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. We show that under certain macro-level conditions but irrespective of the micro-level assumptions concerning trade the puzzle arises because trade fails to substantially increase the correlation between each country's import penetration ratio and the trade partner's technology shock. Within a large class of trade models, there are three channels through which bilateral trade may increase business cycle synchronization. Specifically, increased bilateral trade may (i) raise the correlation between each country's technology shocks, (ii) raise the correlation between each country's share of expenditure on domestic goods, and (iii) raise the response of the domestic import penetration ratio to foreign technology shocks. Empirical evidence strongly supports the first and second channels. We show that the trade-comovement puzzle can be resolved if productivity shocks are more correlated between country-pairs that trade more.

Keywords: International Trade, Business Cycle Synchronization.

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, Chong, and Stein (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 model (IRBC), based on Backus, Kehoe, and Kydland (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. One of the objectives of this paper is to investigate the extent to which the trade-comovement puzzle can be solved by more carefully modeling the international trade linkages and, in particular, allowing for more sophisticated micro-level assumptions. Our starting point is a multi-country model of international trade with endogenous specialization inspired by Eaton and Kortum (2002). We embed it into a real business cycle framework by including aggregate technology shocks and allowing for a 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. The baseline model (with uncorrelated technology shocks) explains only 12.4% of the empirical relation between trade intensity and comovement and, in this way, the puzzle remains.

The second and most important 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), technology shocks in country i are transmitted to country j if and only if they change country j's import penetration ratio. This finding implies that if shocks are uncorrelated across countries, higher bilateral trade increases business cycle synchronization only if the elasticity of the domestic import penetration ratio to foreign technology shocks increases with

bilateral trade. 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. 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.

This result relates to recent work by Arkolakis et al. (2008) and Arkolakis et al. (2010) concerning the welfare gains from trade. These authors show that the real wage (which determines the welfare gains from trade) can be computed 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. (2010) 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 are the only determinants of employment fluctuations in response to foreign shocks. Thus, a positive technology shock in country i increases employment in country j significantly if and only if it increases country j's import penetration ratio substantially or if the elasticity parameter is large.

Using data on bilateral trade in manufacturing for a panel of 21 OECD countries, we estimate each country's technology level between 1988 and 2007 extending the procedure developed in Eaton and Kortum (2002) to panel data. Based on these estimates we show that, taken together, two statistics—the correlations between each country-pair's technology levels and the correlation between each country-pair's import penetration ratios—imply that trade leads to increased synchronization of each country's productivity shocks. In turn, this feature is consistent with the behavior of our estimated productivity shocks. Therefore, a large class of trade models, which are popular because they are consistent with important cross-sectional trade facts, are also consistent with the empirical relation between trade and business cycle synchronization once we allow for higher correlation of productivity shocks as bilateral trade increases. When we feed the estimated technology shocks in the theoretical model of the world economy we explain up to 83.9% of the trade-comovement relation.

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. Instead, a many-country world economy would capture both the bilateral trade linkages and the trade linkages with common trading partners. In particular, our analysis shows that the output correlation for each country-pair increases if the import penetration ratios of both countries comove positively. In a two country world, the import penetration ratios comove negatively. Instead, in a multi-country world, a country-pair's import penetration ratios may comove positively provided both countries share the same trading partners. 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.[1] Arkolakis and Rama-narayanan (2009) develop a two-country international business cycle model augmented with vertical specialization, and consider, alternatively, the cases of perfect competition and Bertrand 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.

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

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[1]In 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.

the empirical relation between trade and comovement. In Section 5, we study in depth the channels through which trade affects business cycle synchronization, and extend the baseline model to allow for correlated shocks. 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 $s^t = (s_0, \ldots, s_t)$ 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 differentiated manufactured intermediate commodities indexed by $n \in [0, 1]$ that are combined as follows:

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

where $Q_i\left(n, s^t\right)$ 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

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

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

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

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 $\left[\varphi_i^n \left(s^t\right)\right]^{-1}$ units of labor. Therefore, the cost for intermediate firms in country i to deliver one unit of intermediate commodity n to country j is

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

where $W_i\left(s^t\right)$ 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 $p_{ji}\left(n, s^t\right)$. The commodity is purchased from the lowest-cost supplier; hence, the price of commodity n in country j is given by

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

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:

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

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

following cumulative distribution function:

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

The resulting distribution of $p_j\left(n, s^t\right)$, 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 $G_j\left(p; s^t\right) = \text{Prob}\left[p_j\left(n, s^t\right) \le p \mid s^t\right]$ is given by

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

where the aggregate stochastic variable $\Phi_j\left(s^t\right) = \sum_{i=1}^{M} T_i\left(s^t\right)\left[W_i\left(s^t\right)\tau_{ji}\right]^{-\theta}$ 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

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

where κ is a positive constant.[2]

Bilateral trade flows.— The probability λ_{ji} that country i is the lowest-cost supplier to j for any particular intermediate commodity is given by[3]

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

Since the distribution of differentiated intermediate commodity prices in the destination country is independent of the source country i, the measure λ_{ji} corresponds to country j's expenditure on

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[2] $\kappa = \left[\Gamma\left(\frac{1-\sigma+\theta}{\theta}\right)\right]^{1/(1-\sigma)}$, where $\Gamma(.)$ is the Gamma function and it is assumed that $\theta > \sigma - 1$. See Appendix A.3 for details.

