The Trade Comovement Problem in International Macroeconomics

M. Ayhan Kose and Kei-Mu Yi*

Abstract

Recent empirical research finds that pairs of countries with stronger trade linkages tend to have more highly correlated business cycles. We assess whether the standard international business cycle framework can replicate this intuitive result. We employ a three-country model with transportation costs. We simulate the effects of increased goods market integration under two asset market structures: complete markets and international financial autarky. Our main finding is that under international financial autarky the model can generate stronger correlations for pairs of countries that trade more, but the increased correlation falls far short of the empirical findings. In our benchmark calibrations, the model explains at most six percent of the responsiveness of GDP correlations to trade found in the empirical research. This result is robust to many combinations of shock specifications, import shares, and elasticities of substitution. Because the difference between business cycle theory and the empirical results cannot be resolved by changes in parameter values and the structure of the standard models, we call this discrepancy the *trade comovement problem.*

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1 Introduction

Do countries that trade more with each other have more closely synchronized business cycles? Yes, according to the conventional wisdom. Increased trade simply increases the magnitude of the transmission of shocks between two countries. Although this wisdom has circulated widely for a long time, it was not until recently that empirical research was undertaken to assess its validity. Running cross country or cross region regressions, first Frankel and Rose (FR, 1998), and then, Clark and van Wincoop (2001), Otto, Voss, and Willard (2001), Calderon, Chong, and Stein (2002) and others have all found that, among industrialized countries, pairs of countries that trade more with each other exhibit a higher degree of business cycle comovement.[1] Using updated data, we re-estimate the FR regressions, and find that a one standard deviation increase in trade between a pair of countries raises the country-pair's GDP correlation by 0.15. These empirical results are all statistically significant, and they suggest that increased international trade leads to a significant increase in output comovement.

While the results are in keeping with the conventional wisdom, it is important to interpret them from the lens of a formal theoretical framework. The international real business cycle (RBC) framework is a natural setting for this purpose because it is one of the workhorse frameworks in international macroeconomics, and because it embodies the demand and supply side spillover channels that many economists have in mind when they think about the effect of increased trade on comovement. For example, in the workhorse Backus, Kehoe, Kydland (BKK, 1994) model, final goods are produced by combining domestic and foreign intermediate goods. Consequently, an increase in final demand leads to an increase in demand for foreign intermediates.

The impact of international trade on the degree of business cycle comovement has yet to be studied carefully with this framework, as FR note: "the large international real business cycle literature, which *does* endogenize [output correlations] ... does not focus on the effects of changing economic integration on ... business cycle correlations."[2] The goal of this paper is to focus on these effects by assessing whether the international RBC framework is capable of replicating the strong empirical findings discussed above. We develop, calibrate, and simulate an international business cycle model designed to address whether increased trade is associated with increased GDP comovement. Our model extends the BKK model in three ways. First, recent research by Heathcote and Perri (2002) shows that an international RBC model with no international financial asset markets (international financial autarky) generates a closer fit to several key business cycle moments than does the model in a complete markets setting or a one-bond setting. Based on this work, in our model we study settings with international financial autarky, as well as complete markets. Second, in the above empirical work, the authors recognize the endogeneity of trade and instrument for it.

[1] Anderson, Kwark, and Vahid (1999) also find that there is a positive association between trade volume and the degree of business cycle synchronization. Canova and Dellas (1993) find international trade plays a relatively moderate role in transmitting business cycles across countries.

[2] FR, p. 1015-1016. While several papers (that we cite in section 4.1) have looked at the relationship between trade and business cycle comovement, their focus was not on explaining the recent cross-sectional empirical research.

In our framework, we introduce transportation costs as a way of introducing variation in trade. Different levels of transportation costs will translate into different levels of trade with consequent effects on GDP comovement.

The typical international business cycle model is cast in a two-country setting. Indeed, in a previous paper (Kose and Yi, 2001), we partially addressed the issue of this paper using a two-country model. We argued that the model was able to explain about one-third to one-half of the FR findings; our conclusion was that the model had failed to replicate these findings. However, it turns out that this setting is a flawed one for capturing the empirical link between trade and business cycle comovement. In particular, in a two-country setting, by definition, the (single) pair of countries constitutes the entire world, and one country is always at least one-half of the world economy. This would appear to grossly exaggerate the impact of a typical country on another. In reality, a typical pair of countries is small compared to the rest-of-the-world. Also, a typical country-pair trades much less with each other than it does with the rest-of-the world. Moreover, Anderson and van Wincoop (2001) carefully show theoretically and empirically that bilateral trading relationships depend on each country's trade barrier with the rest of the world. Consequently, a more appropriate framework is one that captures the facts that pairs of countries tend to be small relative to the rest of the world, pairs of countries trade much less with each other than they do with the rest of the world, and bilateral trade patterns depend on trading relationships with the rest-of-the-world. These forces can only be captured in a setting with at least three countries. This is our third, and most important, modification of the BKK model.

Our three-country model is calibrated to be as close to our updated FR regressions as possible. In particular, two of our countries are calibrated to two countries from the FR sample (the two "small" countries), and the third country is calibrated to the other 19 countries, taken together (the "rest of the world"). We solve and simulate our model under a variety of transport costs between the two small countries. We find that under complete international financial markets, the model cannot generate higher GDP correlations with stronger trade linkages. Our main result is that under international financial autarky, the model can match the empirical findings qualitatively, but it falls far short quantitatively. The model explains at most six percent of the responsiveness of GDP co-movement to trade found in our updated FR regressions. That is, in one of our benchmark cases, the model predicts that an increase in trade intensity by a factor of nine will lead to an increase in GDP correlation of only 0.01. Our result is robust to many combinations of shock specifications, import shares, and elasticities of substitution. In sum, the model fails by an order of magnitude more than what our previous paper indicated.

The key reason for the failure of the model is that bilateral trade between a pair of countries is typically quite small as a share of GDP and relative to a country's total trade. Hence, for a typical country-pair, a nine-fold increase in the bilateral trade share of GDP is a small increase in absolute terms - for the benchmark case cited above the increase in the bilateral trade share is only about 0.4 percent of GDP. This will have small effects on the country-pair's comovement. Another reason for the model's failure has to do with the fact that even large increases in the bilateral trade share of GDP will impinge little on the world economy if the country-pair is small. This limits the feedback effects from the world back to the country-pair, which, in turn, limits comovement. We interpret our findings as indicating that the standard international business cycle framework lacks a strong enough propagation mechanism from trade to output comovement. There is a large gap between business cycle theory and the empirical findings that cannot be resolved by changes in parameter values and the structure of standard models. We call this gap the *trade-comovement problem.*

Our problem is distinct from the puzzles that Obstfeld and Rogoff (2001) document; in particular, it is different from the consumption correlation puzzle. The consumption correlation puzzle is about the inability of the standard international business cycle models to generate the ranking of cross-country output and consumption correlations in the data. The trade-comovement problem is about the inability of these models to generate a strong change in output correlations from changes in bilateral trade intensity. In other words, the consumption correlation puzzle is about the levels and ranking of output and consumption correlations, while the trade-comovement problem is about a "slope".

In Section 2, we update the Frankel-Rose regressions to study the empirical relationship between trade and business cycle comovement. Next, we lay out our three-country model and its parameterization. Section 4 provides an intuitive account of how several economic forces influence the relationship between trade and GDP co-movement. Our quantitative assessment of the model is conducted in section 5. Section 6 concludes.

2 Empirical Link between Trade and Comovement

We update the Frankel-Rose (FR) regressions, which employed quarterly data running from 1959 to 1993. Our sample covers the same 21 OECD countries as in FR, but our data are annual, and cover the period 1970-2000. We employ one of the FR measures of bilateral trade intensity, the sum of each country's imports from the other divided by the sum of their GDPs, averaged over the entire period. The median bilateral trade intensity over all countries and all years is 0.0023, and the standard deviation of the trade shares is 0.0098. We employ two of the FR measures of business cycle co-movement, Hodrick-Prescott (HP) filtered and (log) first-differenced correlations of real GDP between the two countries. Summary statistics of the trade and co-movement data are presented in Table 1a.

We then follow FR by running instrumental variables estimation of the following equation:

$$Corr_{ij} = \beta_0 + \beta_1 \ln(Trade_{ij}) + \epsilon_{ij} \tag{1}$$

where i and j denote the two countries. Note that this is a cross-section regression. We employ a GMM estimator that corrects for heteroskedasticity in the error terms. Our instruments for $Trade_{ij}$ are the same as in FR: a dummy variable for whether the two countries are adjacent, a dummy variable for whether the two countries share a common language, and the log of distance. The coefficients on trade intensity are listed in Table 1b.

Our estimates are broadly consistent with those in the empirical literature, but are larger than those in FR. In the estimation with HP-filtered GDP, our coefficient estimate, 0.091, implies that a doubling of trade will raise the GDP correlation by .063. FR's estimates with HP-filtered GDP, by contrast, imply that a doubling of trade will raise the GDP correlation by .033. With first-differenced GDP, our coefficient estimate implies that a doubling of trade will raise the GDP correlation by .054. Our estimates indicate that an increase in bilateral trade intensity from 0.0023 to 0.0121, an increase from the median trade intensity of one standard deviation, will raise the correlation by .15.

