 are satisfied, it follows from the results in Arkolakis et al. (2012) that the following gravity equation holds

$$X_{ji}(s^t) = \left[\frac{\Psi W_i(s^t) \tau_{ji}}{P_j(s^t)} \right]^{-\theta} T_i(s^t) X_j(s^t), \quad (\text{C.1})$$

where Ψ is a constant parameter, $T_i(s^t)$ is an (appropriately defined) exogenous technology shock that determines the marginal cost of producing intermediate inputs in country i , and the aggregate price level is $P_j(s^t) = \left[\int_0^1 p_j(n, s^t)^{1-\sigma} dn \right]^{1/(1-\sigma)}$. From (C.1) we obtain

$$\lambda_{jj}(s^t) \equiv \frac{X_{jj}(s^t)}{X_j(s^t)} = \left[\frac{\Psi W_j(s^t)}{P_j(s^t)} \right]^{-\theta} T_j(s^t), \quad (\text{C.2})$$

and solving for the real wage we obtain

$$\frac{W_j(s^t)}{P_j(s^t)} = \frac{1}{\Psi} \left[\frac{T_j(s^t)}{\lambda_{jj}(s^t)} \right]^{1/\theta}. \quad (\text{C.3})$$

From assumption A4, it follows that the labor supply is a function only of the real wage, so that

$$N_j(s^t) = \left[\frac{1}{\xi} \frac{W_j(s^t)}{P_j(s^t)} \right]^{1/\nu}, \quad (\text{C.4})$$

where $1/\nu$ is the labor supply elasticity. From the balance trade assumption A1, it follows that

$$\begin{aligned} W_j(s^t) N_j(s^t) + \Pi_j(s^t) &= X_j(s^t) \\ &= P_j(s^t) Y_j(s^t), \end{aligned}$$

where $\Pi_j(s^t)$ are profits. From assumption A2 profits are a constant share γ of revenues, so that $\Pi_j(s^t) = \gamma X_j(s^t)$.²⁰ Using (C.4) to substitute out $N_j(s^t)$ we obtain

$$Y_j(s^t) = \frac{1}{1-\gamma} \left(\frac{1}{\xi} \right)^{1/\nu} \left[\frac{W_j(s^t)}{P_j(s^t)} \right]^{1+1/\nu}. \quad (\text{C.5})$$

Making use of (C.2) to substitute out the real wage yields

$$Y_j(s^t) = \frac{1}{1-\gamma} \left(\frac{1}{\xi} \right)^{1/\nu} \left[\frac{1}{\Psi} \left(\frac{T_j(s^t)}{\lambda_{jj}(s^t)} \right)^{\frac{1}{\theta}} \right]^{1+1/\nu}. \quad (\text{C.6})$$

so that the output in log-deviations from steady state is given by equation (31) as had to be shown.

D Proof of Result 2

From equation (20) it follows that output fluctuations in country i (in log-deviations from steady state) are given by

$$\tilde{y}_i(s^t) = \left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \left[a_i(s^t) - \tilde{\lambda}_{ii}(s^t) \right]. \quad (\text{D.1})$$

It follows that the covariance between the logarithm of output in country i and in country j is given by

$$\text{cov}(\tilde{y}_i, \tilde{y}_j) = \vartheta \text{cov}(a_i, a_j) + \vartheta \text{cov}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) - \vartheta \left[\text{cov}(a_i, \tilde{\lambda}_{jj}) + \text{cov}(\tilde{\lambda}_{ii}, a_j) \right], \quad (\text{D.2})$$

where $\vartheta = \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2$. We assume a symmetric world economy in the sense that $\text{std}(y_i) = \sigma_y$, $\text{std}(a_i) = \sigma_a$, and $\text{std}(\lambda_{ii}) = \sigma_\lambda$ for all i . The upshot is that by dividing each side of equation (D.2)

²⁰Note that in our theoretical framework profits are zero because we are considering a model of perfect competition.