[3] This probability is obtained by calculating

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

country i's differentiated intermediate goods (X_{ji}) as a fraction of country j's total expenditure on differentiated intermediate goods (X_j), $\lambda_{ji}\left(s^t\right) = X_{ji}\left(s^t\right)/X_j\left(s^t\right)$. 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

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

Stochastic technology shocks.— In each period $t = 0, 1, \ldots$, the event s_t yields a realization for the stochastic technology level in each country, $T_i\left(s^t\right)$. 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:

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

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 $a_i\left(s^t\right)$; this component follows a serially correlated discrete Markov process and is independent across countries.

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

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

where $C_i\left(s^t\right)$ and $N_i\left(s^t\right)$ 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.[4] The Bellman equation characterizing the stand-in household optimal behavior

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

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reads as

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

and is subject to the budget constraint

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

where $B_i\left(s^t\right) \equiv B_{i,t}$ denotes the holdings of domestic, risk-free, one-period-lived bonds by the stand-in household, and $q_i\left(s^{t+1}\right)$ 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 $B_i\left(s^t\right) = 0$ for all s^t.[5]

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:

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

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

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

$$Y_i\left(s^t\right) = C_i\left(s^t\right)$$

$$= \left[\left(\frac{1}{\xi}\right)^{1/\nu} \left(\frac{W_i\left(s^t\right)}{P_i\left(s^t\right)}\right)^{1+\frac{1}{\nu}}\right]. \tag{17}$$

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:

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

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

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

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

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

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

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

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

An equilibrium is a wage vector $\mathrm{W}\left(s^t\right) \in \mathbf{R}_{++}^{M}$ such that $Z_i\left(s^t\right) = 0$ for all $i = 1, \ldots, M$, 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. Considering the symmetric two-country model in log-linear form and taking the wage

in country 1 to be the numéraire wage, employment in country 2 is given by

$$\widetilde{n}_2\left(s^t\right) = \frac{1}{\theta\nu}\left[a_2\left(s^t\right) - \widetilde{\lambda}_{22}\left(s^t\right)\right],\tag{23}$$

where $\widetilde{x}$ denotes the variable X in log deviation from steady state and, in particular, $\widetilde{\lambda}_{22}\left(s^t\right)$ is the log deviation from steady state of the share of expenditure on domestic goods in country 2, $\lambda_{22}\left(s^t\right)$. In turn, the share of domestic expenditure in country 2 is given by[6]

$$\widetilde{\lambda}_{22}\left(s^t\right) = (1-\theta\delta)\left(1-\alpha\right)\left[a_2\left(s^t\right) - a_1\left(s^t\right)\right].$$

From equation (23), it is apparent that country 1 shocks are transmitted to country 2 by affecting the latter's share of domestic expenditure. As long as $\theta\delta < 1$, a positive technology shock in country 1 lowers country 2's share of expenditure in domestic goods and results in an increase in employment and output.[7] Thus, business cycle synchronization emerges through the response of the share of domestic expenditure to foreign shocks.

The degree of synchronization depends on the value of the bilateral trade cost τ, the labor supply elasticity ν^{-1}, and the technology parameter θ. In particular, the elasticity of domestic employment to foreign shocks is given by the function

$$\mathcal{E}\left(\theta,\nu,\tau\right) = \frac{(1-\theta\delta)\left(1-\alpha\right)}{\theta\nu}.\tag{24}$$

This function is decreasing in the trade cost parameter τ, implying that a lower trade cost (hence, more bilateral trade) increases the elasticity of domestic employment to foreign shocks. Thus, qualitatively the model is consistent with the empirical relation between trade and business cycle synchronization. The magnitude of the synchronization effect of trade in turn depends on the labor supply elasticity. Figure 1 shows the response of employment in country 2, following a technology shock in country 1, for alternative labor supply elasticities when $\tau = 1$ (no trade costs).

[Figure 1 about here]

The figure shows that the larger the labor supply elasticity, the larger is the response of employment in country 2. The implications for the relation between business cycle synchronization

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[6]With $\alpha = 1/\left(1+\tau^{-\theta}\right)$ and $\delta = \left[\theta + \left(1+\frac{1}{\nu}\right)\left(\frac{\theta\nu}{1-2\alpha+2\alpha\theta\nu}\right)\right]^{-1}$. See Appendix B for detailed derivations.

[7]To guarantee that $\theta\delta < 1$, it suffices to assume that $\theta\nu > 1 - \frac{1}{2}\left(1+\tau^{-\theta}\right)$.

and trade intensity are illustrated in Figure 2, which shows the output correlation arising from two alternative levels of trade cost, for various labor supply elasticities.