3 The Model

Our model extends the basic two-country, free trade, complete market BKK (1994) framework by having three countries, transportation costs, and allowing for international financial autarky (zero international asset markets).[3] We first describe the preferences and technology. Then, we describe the characteristics of the asset markets. All variables denote own country per capita quantities.

3.1 Preferences

In each of the three countries there are representative agents who derive utility from consumption and leisure. Agents choose consumption and leisure to maximize the following utility function:

$$E_0\left(\sum_{t=0}^{\infty}\beta^t \frac{\left[c_{it}^{\mu}(1-n_{it})^{1-\mu}\right]^{1-\gamma}}{1-\gamma}\right), \qquad 0<\mu<1; \quad 0<\beta<1; \quad 0<\gamma; \qquad i=1,2,3 \tag{2}$$

where c_{it} is consumption and n_{it} is the amount of labor supplied in country i in period t. μ is the share of consumption in intratemporal utility, and γ is the intertemporal elasticity of substitution. Each agent has a fixed time endowment normalized to 1.

3.2 Technology

There are two sectors in each country: a traded intermediate goods producing sector and a non-traded final goods producing sector. Each country is completely specialized in producing an intermediate good.

The Intermediate Goods Sector

Perfectly competitive firms in the intermediate goods sector produce traded goods according to a Cobb-Douglas production function:

$$y_{it} = z_{it}k_{it}^{\theta}n_{it}^{1-\theta}, \qquad 0<\theta<1; \qquad i=1,2,3 \tag{3}$$

[3] Heathcote and Perri (2002) and Kose and Yi (2001) examine international financial autarky; Backus, Kehoe, Kydland (1992), Zimmermann (1997), Kose and Yi (2001) and Ravn and Mazzenga (2002), all examine the effects of transport costs; and Zimmermann (1997) employs a three-country model. To our knowledge, no previous paper has included all three features.

where y_{it} is the amount of intermediate good produced in country i in period t; z_{it} is the productivity shock; k_{it} is capital input. θ denotes capital's share in output. Firms in this sector rent capital and hire labor in order to maximize profits:

$$\max_{k_{it},\, n_{it}} \; p_{it}y_{it} - r_{it}k_{it} - w_{it}n_{it} \tag{4}$$
$$\text{subject to} \quad k_{it},\ n_{it} \geq 0; \qquad i = 1, 2, 3$$

where w_{it} (r_{it}) is the wage (rental rate), and p_{it} is the price of intermediate good produced in country i.

The market clearing conditions for the intermediate goods producing firms are:

$$\pi_1 a_{1t} + \pi_2 a_{2t} + \pi_3 a_{3t} = \pi_1 y_{1t} \tag{5}$$
$$\pi_1 b_{1t} + \pi_2 b_{2t} + \pi_3 b_{3t} = \pi_2 y_{2t} \tag{6}$$
$$\pi_1 d_{1t} + \pi_2 d_{2t} + \pi_3 d_{3t} = \pi_3 y_{3t} \tag{7}$$

where π_i is the number of households in country i, and determines country size. a, b, and d denote the intermediate inputs produced by countries 1, 2, and 3, respectively. a_{it} denotes the amount of the intermediate input a used by country i in period t. And b_{1t} is the amount of country 2's intermediate goods that country 1 imports (f.o.b.) in period t.

The total number of households in the world is normalized to 1, implying that

$$\sum_{i=1}^{3} \pi_i = 1 \tag{8}$$

Transportation Costs

When the intermediate goods are exported to the other country, they are subject to transportation costs. We think of these costs as a stand-in for tariffs and other non-tariff barriers, as well as transport costs. Following BKK (1992) and Ravn and Mazzenga (1999), we model the costs as quadratic iceberg costs. This formulation of transport costs generalizes the standard Samuelson linear iceberg specification and takes into account that transportation costs become higher as the amount of traded goods gets larger. Specifically, if country 2 exports b_1 units to country 1, (suppressing the time subscripts) $g_{21}(b_1)^2$ units are lost in transit, where g_{21} is the transport cost parameter for country 2's exports to country 1. That is, only $(1 - g_{21}b_1)b_1 \equiv b_{1m}$ units are imported by country 1. We think of $g_{21}b_1$ as the "iceberg" transportation cost; it is the fraction of the exported goods that are lost in transit. In our simulations, we evaluate the transport costs at the steady state values of b_1.

We think of the transportation costs as arising from transportation services provided to ship goods between countries, where the quadratic costs arise because the transportation "technology" is decreasing returns to scale. The firms providing the transportation services pay the exporting country the f.o.b. (free on board) price of the good, and then receive the c.i.f. (cost, insurance, and freight) price from the importing country. We assume that households in the importing country own these firms; the firms' profits are distributed as dividends to the households.

The Final Goods Sector

Each country's output of intermediates is used as an input into final goods production. Final goods firms in each country produce their goods by combining domestic and foreign intermediates via an Armington aggregator. The Armington aggregator is widely used in international trade models as it allows imperfect substitutability between goods produced in different countries. To be more specific, the final goods production function is given by:

$$F(a_{it}, b_{it}, d_{it}) = \left[\omega_{1i}[(1-g_{1i}a_{it})a_{it}]^{1-\alpha} + \omega_{2i}[(1-g_{2i}b_{it})b_{it}]^{1-\alpha} + \omega_{3i}[(1-g_{3i}d_{it})d_{it}]^{1-\alpha}\right]^{1/(1-\alpha)} \quad (9)$$

$$= [\omega_{1i}a_{imt}^{1-\alpha} + \omega_{2i}b_{imt}^{1-\alpha} + \omega_{3i}d_{imt}^{1-\alpha}]^{1/(1-\alpha)} \qquad \omega_{1i}, \omega_{2i}, \omega_{3i} \geqslant 0; \qquad \alpha \geqslant 0; \qquad i = 1,2,3$$

where ω_{1i} denotes the Armington weight applied to the intermediate good produced by country 1 and imported by country i (a_{im}). We assume that $g_{ii} = 0$ and that $g_{ij} = g_{ji}$. In other words, there is no cost associated with intra-country trade, and transport costs between two countries do not depend on the origin of the goods. Since $b_{imt} = (1 - g_{2i}b_{it})b_{it}$ is defined as the amount of intermediate inputs produced by country 2 and imported by country i, $b_{2mt} = b_{2t}$. $1/\alpha$ is the elasticity of substitution between the inputs.

Final goods producing firms in each country maximize their profits :

$$\max_{a_{1t}, b_{1mt}, d_{1mt}} q_{1t}[\omega_{11}a_{1t}^{1-\alpha} + \omega_{21}b_{1mt}^{1-\alpha} + \omega_{31}d_{1mt}^{1-\alpha}]^{1/(1-\alpha)} - p_{a1t}a_{1t} - p_{b1mt}b_{1mt} - p_{d1mt}d_{1mt} \quad (10)$$

$$\max_{a_{2mt}, b_{2t}, d_{2mt}} q_{2t}[\omega_{12}a_{2mt}^{1-\alpha} + \omega_{22}b_{2t}^{1-\alpha} + \omega_{32}d_{2mt}^{1-\alpha}]^{1/(1-\alpha)} - p_{a2mt}a_{2mt} - p_{b2t}b_{2t} - p_{d2mt}d_{2mt} \quad (11)$$

$$\max_{a_{3mt}, b_{3mt}, d_{3t}} q_{3t}[\omega_{13}a_{3mt}^{1-\alpha} + \omega_{23}b_{3mt}^{1-\alpha} + \omega_{33}d_{3t}^{1-\alpha}]^{1/(1-\alpha)} - p_{a3mt}a_{3mt} - p_{b3mt}b_{3mt} - p_{d3t}d_{3t} \quad (12)$$

where q_{it} represents the price of final good produced by country i, p_{ait} is the f.o.b. price of the good a imported by country i, and p_{aimt} is the c.i.f. price of good a imported by country i.

Capital is accumulated in the standard way:

$$k_{it+1} = (1-\delta)k_{it} + x_{it}, \qquad i = 1,2,3 \quad (13)$$

where x_{it} is investment, and δ is the rate of depreciation. Final goods are used for domestic consumption and investment in each country:

$$c_{it} + x_{it} = F(a_{it}, b_{it}, d_{it}), \qquad i = 1,2,3 \quad (14)$$

3.3 Asset Markets

We consider two asset market structures, complete markets and (international) financial autarky. The complete markets framework, i.e., complete contingent claims or fully integrated international asset markets, is standard. Under financial autarky, there is no asset trade; hence, trade is balanced period by period. The following budget constraint must hold in each period:

$$q_{it}(c_{it} + x_{it}) - r_{it}k_{it} - w_{it}n_{it} - R_{it} = 0, \qquad \forall t = 0, ..., \infty; \quad i = 1,2,3 \quad (15)$$

where R_{it} is profits that the transportation firms distribute as dividends to households.