by σ_y^2 and dividing and multiplying the first term of the RHS by σ_a^2 , the second term by σ_λ^2 , and the third term by $\sigma_a\sigma_\lambda$ yields the equation

$$\begin{aligned} \text{cor}(\tilde{y}_i, \tilde{y}_j) &= \frac{\vartheta\sigma_a^2}{\sigma_y^2} \text{cor}(a_i, a_j) + \frac{\vartheta\sigma_\lambda^2}{\sigma_y^2} \text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj}) - \frac{\vartheta\sigma_a\sigma_\lambda}{\sigma_y^2} \left[\text{cor}(a_i, \tilde{\lambda}_{jj}) + \text{cor}(\tilde{\lambda}_{ii}, a_j) \right] \\ &= \beta_1 \underbrace{\text{cor}(a_i, a_j)}_{(i)} + \beta_2 \underbrace{\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj})}_{(ii)} + \beta_3 \underbrace{\left[\text{cor}(a_i, \tilde{\lambda}_{jj}) + \text{cor}(\tilde{\lambda}_{ii}, a_j) \right]}_{(iii)}, \end{aligned} \tag{D.3}$$

where the factor loadings are given by

$$\begin{aligned} \beta_1 &\equiv \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_a^2}{\sigma_y^2}, \\ \beta_2 &\equiv \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_\lambda^2}{\sigma_y^2}, \\ \beta_3 &\equiv - \left[\left(1 + \frac{1}{\nu} \right) \frac{1}{\theta} \right]^2 \frac{\sigma_a\sigma_\lambda}{\sigma_y^2}. \end{aligned}$$

Result 2 follows immediately from equation (D.3), where the factors (i), (ii) and (iii) are as follows: (i) the correlation between each country's technology shocks; (ii) the correlation between each country's share of expenditure on domestic goods; (iii) the correlation between the country's share of expenditure on domestic goods and the country-pair's technology shocks (equal to the negative of the correlation between the country's import penetration ratio and the country-pair's technology shocks).

Table 1: Calibrated Iceberg Costs and their Empirical Proxies.

| | Iceberg cost = $\tau_{ij} + \tau_{ji}$ | | |
|--------------------------|--|------------|----------------------|
| | coefficient | p -value | 95% C. I. |
| $\ln(\textit{distance})$ | 0.7708 | 0.000 | [0.6600 0.8815] |
| <i>border</i> | -0.2091 | 0.372 | [-0.6703 0.2521] |
| <i>language</i> | -0.5185 | 0.010 | [-0.9136 -0.1233] |
| Observations | | 210 | |
| R^2 | | 0.58 | |

Note: The dependent variables are the model based calibrated trade costs while the explanatory variables are the empirical proxies for trade costs.

Table 2: Trade Business Cycle Synchronization (Data)

| | cor(\tilde{y}_i, \tilde{y}_j) | |
|---------------------|-----------------------------------|--------------------------------|
| | (1) | (2) |
| Bilateral Trade | 8.362 ^{***} [0.00] | |
| ln(Bilateral Trade) | | 0.093 ^{***} [0.00] |
| Constant | 0.339 ^{***} [0.00] | 0.919 ^{***} [0.00] |
| Observations | 210 | 210 |
| Adjusted R^2 | 0.06 | 0.10 |

Notes: p -values are shown in brackets.

*, **, *** denote significance at the 10, 5, and 1 percent levels, respectively.

The dependent variable is the pairwise correlation of linearly detrended real manufacturing output for each country pair over the period 1988–2007.

Bilateral trade data from 21 OECD countries are averaged over 1988–2007.

Data definitions and sources are in Appendix A.

Table 3: Trade and Business Cycle Synchronization (Simulated Data).

| Panel A: Level regression | | | | |
|---------------------------|--|----------------------------|----------------------------|----------------------------|
| | $\text{cor}(\tilde{y}_i, \tilde{y}_j)$ | | | |
| | $\frac{1}{\nu} = 1$ | $\frac{1}{\nu} = 2$ | $\frac{1}{\nu} = 2.33$ | $\frac{1}{\nu} = 3$ |
| Trade | 0.617 [-2.632 , 4.399] | 0.781 [-2.732 , 4.455] | 1.040 [-2.295 , 5.048] | 1.097 [-2.187 , 5.469] |
| Constant | -0.007 [-0.056 , 0.076] | -0.004 [-0.054 , 0.080] | -0.006 [-0.056 , 0.071] | -0.002 [-0.056 , 0.082] |
| Observations | 210 | 210 | 210 | 210 |
| Panel B: Log regression | | | | |
| | $\text{cor}(\tilde{y}_i, \tilde{y}_j)$ | | | |
| | $\frac{1}{\nu} = 1$ | $\frac{1}{\nu} = 2$ | $\frac{1}{\nu} = 2.33$ | $\frac{1}{\nu} = 3$ |
| $\ln(\text{Trade})$ | 0.005 [-0.034 , 0.057] | 0.007 [-0.040 , 0.055] | 0.010 [-0.038 , 0.065] | 0.010 [-0.035 , 0.066] |
| Constant | 0.024 [-0.175 , 0.308] | 0.037 [-0.190 , 0.314] | 0.054 [-0.173 , 0.368] | 0.051 [-0.161 , 0.380] |
| Observations | 210 | 210 | 210 | 210 |

Notes: CIs in brackets correspond to the 2.5% and 97.5% quantiles of the monte carlo replications. We perform 500 replications. The point estimate is the median of the monte carlo replications.