[Figure 2 about here]

The red bar in Figure 2 shows the difference in output correlations across alternative trade cost levels for different labor supply elasticities (i.e., the synchronizing effect of trade). The figure illustrates two facts: First, that the model is able to qualitatively obtain the positive relation between trade intensity and business cycle synchronization. Second, the magnitude of the synchronizing effect of trade is larger at high labor supply elasticities. Hence, to judge if the model can resolve the trade-comovement puzzle, it is necessary to determine whether, for a reasonable value of the labor supply elasticity, 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 $i, j = 1, \ldots 21$, with $i \neq j$. The first two parameters are chosen based on evidence in Bernard et al. (2003), who choose the parameters

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θ and σ matching the productivity and size advantage of exporters as 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:

$$\frac{\lambda_{ji}}{\lambda_{jj}} = \frac{\mathcal{T}_i}{\mathcal{T}_j}\left(\frac{W_i\tau_{ji}}{W_j}\right)^{-\theta}, \tag{25}$$

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

$$\tau_{ji} = \left(\frac{\lambda_{ji}}{\lambda_{jj}}\frac{\lambda_{ij}}{\lambda_{ii}}\right)^{-\frac{1}{2\theta}}. \tag{26}$$

The upshot is that, by making use of the symmetry assumption, the bilateral trade costs are very easily identified using the data on trade shares described in the Appendix A. Figure 3 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 0.09%.

[Figure 3 about here]

Figure 4 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

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capture well the empirical trade barriers.

[Figure 4 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:

$$\mathcal{T}_i = \kappa^\theta \lambda_{ii} \xi^{\theta/(1+\nu)} Y_i^{\nu/(1+\nu)}. \tag{27}$$

The value of each $\mathcal{T}_i$ by 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 data and simulated data:

$$\mathrm{cor}\left(\widetilde{y}_j, \widetilde{y}_i\right) = \alpha + \beta \left(\text{Bilateral Trade}\right)_{ji} + \varepsilon_{ji}, \tag{28}$$

where $\mathrm{cor}\left(\widetilde{y}_j, \widetilde{y}_i\right)$ 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 this 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 counter factual and inconsistent with the IRBC model.

We first estimate Equation (28) using our data, obtained from the OECD STAN database over the 1988–2007 period (see Appendix A for details). We define $\mathrm{cor}\left(\widetilde{y}_j, \widetilde{y}_i\right)$ 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. In our baseline calibration $(1/\nu = 2.33)$ 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 generate simulated data using 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

---

[8] We 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.

high business cycle correlations between countries with stronger trade linkages we estimate by OLS equation (28), 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 shows that the β coefficients are positive, indicating that the model qualitatively replicates the trade-comovement relation but falls short quantitatively compared with the data. We 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

$$\widetilde{y}_{ii}\left(s^t\right) = \left(1 + \frac{1}{\nu}\right)\frac{1}{\theta}\left[a_i\left(s^t\right) - \widetilde{\lambda}_{ii}\left(s^t\right)\right]. \tag{29}$$

Expression (29) implies that the degree of comovement between any country-pair depends on the correlation between each country's productivity shock $a_i\left(s^t\right)$ and on the correlation between each country's share of expenditures on domestic goods $\widetilde{\lambda}_{ii}\left(s^t\right)$ (which, in log-deviation from steady state, is equal to the negative of the import penetration ratio). It turns out that expression (29) 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 (29).

See appendix C for proof.

This result builds on the work of Arkolakis et al. (2010), who show that the predictions of a large class of trade models concerning the change in real income associated with any foreign shock only depends 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 (29), 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

$$\operatorname{cov}\left(\widetilde{y}_i, \widetilde{y}_j\right) = \left[\left(1 + \frac{1}{\nu}\right)\frac{1}{\theta}\right]^2 \left[\operatorname{cov}\left(a_i, a_j\right) + \operatorname{cov}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right) - \operatorname{cov}\left(a_i, \widetilde{\lambda}_{jj}\right) - \operatorname{cov}\left(\widetilde{\lambda}_{ii}, a_j\right)\right], \quad (30)$$

where $\operatorname{cov}\left(x, z\right)$ 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 (30) 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 $\widetilde{\lambda}_{ii}$ and $\widetilde{y}_i$ are the same across countries, by manipulating (30) we obtain the following three-factor model for the output correlation between countries i and j

$$\text{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right) = \beta_1 \text{cor}\left(a_i, a_j\right) + \beta_2 \text{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right) + \beta_3 \left[\text{cor}\left(a_i, \widetilde{\lambda}_{jj}\right) + \text{cor}\left(\widetilde{\lambda}_{ii}, a_j\right)\right], \quad (31)$$

where $\text{cor}\left(x, z\right)$ denotes the correlation between two variables x and z.[9] Equation (31) 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 (31). It follows that there are three channels through which an increase in bilateral trade may increase business cycle synchronization: (i) Increased trade resulting in a higher correlation between each country's technology shocks; (ii) increased trade resulting in a higher correlation between each country's share of expenditure on domestic goods; and (iii) increased trade raising the correlation between the domestic import penetration ratio and foreign technology shocks.*

See appendix D for proof.