3.4 Equilibrium

Definition 1 *An equilibrium is a sequence of goods and factor prices and quantities such that the first order conditions to the firms' and households' maximization problems, as well as market clearing conditions 5,6,7, and 14 are satisfied* $\forall t$.

3.5 Calibration and Solution

Calibration

In our model, one period corresponds to one year. This maintains consistency with the empirical estimation we presented earlier. Most of the parameters draw directly from or are the annualized versions of those in BKK (1994). The share of consumption in the utility function is 0.34, which implies that 30% of available time is devoted to labor activity. The coefficient of relative risk aversion is 2. The preference discount factor is 0.96, which corresponds to an approximately 4% annual interest rate. The capital share in production is set to 0.36 and the (annual) depreciation rate is 0.1. We also follow BKK (1994) and set the elasticity of substitution between domestic and foreign goods in the Armington aggregator at 1.5. We calibrate the Armington weights so that they yield a steady-state import share of output of 0.15 under free trade.

We use two sets of productivity shocks in our analysis. In the next section we use the three-country analogue of what is used in Kose and Yi (2001). We now describe these shocks. The other set of productivity shocks, those used in our quantitative analysis, are described later. In Kose and Yi (2001), we constructed Solow residuals using output, capital and totals hours worked.series for the U.S., Germany and Japan.[4] We then estimated a bivariate vector autoregression (VAR) involving the Solow residuals of the U.S. and one of the other two countries, and calculated the symmetric autoregressive matrix with the same eigenvalues as the average of our coefficient matrix. We also average the standard deviations and correlations of the residuals from the two estimations. The symmetric three-country analogue to the two-country productivity matrix is:

$$\begin{bmatrix} \log z_{1t} \\ \log z_{2t} \\ \log z_{3t} \end{bmatrix} = \begin{bmatrix} \overline{z_1} \\ \overline{z_2} \\ \overline{z_3} \end{bmatrix} + \begin{bmatrix} 0.717 & 0.033 & 0.033 \\ 0.033 & 0.717 & 0.033 \\ 0.033 & 0.033 & 0.717 \end{bmatrix} \begin{bmatrix} \log z_{1t-1} \\ \log z_{2t-1} \\ \log z_{3t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} \tag{16}$$

where $\begin{bmatrix} \varepsilon_{1t} & \varepsilon_{2t} & \varepsilon_{3t} \end{bmatrix}' \sim N(0, \Sigma)$. The standard deviation of the error terms, $\sigma(\varepsilon_{it}),\ = 0.013$, and the correlation of the errors, $\rho(\varepsilon_{it}) = 0.255$ for $i = 1, 2, 3$.

Solution

Because analytical solutions do not exist under either asset market structure, we solve the model following the standard linearization approach in the international business cycle literature. Under complete markets, the model is converted into the equivalent social planning problem and solved accordingly. The social

[4] The main data source was the OECD's Intersectoral Database, covering the period 1970-1996. See Kose and Yi (2001) for details.

planning weights associated with the complete markets version of the three-country model are solved for so that each country's budget constraint is satisfied in the steady state; the weights are close, but not equal, to the countries' population weights. Under financial autarky, the optimization problems of the two types of firms, as well as of the households, are solved, along with the equilibrium conditions.[5]

The bilateral trade intensity measure is given by the following expression for countries 1 and 2:

$$\frac{2 * (\frac{\pi_2}{\pi_1}) a_{2t}}{\left[\left(a_{1t} + (\frac{\pi_2}{\pi_1}) a_{2t} + (\frac{\pi_3}{\pi_1}) a_{3t}\right) + p_{12t}\left(b_{1t} + (\frac{\pi_2}{\pi_1}) b_{2t} + (\frac{\pi_3}{\pi_1}) b_{3t}\right)\right]} \tag{17}$$

where p_{12t} is country 1's terms of trade with country 2 (the price of country 2's good in terms of country 1's good).[6] In the case of three equally sized countries, and with symmetric Armington weights, the trade intensity measure captures bilateral exports expressed as a share of country 1's (or country 2's) GDP.

4 Effects of Trade on Comovement in a Business Cycle Model

In this section, our objective is to provide intuition on how changes in the volume of trade (driven by changes in transportation costs) between a pair of countries affects that country-pair's GDP correlation. In addition, we examine how the effects are altered by key aspects of the model, including the asset market structure, the Armington weights, the elasticity of substitution between home and foreign intermediates, and country-size. To facilitate the intuition, we mainly employ a symmetric version of the model, where all parameters are symmetric and identical across countries. Moreover, in all our experiments other than the country-size experiments, the three countries are identical in size.[7]

As a reminder, the exercises we undertake are cross-section exercises, not time series exercises.[8] In particular, they are designed to conform to the cross-section regressions of FR and others. The regression coefficient on the trade intensity variable tells us that if trade between a pair of countries increases by a factor of e, then, all else equal, the GDP correlation will increase by the value of the coefficient.

We undertake the model analogue of these regressions. To study a range of trade intensities, we simulate the model over a range of transport costs ranging from zero to thirty-five percent. Given our benchmark Armington elasticity of 1.5, this range of transport costs generates trade intensities that differ by a factor of 3.5, which is close to one standard deviation from the median bilateral trade intensity. For each transportation

[5] In the complete market setting, the rebates associated with transports costs are subsumed in the social planning problem. In the portfolio autarky setting, the rebates must be explicitly included for as given in equation (15).

[6] Following the convention of BKK (1994) we define the terms of trade to be the relative price of imports to exports, rather than the other way around.

[7] In an appendix available from us on request, we also examine the effects of different parameterizations of the productivity shocks, as well as of convex adjustment costs in capital accumulation. In particular, we study how changes in the spillover coefficient, persistence, and correlation of the shocks affect the responsiveness of output comovement to increased trade.

[8] For recent time series work on the transmission of business cycles via international trade, see Prasad (2001) and Schmitt-Grohe (1998).

cost, we simulate the model 1000 times over 35 years, and then apply the Hodrick-Prescott filter.[9] We first examine the impact of trade on output comovement under two asset market structures. Then, we study the effects of import shares and elasticity of substitution on the responsiveness of output comovement to changes in trade. Next, we consider the role of country size.

4.1 Effects of Asset Markets: Complete Markets vs. Financial Autarky

In our first set of experiments, we fix transportation costs between countries 1 and 3, and between countries 2 and 3 at 15%. We then vary transportation costs between countries 1 and 2 and examine how the volume of trade between them is related to their GDP correlation. We do this for both the complete markets and financial autarky asset market structures. Figure 1 plots the average GDP correlation against their trade intensity.[10] The figure shows that under complete markets, countries with greater trade linkages have (slightly) lower correlations, which is counterfactual. Two opposing forces operate here. The first one is the "trade-magnification" force: greater trade linkages leads to greater business cycle co-movement according to the standard demand and supply-side channels mentioned previously. Second, greater trade linkages lead to more "resource-shifting", in which capital and other resources shift to the country receiving the favorable productivity shock. All else equal, this resource-shifting force lowers business cycle co-movement. From the figure, we can infer that the latter force is stronger.

Our finding that the model with complete asset markets cannot produce the positive relationship between trade intensity and business cycle comovement in the data is consistent with other research that has examined the effects of transport costs on comovement. BKK (1992) report that adding transport costs *increases* the GDP correlation from -0.18 to 0.02 in a one-good model. Zimmermann (1997) finds that introducing transport costs has almost no impact on the cross-country output correlations. Mazzenga and Ravn (2002) employ a transportation service sector in their model; the cross-country output correlation is 0.03. In the model without that sector, i.e., no transport costs, the correlation is -0.01.[11]

None of these papers, however, examined the effects of transportation costs and trade on output comovement in an international financial autarky setting. Figure 1 and the top panel of Table 2 show that under financial autarky countries with greater trade linkages do have greater GDP correlations. In a world of zero international asset trade, countries are unable to run current account deficits. They cannot utilize the "resource shifting" force to take advantage of favorable productivity shocks. So, there is only one force at work here, the "trade-magnification" force. To provide further intuition, we examine the impulse response

[9] For some of our experiments, we also used a first difference filter, as in Clark and van Wincoop (2001). The results are virtually identical.

[10] The trade intensity (which in the symmetric case is the bilateral trade share of output) of countries 1 and 2 in steady state varies between 0.021 and 0.077 as transport costs decline from 0.35 to 0. The trade intensity when countries 1 and 2 are under free trade (0.077) is slightly larger than 0.075; this is because of positive transportation costs between the two other pairs of countries.