Table 4: OLS Estimates of Equation (34)

| | $\text{cor}(\tilde{y}_i, \tilde{y}_j)$ | | | |
|--|--|--------------------------------|--------------------------------|---------------------------------|
| $\text{cor}(a_i, a_j)$ | 0.156 ^{***} [0.00] | | | 0.170 ^{***} [0.00] |
| $\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj})$ | | 0.137 ^{**} [0.02] | | 0.144 ^{***} [0.01] |
| $(\text{cor}(a, \tilde{\lambda}))_{ij}$ | | | -0.278 ^{**} [0.02] | -0.321 ^{***} [0.00] |
| Constant | 0.311 ^{***} [0.00] | 0.317 ^{***} [0.00] | 0.428 ^{***} [0.00] | 0.242 ^{***} [0.00] |
| Observations | 210 | 210 | 210 | 210 |
| Adjusted R^2 | 0.04 | 0.03 | 0.03 | 0.10 |
| F -Stat | 9.01 | 5.41 | 5.86 | 7.92 |

Note: p -values are shown in brackets.

*, **, *** denote significance at the 10, 5, and 1 percent levels, respectively.

Table 5: Trade and Business Cycle Synchronization Channels (Data)

| | $\text{cor}(a_i, a_j)$ | $\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj})$ | $(\text{cor}(a, \tilde{\lambda}))_{ij}$ |
|----------------|------------------------|--|---|
| Trade | 7.680** [0.01] | 9.254*** [0.00] | -2.091 [0.14] |
| Constant | 0.530*** [0.00] | 0.555*** [0.00] | 0.106*** [0.00] |
| Observations | 210 | 210 | 210 |
| Adjusted R^2 | 0.03 | 0.05 | 0.01 |

Note: p -values are shown in brackets.

*, **, *** denote significance at the 10, 5, and 1 percent levels, respectively.

Table 6: Trade and Business Cycle Synchronization Channels (Theoretical Model)

| | $\text{cor}(a_i, a_j)$ | $\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj})$ | $(\text{cor}(a, \tilde{\lambda}))_{ij}$ |
|--------------|---------------------------|--|---|
| Trade | -0.045 [-3.237, 3.835] | -5.078 [-7.324, -2.513] | -5.552 [-10.855, 0.528] |
| Constant | -0.005 [-0.048, 0.065] | 0.017 [-0.014, 0.058] | -0.005 [-0.074, 0.099] |
| Observations | 210 | 210 | 210 |

Notes: CIs correspond to the 2.5% and 97.5% quantiles of the monte carlo replications.

We perform 500 replications. The point estimate is the median of the monte carlo replications.

The value of the labor supply elasticity $1/\nu$ is set to 2.33.

Table 7: Quantitative Assessment of Effects of Trade on Synchronization

| Panel A: Level regression | | | |
|-------------------------------|-------|--------------------------------|-----------------------------|
| | Data | Model (uncorrelated shocks) | Model (estimated shocks) |
| Bilateral Trade | 8.362 | 1.040 | 4.638 |
| Constant | 0.339 | -0.006 | 0.578 |
| Percentage Explained | | 12.4% | 55.5% |
| Observations | 210 | 210 | 171 |
| Panel B: Log regression | | | |
| | Data | Model (uncorrelated shocks) | Model (estimated shocks) |
| $\ln(\text{Bilateral Trade})$ | 0.093 | 0.010 | 0.078 |
| Constant | 0.919 | 0.054 | 1.024 |
| Percentage Explained | | 10.8% | 83.9% |
| Observations | 210 | 210 | 171 |

Note: Percentage Explained refers to the ratio between the model implied OLS coefficient for the trade-comovement relation and its empirical counterpart reported in the first column.

The value of the labor supply elasticity $1/\nu$ is set to 2.33.