Equation (31) 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

$$\text{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right) = \alpha + \beta_1 \text{cor}\left(a_i, a_j\right) + \beta_2 \text{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right) + \beta_3 \left(\text{cor}\left(a, \widetilde{\lambda}\right)\right)_{ij} + e_{ij}, \quad (32)$$

---

[9]The factor loadings are given by

$$\beta_1 \equiv \left[\left(1 + \frac{1}{\nu}\right)\frac{1}{\theta}\right]^2 \frac{\sigma_a^2}{\sigma_y^2},$$

$$\beta_2 \equiv \left[\left(1 + \frac{1}{\nu}\right)\frac{1}{\theta}\right]^2 \frac{\sigma_\lambda^2}{\sigma_y^2},$$

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

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

where

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

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) the greater the 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 $a_i\left(s^t\right)$ for 21 countries using panel 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

$$\frac{X_{jit}}{X_{jjt}} = \frac{T_{it}}{T_{jt}} \left(\frac{W_{it}}{W_{jt}}\right)^{-\theta} \tau_{jit}^{-\theta}, \tag{33}$$

---

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

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

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

[11]See 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 (33) gives

$$
\begin{aligned}
\ln \frac{X_{jit}}{X_{jjt}} &= -\theta \ln \tau_{jit} + \ln \frac{T_{it}}{T_{jt}} - \theta \ln \frac{W_{it}}{W_{jt}} \\
&= -\theta \ln \tau_{jit} + S_{it} - S_{jt},
\end{aligned}
\tag{34}
$$

where

$$
S_{it} \equiv \ln T_{it} - \theta \ln W_{it}
\tag{35}
$$

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

The left-hand side of (34) 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:

$$
\tau_{jit} = d_k + b + l + e + m_j - \delta_{ji} - \eta_{jit},
\tag{36}
$$

where the dummy variables associated with each component are omitted to simplify the notation.[12] The term d_k $(k = 1, ..., 6)$ captures the effect of the distance between j and i lying in the kth 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 $(j = 1, ..., 21)$ is a destination fixed effect. The error terms δ_{ji} and η_{jit} 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 η_{jit} is a classical disturbance with variance σ_η^2.[13]

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[12]In the empirical specification it is important to allow the trade costs τ_{jit} 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.

[13]This 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 (34) yields the regression equation

$$\ln \frac{X_{jit}}{X_{jjt}} = S_{it} - S_{jt} - \theta m_j - \theta d_k - \theta b - \theta l - \theta e + \theta \delta_{ji}^2 + \theta \delta_{ji}^1 + \theta \eta_{jit}, \tag{37}$$

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 (35) and setting θ equal to 3.60 as in Section 4.1.[14] Once we have the technology levels, the estimated technology shocks $\widehat{a}_i\left(s^t\right)$ are given by

$$\widehat{a}_i\left(s^t\right) = \ln\left(\frac{\widehat{T}_{it}}{\text{avg } \widehat{T}_{it}}\right), \tag{38}$$

where 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 $\widehat{a}_i\left(s^t\right)$, we can compute the three factors in equation (32). 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

---

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

[15]We also estimated equation (32) using the instrumental variable method proposed in Heckman and Vytlacil (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. Higher technology correlation between pairs of countries is associated with higher output comovement, and when the correlation between each country's share of expenditure on domestic goods is higher, countries exhibit higher output correlation. 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 and using the simulated data (but within the theoretical framework of Result 2) the channels through which trade leads to higher business cycle synchronization. To do this, we regress each of the three factors on the bilateral trade intensity as follows:

$$\text{cor}\left(a_i, a_j\right) \quad = \quad \alpha_1 + \gamma_1 \left(\text{Bilateral Trade}\right)_{ij} + \varepsilon_{ij}^1 \tag{39}$$

$$\text{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right) \quad = \quad \alpha_2 + \gamma_2 \left(\text{Bilateral Trade}\right)_{ij} + \varepsilon_{ij}^2 \tag{40}$$

$$\left(\text{cor}\left(a, \widetilde{\lambda}\right)\right)_{ij} \quad = \quad \alpha_3 + \gamma_3 \left(\text{Bilateral Trade}\right)_{ij} + \varepsilon_{ij}^3 \tag{41}$$

We estimate each regression by OLS. 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 in 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.

[Table 5 about here]

These results are in contrast to the regression performed with the simulated data, shown in Table 6. First, the association between trade and the technology shocks' correlation is statistically insignificant 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 negative and insignif-

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icant. 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_{jj} falls). Hence, the positive association between trade and co-movement 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 trade-comovement puzzle could be resolved by strengthening the mechanisms though which trade affects each of the three components of equations (39)—(41). The empirical results provide guidance on how to do it. In particular, they show that the correlation of the technology shocks increases with the bilateral trade intensity. Therefore, 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 in 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 to account for the fact that the correlation of technology shocks increases with bilateral trade intensity.