[11] See Head (2002) for an international business cycle model based on monopolistic competition. In this model, higher transport costs lead to lower output comovement under complete markets.

of country 2's output to a period 1 productivity shock in country 1. Figure 2 illustrates the output response under free trade and under 35% transportation costs (between countries 1 and 2). Under free trade the impact effect is positive, with output following a hump-shaped pattern thereafter. By contrast, the impact effect under high transport costs is negative, and while the ensuing effect is positive, it is not as large as it is under free trade. The output response to country 1 (not shown) is the usual upwards spike followed by declining, but positive deviations of output from steady-state. The magnitudes are considerably larger than in country 2, and they vary little with transportation costs. Consequently, it is not surprising that the free trade time paths of output in the two countries are more closely correlated than the time paths under 35% transport costs. Because the financial autarky results are qualitatively consistent with the basic empirical facts, and the complete markets results are not, in the remainder of this paper we focus only on the financial autarky case.

4.2 Effects of Import Shares and Elasticity of Substitution

We now examine how changes in key parameters of the symmetric model affect the responsiveness of output correlations to changes in trade. Our first analysis is to increase the free trade import share of GDP. We alter the Armington weights to double the steady-state import share from 0.15 to 0.30, which also implies a doubling of the trade intensity variable from 0.075 to 0.15 (under free trade). Again, holding transport costs between countries 1 and 3, and between countries 2 and 3, constant at 15%, while transport costs between countries 1 and 2 are varied, yields qualitatively the same results as before.[12] However, the responsiveness of the GDP correlation to trade intensity is more than twice as strong as in the baseline experiment as indicated by the "slope" coefficient in panel 2 of Table 2.

Second, we vary the elasticity of substitution between domestic and foreign intermediates, because it is a key parameter, and because there are differing views on the value of this elasticity.[13] An increase in the elasticity of substitution generates larger differences in trade volume at each level of trade barriers. When the elasticity is equal to 3, the volume of trade between two countries under free trade is twenty times larger than that with 35% transportation costs. By contrast, when the elasticity is 0.9, two free-trade countries trade about two times as much in steady state as two countries with 35% transportation costs. However,

[12] As discussed in section 3.5, we calibrate the Armington weights to match the desired steady-state import shares under free trade. We create variation in trade in our experiments by varying the transport costs. An alternative approach would be to conduct our analysis under free trade, and vary the Armington weights to yield the desired trade intensities. This is not pleasing because we view these weights as deep parameters, while the transport costs are a variable. Also, simulations show that the effects of the two approaches are different. For example, in a two-country free trade setting, altering the Armington weights so that the import share rises from 0.15 to 0.30 implies an increase in the GDP correlation from 0.29 to 0.34. However, setting the Armington weights so that the free trade import share is 0.30, and using transport costs to create variation in trade implies that the GDP correlation when the import share is 0.15 is 0.26. So the transport cost approach yields greater responsiveness in output comovement to changes in trade shares.

[13] See Obstfeld and Rogoff (2001), Heathcote and Perri (2002), and Erkel-Rousse and Mirza (2002), for discussions on these views.

when the elasticity is 3, the results of our experiments indicate that the increase in trade volume does not translate into a substantial increase in the correlation of output. Panels 3 and 4 of Table 2 show that the responsiveness of GDP comovement to trade intensity is about four times as large in the low elasticity case compared to the benchmark case, and about 20 times as large in the low elasticity case compared to the high elasticity case.

Why is the responsiveness of the correlations to increased trade larger under the low elasticity compared to the high elasticity? To answer this question, we calculate the impulse responses of output of countries 1 and 2, as well as of the terms of trade of country 2, to a productivity shock in country 1. We do this for free trade and for high (35%) transport costs, and for high and low elasticities of substitution. (Figures 3 and 4) Consider, first, the case of a high (3) elasticity of substitution. Figure 3a shows that country 1's output is essentially unaffected by transport costs. The direct effect of the productivity shock swamps all other effects. With high elasticities of substitution, relative prices change little, regardless of transport costs, as Figure 3b shows. Country 2's terms of trade fall slightly; in other words, the relative price of its good increases slightly. Capital in country 2 has effectively become more productive. All else equal, this encourages capital accumulation, leading to the hump-shaped response of output shown in Figure 3c.[14] However, because the time path of the terms of trade is very similar under free trade and under high transport costs, the time path of output is very similar under free trade and under high transport costs, as well. Consequently, the co-movement of country 1's output and country 2's output changes little as transport costs are varied, as Figures 3a and 3c show.

Compared to a high elasticity of substitution, with a low (0.5) elasticity of substitution, the relative price of country 2's goods (reciprocal of the terms of trade) increases considerably more in response to a productivity shock in country 1. Moreover, as the economy moves from high transport costs to free trade, the price increase becomes considerably larger, as a comparison of Figures 3b and 4b shows. This implies that the extent of the capital accumulation is larger, in general, in a low elasticity case. In addition, the increase in the capital accumulation is larger (compared with the high elasticity case) as the economy moves from high transport costs to free trade. Consequently, country 2 exhibits a larger responsiveness of output to increased trade under lower elasticities. This makes country 2's output time path closer to country 1's. Hence, the responsiveness of output comovement to increased trade is larger under lower elasticities of substitution.

[14] As Figure 3c shows, the impact effect of country 1's productivity shock on output in country 2 is negative. On impact, output is driven by labor, because capital is pre-determined. There are two forces affecting labor. On the one hand, because of the increased relative price of country 2's good, labor is more productive today, which would encourage increased work effort at the expense of leisure. On the other hand, the higher relative price of country 2's goods in the future implies that the expected productivity of its capital has risen as well. Hence, capital accumulation will occur; this makes labor more productive in the future as well. This will encourage substitution away from labor today towards increased labor in the future. Figure 3c indicates that the effect of capital accumulation in the future dominates; hence, output falls initially. This is true for both high and low transport costs. Under low elasticities of substitution, the short run rise in the relative price of country 2's good is sufficiently large under free trade that the current period effect on labor dominates, and output rises initially. See Figure 4c.

4.3 Country Size Effects

We now examine the effects of country size on the responsiveness of GDP comovement to changes in trade intensity. In particular, we introduce asymmetry in country-sizes. There are two small countries and a large country. We study a case where the large country is 2/3 of the world economy, and each of the small countries is 1/6 of the world economy. In this case, the Armington weights are calibrated so that the import share of the large country is 0.075 and the import share of each small country is 0.1875. The calibration of country sizes and trade shares takes into account the fact that smaller countries tend to have larger trade shares of output. All other parameters are the same as in the previous section. To preview the experiments we run in the next section, we vary the transport costs between the two small countries while holding the transport costs involving the large country constant at 15%.[15]

Panel 5 of Table 2 shows that when the transport costs fall from 35% to 0, the two small countries' trade intensity almost quadruples, rising from 0.01 to 0.038. This is similar to the increase in trade in the symmetric country experiments above. However, the increase in GDP correlation is only about one-half of what it is in the symmetric case. This indicates that with smaller countries, the impact of increased trade on GDP comovement is less than with larger countries. Consistent with this is the result from an experiment where we vary the transport costs between the large and small country, while holding the other transport costs fixed. When the transport costs fall from 35% to 0, bilateral trade intensity only doubles, but the increase in correlation is twice as much as in the previous experiment. Consequently, the responsiveness of GDP comovement to changes in trade is about four times as large when a large and small country are involved, compared to two small countries, as shown in panel 6 of Table 2. Country-size will clearly play a role in whether the model can replicate the empirical results from section 2.

5 Quantitative Assessment of the Model

We now conduct simulations of our model calibrated to match the underlying environment consistent with the empirical estimation from section 2. The goal is to quantitatively assess whether our three country international RBC model under international financial autarky can generate the high responsiveness of GDP co-movement to bilateral trade intensity found in the data. To tie our simulations as closely as possible to the empirical work, we view the world as consisting of the 21 countries in the empirical sample from our earlier regressions. The three countries in our simulations consist of two of the 21 countries, and a third country, the rest-of-the-world (ROW), which is an aggregate of the other 19 countries. There are 210 such three-country combinations. We would like a combination to serve as a benchmark, because it is infeasible to calibrate productivity shocks and other parameters based on every combination. On the other hand, we would not want to base our conclusions on results from just one benchmark. Consequently, we select four benchmarks. We focus on country combinations whose bilateral trade intensity and GDP correlation are

[15] Our results are almost identical when the transport costs involving the large country are fixed at 0 and at 35%.

close to the median values of these variables. For each bilateral country-pair, we calculate the root mean square error of its GDP correlation and trade intensity from their respective medians in the 210 country-pair sample. We do this for both the HP-filtered GDP and the first-differenced GDP. Among the country-pairs that are in the lowest 10 percent in root mean square error - for both GDP correlations - we pick the three country-pairs with the smallest root mean square error. These are Belgium and U.S.; Australia and Belgium; and Finland and Portugal. We also pick the country-pair among the G-7 countries that is closest to the median: France and the U.S.. Table 1c lists the trade intensities and the GDP correlations for each of our benchmark country-pairs.