Table 8: Trade and Synchronization Channels (Model With Estimated Shocks)

| | $\text{cor}(a_i, a_j)$ | $\text{cor}(\tilde{\lambda}_{ii}, \tilde{\lambda}_{jj})$ | $(\text{cor}(a, \tilde{\lambda}))_{ij}$ |
|--------------|------------------------|--|---|
| Trade | 3.600 [0.16] | -1.824 [0.54] | 1.601 [0.77] |
| Constant | 0.547*** [0.00] | 0.388*** [0.00] | 0.915*** [0.00] |
| Observations | 171 | 171 | 171 |

Note: p -values are shown in brackets.

*, **, *** denote significance at the 10, 5, and 1 percent levels, respectively.

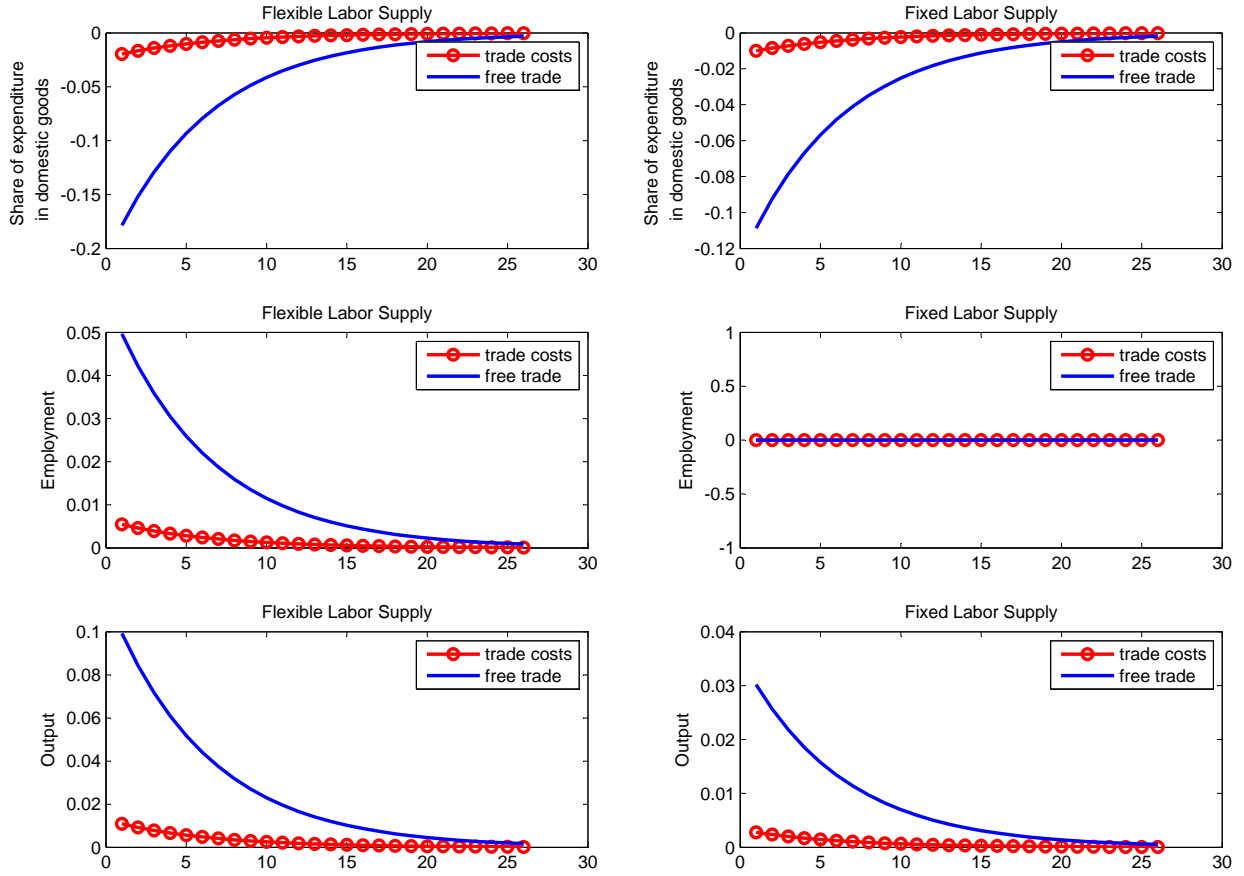


Figure 1: Two-Country Example. Impulse Response Functions of *home*'s share of expenditure on domestic goods (top panels), employment (middle panels) and output (bottom panels) following a positive shock to *foreign*'s technology a^* . The parameter θ is set equal to 3.6, and in the model with trade barriers (red-dotted IRF) the parameter τ is set equal to 2. In the model with flexible labor supply (left-hand panels) the labor supply elasticity σ_n is set equal to 1.