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]

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These results indicate that, independently of the micro-level assumptions about trade, the robustness of the conclusion that bilateral trade raises the correlation of productivity shocks and that this channel is essential to explain the trade-comovement relation.

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 first study whether the trade-comovement puzzle can be solved by allowing for endogenous specialization in a model along the lines of Eaton and Kortum (2002). We show that the baseline model with uncorrelated shocks explains up to 12.4 percent of the empirical relation between trade intensity and comovement and, thus the puzzle remains.

The second and most important contribution of the paper is to 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 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, if we allow technology shocks to be correlated across countries, the first and second channels help resolve the puzzle, provided that trade increases the synchronization of shocks.

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 in domestic goods. In addition, when we feed the estimated technology shocks in the theoretical model we explain up to 83.9% of the trade-comovement relation. We conclude that the trade-comovement puzzle can be resolved if we allow for correlated productivity shocks, and this feature is consistent with the data.

In this paper we have established links between the literature on the welfare gains from trade and the international business cycle literature. We have shown that within a large class of trade models measured technology shocks comovement rises with bilateral trade. This empirical finding 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.

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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 in 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 $\left(\text{Bilateral Trade}\right)_{ij}$, 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.[16] Bilateral measures of distance between Korea and the other countries in the sample are taken from the CEPII database.[17]

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 (country 1 and country 2) such that $\mathcal{T}_1$ and $\mathcal{T}_2$ are equal and $\tau_{12} = \tau_{21} = \tau$. We consider a log-linear approximation around steady state and denote a variable X in log-deviation from steady state as $\widetilde{x}$. Taking the wage in country 1 to be the numéraire wage, log-linearization of (19) implies the following expression for country 2's employment:

$$\widetilde{n}_2\left(s^t\right) = \frac{1}{\theta\nu}\left[a_2\left(s^t\right) - \widetilde{\lambda}_{22}\left(s^t\right)\right], \tag{B.1}$$

and from equation (9) it follows that

$$\widetilde{\lambda}_{22} = a_2\left(s^t\right) - \theta\widetilde{w}_2 - \widetilde{\phi}_2. \tag{B.2}$$

By log-linearizing the expression $\Phi_j\left(s^t\right) = \sum_{i=1}^{M} T_i\left(s^t\right)\left[W_i\left(s^t\right)\tau_{ji}\right]^{-\theta}$, we obtain the following conditions

$$\widetilde{\phi}_1 = \alpha a_1\left(s^t\right) + (1-\alpha)a_2\left(s^t\right) - (1-\alpha)\theta\widetilde{w}_2, \tag{B.3}$$

$$\widetilde{\phi}_2 = (1-\alpha)a_1\left(s^t\right) + \alpha a_2\left(s^t\right) - \alpha\theta\widetilde{w}_2, \tag{B.4}$$

---

[16]http://faculty.haas.berkeley.edu/arose
[17]http://www.cepii.fr/anglaisgraph/bdd/distances.htm

where $\alpha \equiv 1/\left(1+\tau^{-\theta}\right)$. Finally, the labor market clearing condition (22) in the symmetric two country example is

$$\Phi_1^{\frac{1}{\theta\nu}} \Big/ T_1 = \sum_{j=1}^{2} W_j^{1+1/\nu} \frac{\Phi_j^{\frac{1}{\theta\nu}-1}}{\tau_{j1}^{\theta}}.$$

The LHS of the above equation in log-linear form is

$$\text{LHS} = \frac{1}{\theta\nu}\widetilde{\phi}_1 - a_1\left(s^t\right),$$

while the RHS admits the log-linear approximation

$$\text{RHS} = \alpha\left(\frac{1}{\theta\nu}-1\right)\widetilde{\phi}_1 + (1-\alpha)\left(\frac{1}{\theta\nu}-1\right)\widetilde{\phi}_2 + (1-\alpha)\left(1+\frac{1}{\nu}\right)\widetilde{w}_2.$$

Combining the above two expressions implies

$$(1-\alpha)\left(1+\frac{1}{\nu}\right)\hat{w}_2 = \left(\frac{1-\alpha}{\theta\nu}+\alpha\right)\widetilde{\phi}_1 - \left(\frac{1-\alpha}{\theta\nu}-1+\alpha\right)\widetilde{\phi}_2 - a_1\left(s^t\right). \tag{B.5}$$