5.1 Calibration

The two key elements of the calibration are the import shares and the productivity shocks. The import shares implicitly determine country-size and also map directly into the Armington aggregator weights. All other parameters are the same as in the previous section. We estimate the productivity shocks using the data of the benchmark country-pairs and the ROW. We begin by calculating Solow residuals from the Penn World Tables version 6.0. For each benchmark country-pair, we calculate Solow residuals for the two countries, which we will think of as small, and for the aggregate of the other 19 countries (ROW). We do this for 1970 through 1998. With the Solow residuals, we estimate an AR1 shock process. Then, we symmetrize the estimated productivity shock matrix, but in such a way to maintain the same eigenvalues as in the originally estimated shock process. To calculate import shares, we eliminate the "redundant" imports of the ROW's 19 countries from each other. Further details about this calibration are given in the Appendix.

5.2 Results

We conduct the same set of experiments as we did previously. For each benchmark country-pair we simulate the model at several different transport costs. Each transport cost generates a different trade intensity and GDP correlation. Comparing across transport costs, we can calculate the change in correlation per unit change in steady-state trade intensity. This model-generated implied "slope" is compared against the empirical estimates from section 2.

In our first and primary set of experiments, we fix the transport costs between each small country and the ROW at 15%. We then vary transport costs between the two small countries. This produces variation in trade intensities close to one standard deviation of that in the data. The top panel of Table 3 presents the resulting trade intensities and GDP correlations when the model is simulated with transport costs between the two small countries set to 35% and to 0. The trade intensity column lists the steady-state trade intensities. For the Belgium-U.S. benchmark, for example, the trade intensity rises by almost an order of magnitude, from .00046 to .00435, as transport cost fall from 35% to 0. In addition, the GDP correlation rises from 0.323 to 0.335, an increase of .012. The responsiveness of GDP co-movement to trade, i.e., the implied slope is 0.0053, which is just 5.8% of our estimate of 0.091 from section 2. Consequently, with this benchmark country-pair, and across these particular transport costs, the model explains only about 6 percent of what would be predicted by the empirical results.

The top panel of Table 3 also shows that for other benchmark country-pairs, similar results are obtained. In none of them can the model generate increases in GDP correlations even 4 percent of what would be predicted by the empirical estimates. We also conduct experiments with transport costs between the two small countries set to 20% and 10%, and we calculate the model's implied increase in GDP correlation as the costs fall from 35% to 20%, from 20% to 10% and from 10% to 0. We do this for all four benchmark country-pairs. The results are essentially the same; the median experiment explains just 1.5 percent.

The small explanatory power of the model is due to one key force. As alluded to above, bilateral trade intensity for our benchmark country-pairs is small to begin with. A typical country does not trade much with any other country. This implies that large percentage increases in bilateral trade intensity do not translate into large increases in absolute terms. In the Belgium-U.S. case above, the order of magnitude increase in trade intensity translates into an increase in intensity of only 0.004, or approximately 0.4 percent of GDP. This small increase is not enough to generate large changes in comovement. There is an additional, indirect force, as well. The top panel of Table 3 shows that the explanatory power of the model for the two benchmark country-pairs involving the U.S. is greater than for the two other benchmark country-pairs. This is because a given increase in trade intensity translates into a greater impact on the world economy the larger is the country-pair. (It is useful to recall that bilateral trade intensity is bilateral trade divided by the sum of the two country's GDPs.) In general equilibrium, the greater impact on the world economy will eventually be transmitted back to the two countries, generating greater comovement.

We also conduct the same set of experiments except with the transport costs between each small country and the ROW fixed at 35%, and also at 0%. Panel 2 of Table 3 presents results for the 35% case; it shows that the results are virtually identical. From the main results presented in the top panel of Table 4, as well as our sensitivity analysis, we conclude, then, that the basic international business cycle framework, even under financial autarky, falls far short of explaining the data. It explains only about 1.5 percent.

Heathcote and Perri (2002) argue that the Armington elasticity is less than 1. We re-run our primary set of experiments with the elasticity they use, 0.9. As discussed above, with a lower Armington elasticity, smaller increases in trade translate into larger increases in GDP co-movement, which helps the model fit the empirical findings better. However, the model still falls far short, as seen in the bottom panel of Table 3. For example, with the Belgium-U.S. benchmark, the model now explains 14 percent of what would be predicted by the empirical results, more than twice as much as with the benchmark elasticity, but still very low. The numbers are similar for the other three benchmarks. We also re-run our primary experiments with an Armington elasticity of 3. In this case, the model explains even less than with the benchmark elasticity.[16]

[16] While the model performs relatively better with a low elasticity substitution, we note that such a low elasticity is inconsistent with existing estimates – almost all of which are greater than our benchmark elasticity – and with explaining large differences in trade across countries and over time. See Anderson and van Wincoop (2001), Obstfeld and Rogoff (2001), and Yi (2002), for example. Hence, with respect to the volume of trade, the low elasticity is counterfactual.

We now turn to gaining a better understanding of the sharp difference between the model's implications and the empirical estimates. Many of the European countries in our sample share the same trading partners. For almost all countries, the U.S. is an important trading partner. It is possible, then, that pairs of countries are linked by an indirect trade channel. Two small countries' GDPs may be highly correlated because both trade heavily with the U.S. and other countries. This channel could complement the direct bilateral channel, and would plausibly be stronger the more similar these two countries' trading partners are. If it is the case that pairs of countries with higher (bilateral) trade intensity also tend to have more similar trading partners, then it is possible that the empirical estimates of the effect of trade on GDP correlation suffer from positive omitted variable bias. If there is a bias, one way to rectify this would be to construct a bilateral measure of similarity of trade partners, and to re-estimate equation (1) including this variable in addition to the trade intensity variable. However, it is likely that any similarity measure would be endogenous, and would need to be instrumented for. It is unclear what instruments would be correlated with the similarity of trading partners, and uncorrelated with GDP comovement.

Moreover, given the approach of this paper, we instead assess the possibility that the empirical estimates are upwardly biased by running simulations in which transport costs between all three countries are varied simultaneously, and by continuing to focus on the relationship between the two small countries' bilateral trade intensity and (bilateral) GDP correlation. By doing so, we are essentially comparing pairs of countries that trade heavily with each other and with the ROW to countries that trade little with each other and with the ROW. Increased trade with the ROW will presumably lead to higher GDP comovement, which will lead to a larger association between bilateral trade and GDP comovement. As before, we calculate the change in GDP correlation between the two small countries as the transport costs between them are varied, and compare that against what would be predicted by the empirical estimates (based on the change in the two countries' trade intensities).

The top panel in Table 4 reports our results. The panel shows clearly that when all transport costs decline simultaneously, the explanatory power of the model increases substantially. Consider, for example, the Australia-Belgium benchmark case. Reducing all transport costs from 35% to 0 raises the Australia-Belgium trade intensity from 0.00077 to 0.00223.[17] The lower transport costs raises the GDP correlation from 0.1197 to 0.1579. The implied slope of 0.036 is 40 percent of our estimated slope of 0.091. Hence, compared to the earlier results, the explanatory power of the model for this benchmark case has increased by 50-fold! On the other hand, the improvement for the France-U.S. benchmark case is considerably less, as the explanatory power of the model rises from 3.4 percent to 7.7 percent.

The table shows that the two benchmark cases with the largest improvement are the ones in which both countries in the country-pair are very small. The two benchmark pairs that include the U.S. have

[17] This is a smaller increase than in the first experiment, but is consistent with the insight from Anderson and VanWincoop (2001) that bilateral trade flows depend on barriers relative to other countries. If all barriers fall, the increase in (bilateral) trade is less than what would occur if only bilateral barriers fell.

considerably less improvement. This is consistent with our discussion above. For country-pairs with very small countries like Australia and Belgium or Finland and Portugal, what matters for their GDP correlation is not so much their bilateral trade, but their indirect trade, that is, their trade with the rest-of-the-world. For country-pairs like Belgium and the U.S., because the U.S. is such a large partner, increased trade with the ROW is less likely to make a difference for the correlation of their GDPs.

Our idea is borne out further in the second panel of Table 4. In this panel, we isolate the indirect trade effect by setting transport costs between the two small countries at 15% and holding them constant while we vary the transport costs between the two small countries and ROW. In other words, we are comparing a pair of countries that trades little with the ROW with a pair of countries that trades a lot with the ROW. Comparing the increase in GDP correlation in this panel with that of the top panel of Table 3 (Experiment 1), it is easy to see that for the Australia-Belgium and Finland-Portugal benchmarks, the increase in GDP correlation is more than an order of magnitude larger when costs between these countries and the ROW fall than when costs between the two countries fall. For these benchmarks, indirect trade is much more important than direct trade in driving GDP co-movement. For the two U.S. benchmark country-pairs, the increase in GDP correlation generated by increased indirect trade is about the same as that generated by increased direct trade.