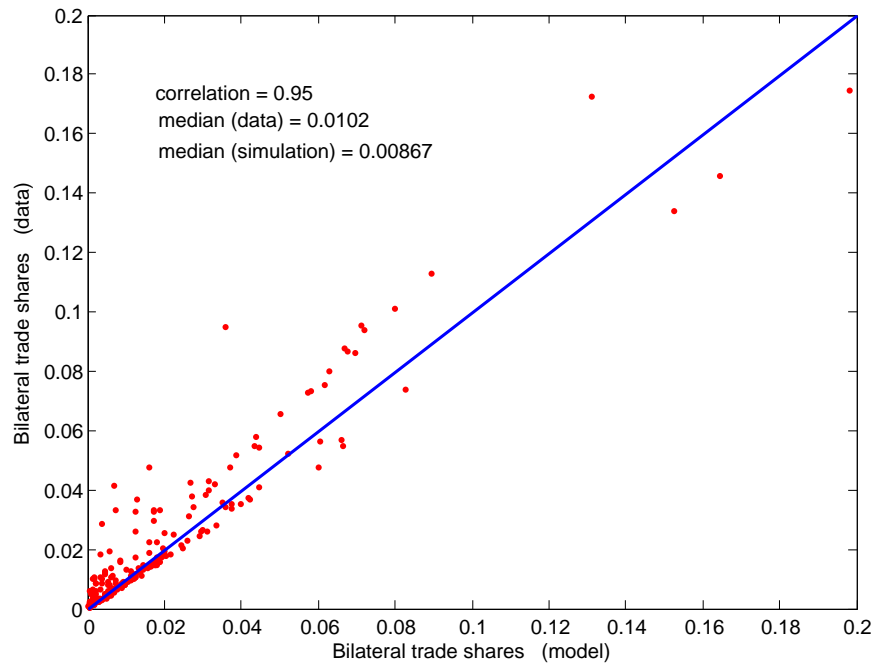


Figure 2: Bilateral Trade Shares, $\frac{1}{2}(\lambda_{ij} + \lambda_{ji})$: Data vs. Model

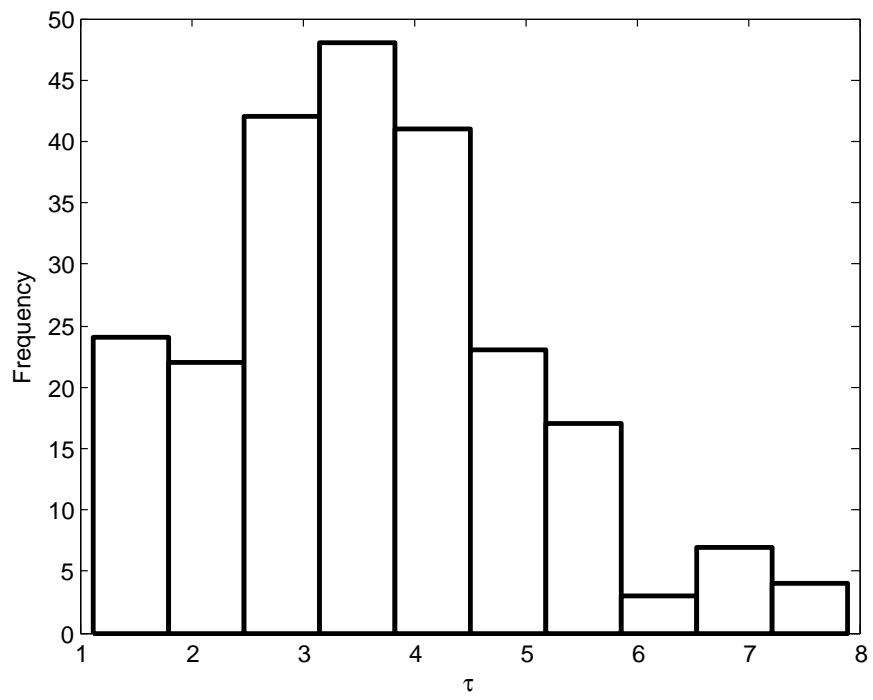


Figure 3: Calibrated Iceberg Costs