By combining (B.2)—(B.5), we obtain the expression

$$\widetilde{\lambda}_{22}\left(s^t\right) = (1-\theta\delta)(1-\alpha)\left[a_2\left(s^t\right) - a_1\left(s^t\right)\right], \tag{B.6}$$

where $\delta = \left[\theta + \left(1+\frac{1}{\nu}\right)\left(\frac{\theta\nu}{1-2\alpha+2\alpha\theta\nu}\right)\right]^{-1}$. Finally (B.1) together with (B.6) implies

$$\widetilde{n}_2\left(s^t\right) = \mathcal{E}\left(\theta,\nu,\tau\right)a_1\left(s^t\right) + \left[\frac{1}{\theta\nu} - \mathcal{E}\left(\theta,\nu,\tau\right)\right]a_2\left(s^t\right), \tag{B.7}$$

where the elasticity of employment in country 2 with respect to technology shocks in country 1 is given by the function

$$\mathcal{E}\left(\theta,\nu,\tau\right) = \frac{(1-\theta\delta)(1-\alpha)}{\theta\nu}.$$

This elasticity is positive as long as $\theta\delta < 1$, which is equivalent to $\theta\nu > 1 - \frac{1}{2}\left(1+\tau^{-\theta}\right)$.

C   Proof of Result 1

If assumptions A1—A3 are satisfied, it follows from the results in Arkolakis et al. (2010) that the following gravity equation holds

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

where Ψ is a constant parameter, $T_i\left(s^t\right)$ 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 $P_j\left(s^t\right) = \left[\int_0^1 p_j\left(n,s^t\right)^{1-\sigma} dn\right]^{1/(1-\sigma)}$. From (C.1) we obtain

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

and solving for the real wage we obtain

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

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

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

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

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

where $\Pi_j\left(s^t\right)$ are profits. From assumption A2 profits are a constant share γ of revenues, so that $\Pi_j\left(s^t\right) = \gamma X_j\left(s^t\right)$.[18] Using (C.4) to substitute out $N_j\left(s^t\right)$ we obtain

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

---

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

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

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

so that the output in log-deviations from steady state is given by equation (29) 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

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

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

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

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

$$\mathrm{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right) = \frac{\vartheta\sigma_a^2}{\sigma_y^2}\mathrm{cor}\left(a_i, a_j\right) + \frac{\vartheta\sigma_\lambda^2}{\sigma_y^2}\mathrm{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right) - \frac{\vartheta\sigma_a\sigma_\lambda}{\sigma_y^2}\left[\mathrm{cor}\left(a_i, \widetilde{\lambda}_{jj}\right) - \mathrm{cor}\left(\widetilde{\lambda}_{ii}, a_j\right)\right] \tag{D.3}$$

$$= \beta_1\underbrace{\mathrm{cor}\left(a_i, a_j\right)}_{(i)} + \beta_2\underbrace{\mathrm{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right)}_{(ii)} + \beta_3\underbrace{\left[\mathrm{cor}\left(a_i, \widetilde{\lambda}_{jj}\right) + \mathrm{cor}\left(\widetilde{\lambda}_{ii}, a_j\right)\right]}_{(iii)}, \tag{D.4}$$

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.4), 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.	
$\log\left(distance\right)$	0.7708	0.000	[0.6600	0.8815]
$border$	-0.2091	0.372	[-0.6703	0.2521]
$language$	-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: OLS Estimates. Trade and Output Comovement

	$\mathrm{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right)$	
	(1)	(2)
Bilateral Trade	8.362***	
	[0.00]	
$\log\left(\text{Bilateral Trade}\right)$		0.093***
		[0.00]
Constant	0.339***	0.919***
	[0.00]	[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			
	$\mathrm{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right)$			
	$\frac{1}{\nu} = 1$	$\frac{1}{\nu} = 2$	$\frac{1}{\nu} = 2.33$	$\frac{1}{\nu} = 3$
Trade	0.617	0.781	1.040	1.097
	$[-2.632 \, , \, 4.399]$	$[-2.732 \, , \, 4.455]$	$[-2.295 \, , \, 5.048]$	$[-2.187 \, , \, 5.469]$
Constant	-0.007	-0.004	-0.006	-0.002
	$[-0.056 \, , \, 0.076]$	$[-0.054 \, , \, 0.080]$	$[-0.056 \, , \, 0.071]$	$[-0.056 \, , \, 0.082]$
Observations	210	210	210	210

	Panel B: Log regression			
	$\mathrm{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right)$			
	$\frac{1}{\nu} = 1$	$\frac{1}{\nu} = 2$	$\frac{1}{\nu} = 2.33$	$\frac{1}{\nu} = 3$
$\ln\left(\mathrm{Trade}\right)$	0.005	0.007	0.010	0.010
	$[-0.034 \, , \, 0.057]$	$[-0.040 \, , \, 0.055]$	$[-0.038 \, , \, 0.065]$	$[-0.035 \, , \, 0.066]$
Constant	0.024	0.037	0.054	0.051
	$[-0.175 \, , \, 0.308]$	$[-0.190 \, , \, 0.314]$	$[-0.173 \, , \, 0.368]$	$[-0.161 \, , \, 0.380]$
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 the Regression Equation (32)