In our experiments we simulate the model - calibrated carefully to conform to the conditions underlying the empirical work - under many combinations of productivity shock parameterizations, country sizes, transport costs, and elasticities of substitution. None of these combinations provides a close fit to the data. The model falls far short of replicating the empirical relationship between bilateral trade intensity and GDP comovement. Even when we allow for some omitted variable bias in our simulations, the model still cannot replicate the empirical relationship. We call the large gap between the model's predictions and the empirical evidence the *trade-comovement problem.*

6 Conclusion

Recent empirical research finds that increased trade linkages between a pair of countries leads to higher business cycle co-movement. In this paper we examine whether the standard international business cycle framework can replicate the magnitude of these findings. We study this issue in the context of a three-country business cycle model in which changes in transportation costs induce an endogenous link between trade intensity and output comovement. On the face of it, the model might plausibly be expected to provide a good fit, because it embodies the key demand and supply-side spillover channels that are often invoked in explaining the trade-induced transmission of business cycles. In particular, increased output in one country leads to increased demand for the other country's output. Following Heathcote and Perri (2002), we study a model with international financial autarky, as well as complete markets. Also, we calibrate our three country model as closely as possible to the leading empirical paper in the literature, Frankel and Rose (1998). The three country aspect of the model is important, because it captures the fact that most pairs of countries are small relative to the world.

We find that the standard international business cycle model under international financial autarky is able to capture the positive relationship between trade and output comovement, but it falls far short of explaining the magnitude of the empirical findings. The key reason for the failure of the model is that bilateral trade between countries is typically quite small as a share of GDP and relative to a country's total trade. Large percentage changes in bilateral trade as a share of GDP are not large changes in absolute terms. Another reason for the model's failure has to do with feedback effects from the country-pair to the world economy and then back. Even country-pairs with large absolute changes in their bilateral trade share of GDP will not generate large feedback effects if the pair constitutes a small share of world GDP. Summarizing, the model's propagation mechanisms are not strong enough to generate large changes in output comovement from relatively small changes in goods market integration. Our results hold up under reasonable changes in the parameterization of productivity shocks, the elasticity of substitution between foreign and domestic intermediates, country-sizes, and transport costs. They are also robust to including for the possibility of omitted variable bias in the empirical research. Because the gap between the theory and the empirical results is robust to these changes, we call the gap the *trade-comovement problem*.

The trade-comovement problem is different from the six puzzles in international macroeconomics that Obstfeld and Rogoff (2001) identify. The two puzzles most closely related to ours are the consumption correlations puzzle and the home-bias-in-trade puzzle. As discussed earlier, the consumption correlations puzzle is a puzzle about levels and rankings of cross-country consumption and output correlations. The home-bias-in-trade puzzle is about explaining low levels of trade. Our problem is about the responsiveness of output correlations to changes in bilateral trade. It is about "slopes", not levels, of correlations. We do not seek to explain the low levels of trade; rather, we take these levels as given, and ask how variation in them affects output correlations.

In their empirical work, FR do not control for variables other than bilateral trade intensity. Other researchers, including Imbs (1999), contend that controlling for sectoral similarity in the regressions leads to smaller coefficients on trade. However, Clark and van Wincoop (2001), Otto, Voss, and Willard (2001) and Calderon, Chong, and Stein (2002) also control for industrial or sectoral similarity (among other variables) and the coefficients on trade are still statistically significant. There are indeed models which include multiple sectors, including those by Kouparitsas (1998) and Ambler, Cardia, and Zimmermann (2002). However, these models are limited by the fact that the linkages across countries are driven by the Armington aggregator. With the aggregator, the specialization pattern is hard-wired into the model: one country makes apples, the other makes oranges, regardless of the extent of trade barriers.

Neoclassical trade theory tells us, on the other hand, that changing trade barriers can change the pattern of specialization. A model that allows for changing specialization patterns may yield additional effects from trade to business cycle comovement. In particular, if increased specialization resulted in increased production similarity, as would arise from intra-industry trade, then, there may be an additional channel leading from increased trade to increased output comovement.[18] A further extension then would be a dynamic trade model with multiple sectors that allows for changing specialization patterns. Such a model could easily accommodate industry-specific, in addition to country-specific, shocks. This is a potentially promising setting in which the trade-comovement problem may be resolved.

A Productivity Shock Process and Import Shares

A.1 Estimating Productivity Shock Process

Our raw data for computing the productivity shocks comes from the Penn World Tables, version 6.0. For the period 1970-1998, we obtain data on population, real GDP (chained), and real GDP per worker for the 21 countries in our sample. For each simulation involving a particular country pair, we calculate three sets of Solow residuals. The first two sets correspond to the two countries in the country pair. The third set corresponds to the other 19 countries, which serve as the Rest-of-the-World (ROW). Output and labor are summed across countries to yield a ROW aggregate. The Solow residuals are constructed as follows:

$$Z_{it} = \ln(Y_{it}) - 0.64\ln(L_{it}) \tag{18}$$

where Y_{it} is real GDP for country i in year t, and L_{it} is the number of workers in country i in year t. Our coefficient on labor corresponds to the labor share of output used by BKK, for example. The capital stock data in the latest Penn World Tables are currently not available.

With the three sets of Solow residuals, we estimate an AR1 productivity shock matrix A. We regress each set of residuals on a constant, a time trend, and lagged values of each of the three residuals. This yields the A matrices listed in Appendix Table 1. The standard deviations and correlation matrix of the residuals are used to construct the variance-covariance matrix V of the residuals; these values are also listed in Appendix Table 1. As in BKK (1994) and Zimmermann (1997), we symmetrize the estimated A matrix. We restrict the eigenvalues of the symmetrized matrix to be equal to those of the estimated A matrix. The additional constraints we impose are similar to those imposed in Zimmermann (1997). If $A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$ then the symmetrized matrix $B = \begin{bmatrix} (a_{11}+a_{22})/2 & x & a_{13} \\ x & (a_{11}+a_{22})/2 & a_{13} \\ y & y & a_{33} \end{bmatrix}$ where x and y are unknowns.

[18] Some recent empirical research does find that intra-industry trade is more important than inter-industry trade or total trade in driving the GDP co-movement. See, for example, Fidrmuc (2002) and Gruben, Koo and Millis (2002). Allowing for increased specialization poses a double-edged sword, however. To the extent that it generates less industrial similarity across countries, and to the extent that industry-specific shocks are important drivers of the business cycle, then increased specialization could reduce output comovement.

Our constraints amount to the following assumptions: We assume that the AR1 coefficient on each small country's own lagged productivity shock is the same across the two countries. We also assume the AR1 coefficient on the ROW's own lagged productivity shock is the same as in the original estimation. We assume that the spillover effects of the ROW shock on the two small countries productivities are identical and equal to what is estimated for the first small country. The spillover effects of the two small countries' productivity shocks on each other are assumed to be identical (x). Lastly, the spillover effects of two small countries' shocks on the ROW are assumed to be identical (y). x and y are solved to yield eigenvalues equal to those of A. We conduct our model simulations with the symmetrized matrix B.

A.2 Calculating Import Shares

We follow BKK and Zimmermann (1997) in calibrating the Armington aggegator parameters ω_{ij} as a simple function of the steady-state import shares of GDP under free trade. (We normalize the terms of trade to equal one in the steady-state). For example,

$$\omega_{1j} = \left(\frac{a_j}{y_j}\right)^{1+\rho} \tag{19}$$

In calculating the import shares, e.g. $\frac{a_j}{y_j}$, for each trading partner of each of the three countries is complicated by the fact that imports by ROW countries from other ROW countries are in our framework redundant or internal trade, and need to be subtracted from the raw numbers. For each country, the import share of GDP (with ROW imports appropriately adjusted) is divided among the two other countries according to their share in the country's imports from these two countries. Imports from the own country are defined as 1- import share of GDP (again, with ROW imports appropriately adjusted).

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Figure 1: International Trade and Comovement, Symmetric Version of Model

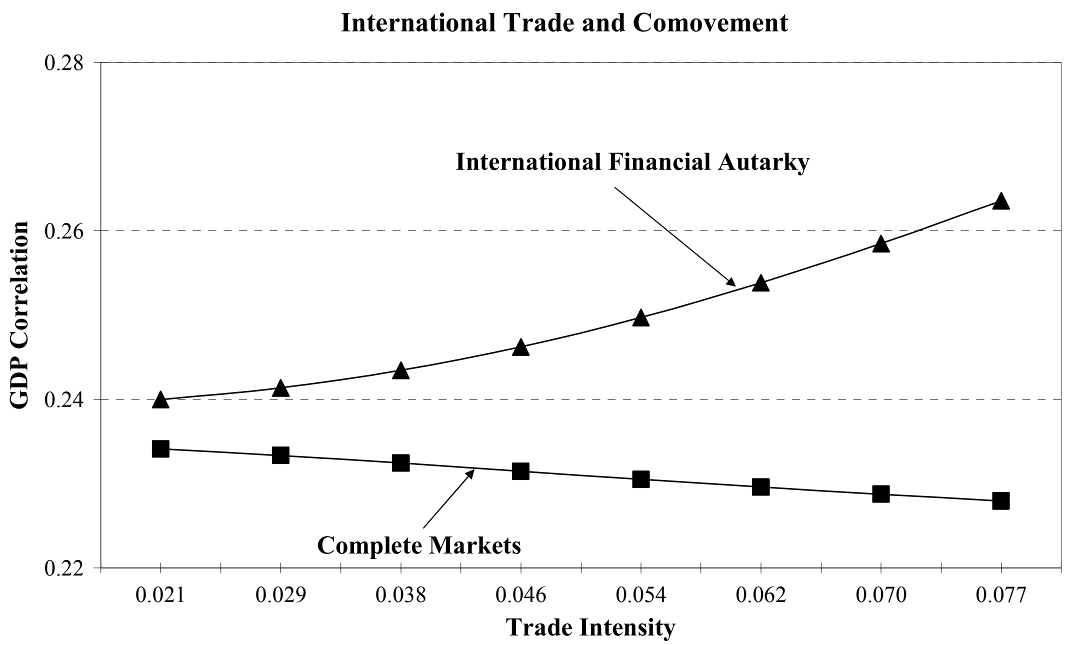


Figure 2: Impulse Response to Productivity Shock in Country 1, International Financial Autarky

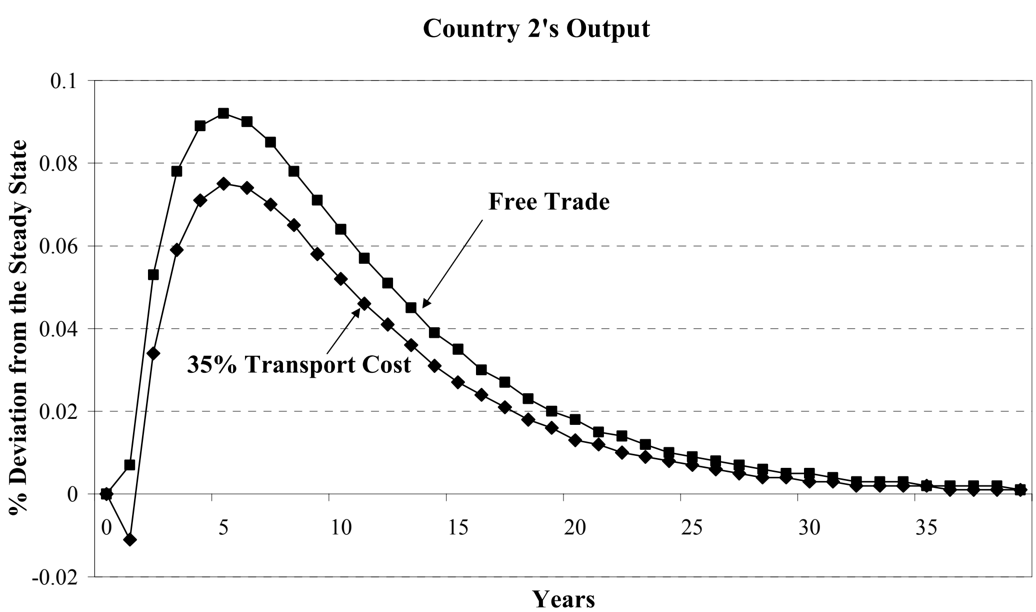


Figure 3: Impulse Response to Productivity Shock in Country 1, International Financial Autarky, High Elasticity Case (3)

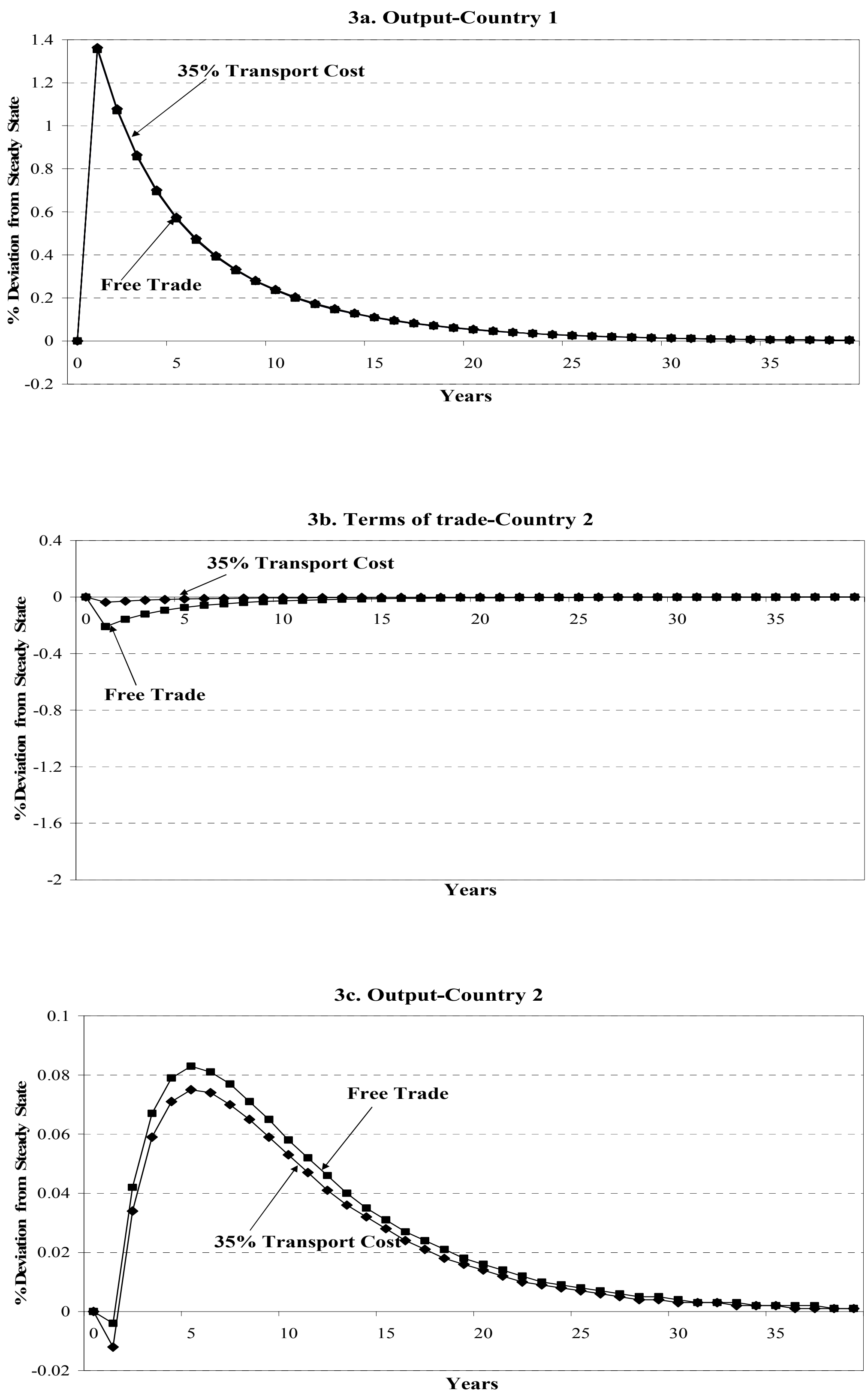
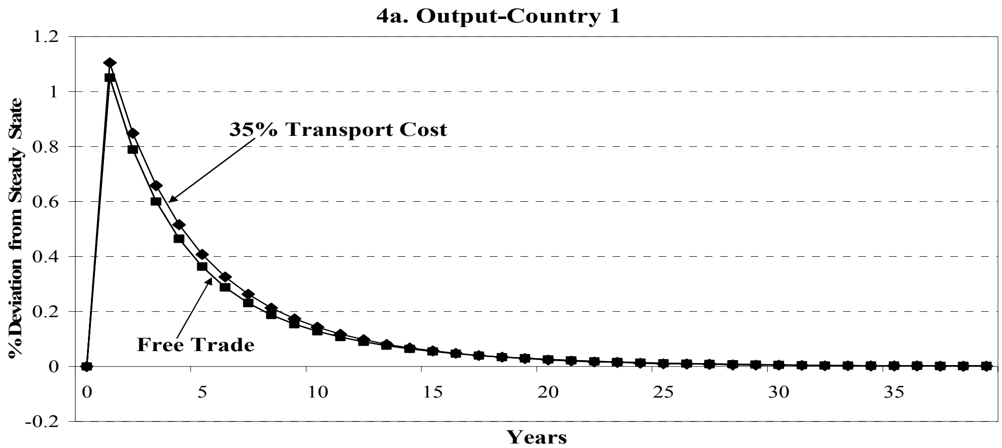
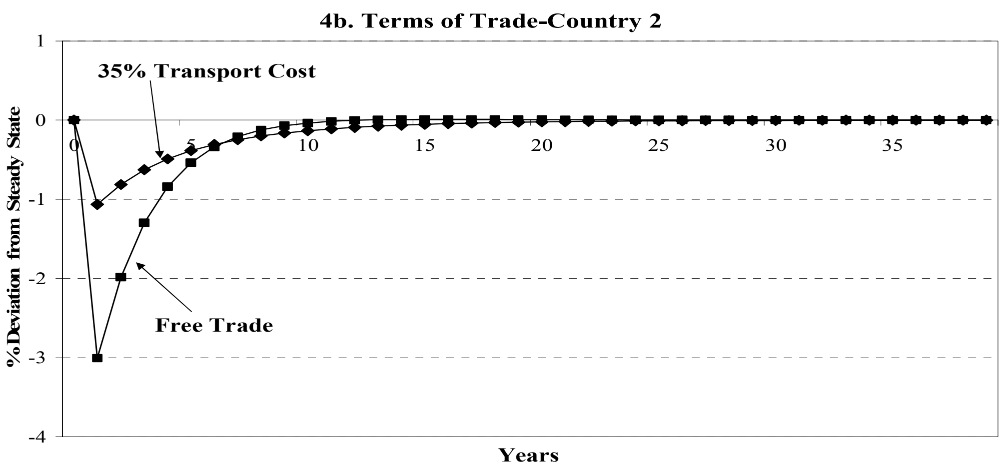