	$\mathrm{cor}\left(\widetilde{y}_i, \widetilde{y}_j\right)$			
$\mathrm{cor}\left(a_i, a_j\right)$	0.156^{***}			0.170^{***}
	$[0.00]$			$[0.00]$
$\mathrm{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right)$		0.137^{***}		0.144^{***}
		$[0.02]$		$[0.01]$
$\left(\mathrm{cor}\left(a, \widetilde{\lambda}\right)\right)_{ij}$			-0.278^{*}	-0.321^{***}
			$[0.02]$	$[0.00]$
Constant	0.311^{***}	0.317^{***}	0.428^{***}	0.242^{***}
	$[0.00]$	$[0.00]$	$[0.00]$	$[0.00]$
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)

	$\mathrm{cor}\left(a_i, a_j\right)$	$\mathrm{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right)$	$\left(\mathrm{cor}\left(a, \widetilde{\lambda}\right)\right)_{ij}$
Trade	7.680**	9.254***	-2.091
	[0.01]	[0.00]	[0.14]
Constant	0.530***	0.555***	0.106***
	[0.00]	[0.00]	[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)

	$\mathrm{cor}\left(a_i, a_j\right)$	$\mathrm{cor}\left(\widetilde{\lambda}_{ii}, \widetilde{\lambda}_{jj}\right)$	$\left(\mathrm{cor}\left(a, \widetilde{\lambda}\right)\right)_{ij}$
Trade	-0.045	-5.078	-5.552
	$[-3.237 , 3.835]$	$[-7.324 , -2.513]$	$[-10.855 , 0.528]$
Constant	-0.005	0.017	-0.005
	$[-0.048 , 0.065]$	$[-0.014 , 0.058]$	$[-0.074 , 0.099]$
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)
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.

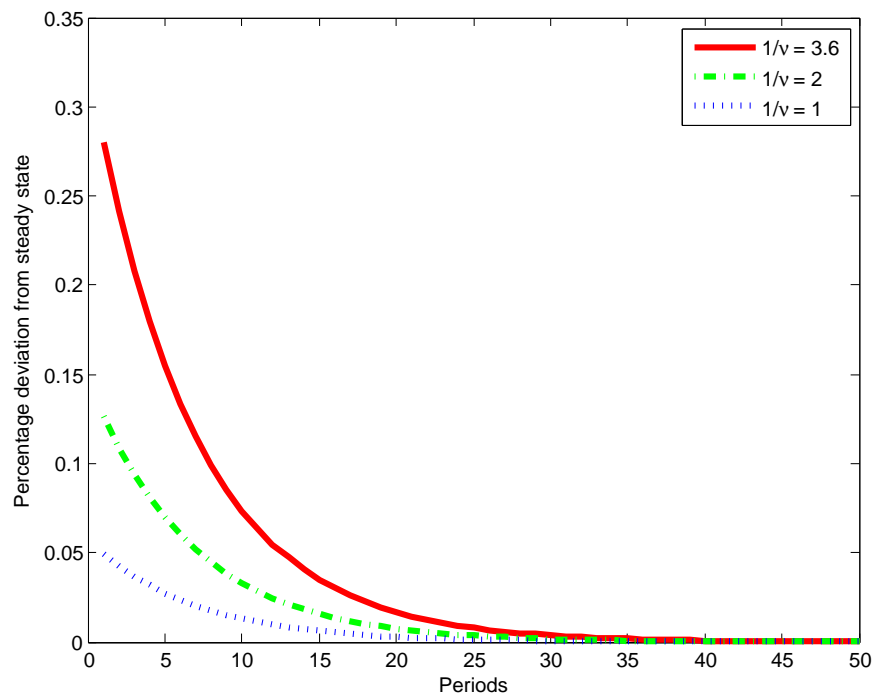The value of the labor supply elasticity $1/\nu$ is set to 2.33.

Figure 1: Impulse Response Function of Employment in Country 2 to a Shock in Country 1 ($\tau = 1$)
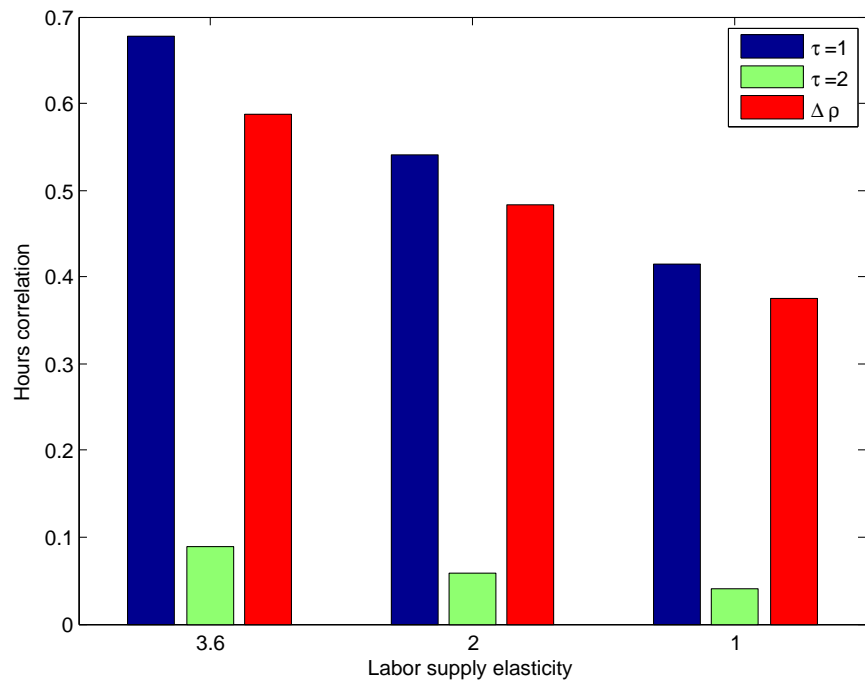
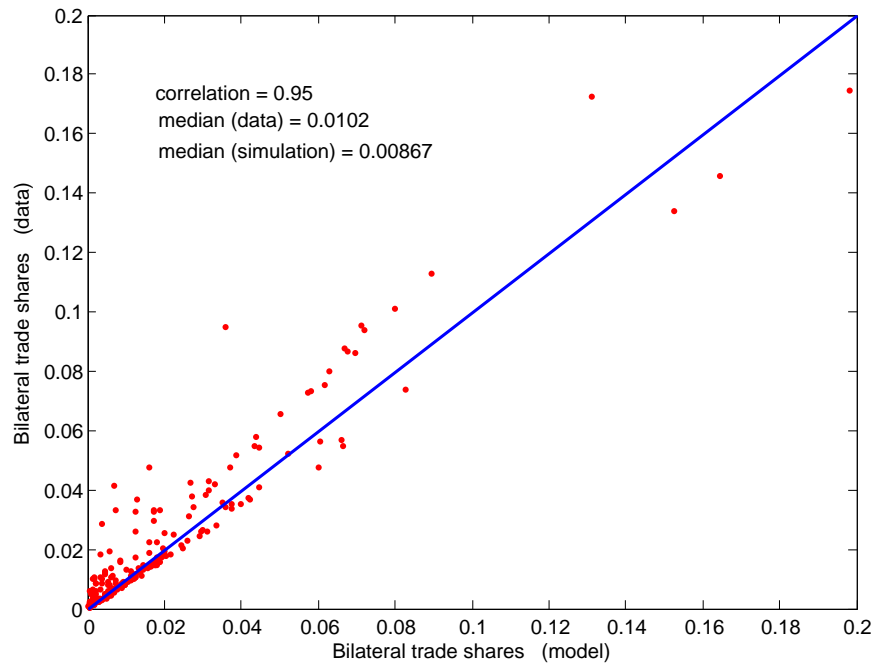Figure 2: Trade and Synchronization: Two-Country Example

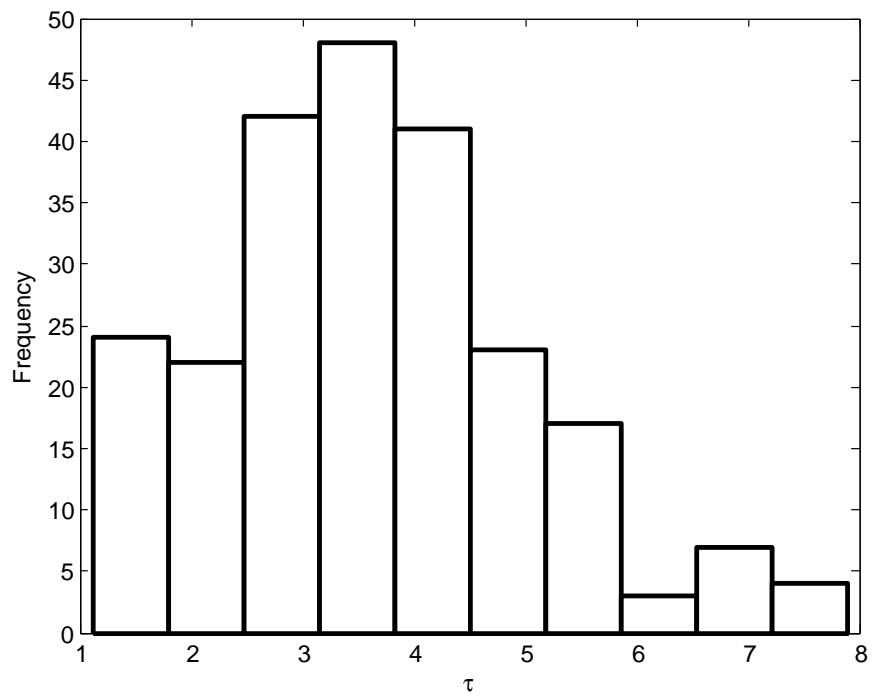Figure 3: Bilateral Trade Shares, $\frac{1}{2}\left(\lambda_{ij} + \lambda_{ji}\right)$: Data vs. Model

Figure 4: Calibrated Iceberg Costs