Figure 4: Impulse Response to Productivity Shock in Country 1, International Financial Autarky, Low Elasticity Case (0.5)





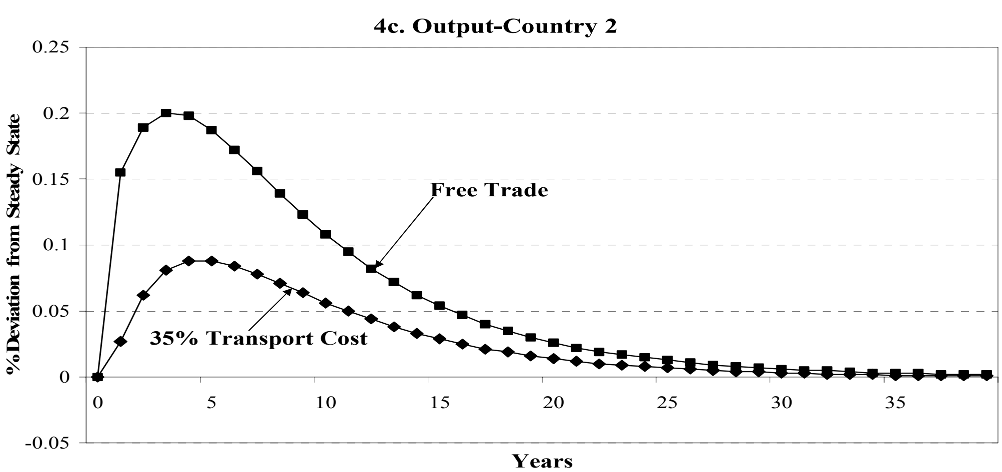


TABLE 1
EMPIRICAL LINK BETWEEN TRADE AND BUSINESS CYCLE COMOVEMENT

1a. Descriptive Statistics

	Bilateral Trade Intensity	HP-filtered GDP correlation	Log first-differenced GDP correlation
Median	0.0023	0.42	0.34
Minimum	0.0002	-0.57	-0.32
Maximum	0.0727	0.93	0.83
Standard deviation	0.0098	0.35	0.22

1b. Estimation Results (Updated Frankel-Rose Regressions)

	Coefficient on Trade Intensity
HP-filtered GDP	0.091 (.022)
Log first-differenced GDP	0.078 (.014)

1c. Trade and Comovement Properties of Benchmark Country Pairs

Country Pair	Bilateral Trade Intensity	HP-filtered GDP correlation	Log first-differenced GDP correlation
Belgium-US	0.0019	0.403	0.359
Australia-Belgium	0.0015	0.442	0.363
Finland-Portugal	0.0017	0.452	0.377
France-U.S.	0.0040	0.434	0.363

Note: Annual GDP and trade data for 21 OECD countries, 1970-2000, is from IMF's International Financial Statistics and Direction of Trade Statistics. Bilateral trade intensity is sum of imports divided by sum of GDPs, averaged over 1970-2000. GMM estimation of GDP correlation on a constant and log of trade intensity. Standard errors in parentheses. Instrumental variables for trade intensity are log of distance, adjacency dummy, and common language, and are obtained from Andrew Rose's web site: http://faculty.haas.berkeley.edu/arose/RecRes.htm

TABLE 2
EFFECTS OF TRADE ON BUSINESS CYCLE CO-MOVEMENT
SYMMETRIC VERSION OF MODEL

Country-Pair	Transport Costs	Trade Intensity	GDP Correlation	Increase in correlation	Implied Slope
Experiment 1: Baseline					
1 and 2	35%	0.021	0.240		
	0%	0.077	0.264	**0.0236**	**0.0179**
Experiment 2: High Import Share — **Same as Experiment 1 with import share=0.3**					
1 and 2	35%	0.045	0.243		
	0%	0.157	0.295	0.0518	0.0415
Experiment 3: High Elasticity — **Same as Experiment 1 with Armington elasticity=3**					
1 and 2	35%	0.004	0.2372		
	0%	0.079	0.2477	0.0105	0.0034
Experiment 4: Low Elasticity — **Same as Experiment 1 with Armington elasticity=0.9**					
1 and 2	35%	0.041	0.2556		
	0%	0.076	0.2984	0.0428	0.0696
Experiment 5: Asymmetric Country Sizes — **Same as Experiment 1 with (1/6, 1/6, 2/3) country sizes**					
1 and 2	35%	0.010	0.243		
	0%	0.038	0.255	0.013	0.0095
Experiment 6: Asymmetric Country Sizes — **Same as Experiment 5, but vary transport costs between small and large country**					
2 and 3	35%	0.030	0.233		
	0%	0.061	0.259	0.026	0.0367

Note: Implied slope is increase in GDP correlation per unit increase in log of trade intensity
In all experiments transport costs between other country-pairs = 15%

TABLE 3
QUANTITATIVE ASSESSMENT OF EFFECTS OF TRADE ON GDP CO-MOVEMENT

Experiment 1: Baseline

Benchmark Country-Pair		**Transport Costs**	**Trade Intensity**	**GDP Correlation**	**Implied slope**	**Implied Slope / Estimated Slope (percent)**
Belgium	U.S.	35%	0.00046	0.3228		
		0%	0.00435	0.3346	0.0053	5.80%
Australia	Belgium	35%	0.00069	0.1414		
		0%	0.00236	0.1423	0.0007	0.80%
Finland	Portugal	35%	0.00066	0.2804		
		0%	0.00274	0.2814	0.0007	0.76%
France	U.S.	35%	0.00110	0.3515		
		0%	0.00836	0.3578	0.0031	3.43%

Experiment 2: Transport costs between each small country and ROW = 35%

Benchmark Country-Pair		**Transport Costs**	**Trade Intensity**	**GDP Correlation**	**Implied slope**	**Implied Slope / Estimated Slope (percent)**
Belgium	U.S.	35%	0.00044	0.3172		
		0%	0.00497	0.3339	0.0069	7.57%
Australia	Belgium	35%	0.00077	0.1197		
		0%	0.00263	0.1208	0.0009	1.00%
Finland	Portugal	35%	0.00073	0.2695		
		0%	0.00297	0.2706	0.0008	0.86%
France	U.S.	35%	0.00130	0.3478		
		0%	0.00906	0.3543	0.0034	3.69%

Experiment 3: Low Elasticity (0.9)

Benchmark Country-Pair		**Transport Costs**	**Trade Intensity**	**GDP Correlation**	**Implied slope**	**Implied Slope / Estimated Slope (percent)**
Belgium	U.S.	35%	0.00100	0.3645		
		0%	0.00411	0.3830	0.0131	14.39%
Australia	Belgium	35%	0.00130	0.1942		
		0%	0.00222	0.1952	0.0019	2.12%
Finland	Portugal	35%	0.00130	0.2959		
		0%	0.00262	0.2970	0.0015	1.64%
France	U.S.	35%	0.00244	0.3734		
		0%	0.00802	0.3857	0.0103	11.35%

Note: Implied slope is increase in GDP correlation per unit increase in log of trade intensity

TABLE 4
FURTHER RESULTS

Experiment 4: Vary all three pairs of transport costs simultaneously

Benchmark Country-Pair		Transport Costs	Trade Intensity	GDP Correlation	Implied slope	Implied Slope / Estimated Slope (percent)
Belgium	U.S.	35%	0.00044	0.3172		
		0%	0.00410	0.3348	0.0079	8.67%
Australia	Belgium	35%	0.00077	0.1197		
		0%	0.00223	0.1579	0.0360	39.57%
Finland	Portugal	35%	0.00073	0.2695		
		0%	0.00263	0.2927	0.0182	19.98%
France	U.S.	35%	0.00130	0.3478		
		0%	0.00800	0.3606	0.0070	7.70%

Experiment 5: Vary transport costs between each small country and ROW

Benchmark Country-Pair		Transport Costs	Trade Intensity	GDP Correlation	Increase in Correlation
Belgium	U.S.	35%	0.00128	0.3180	
		0%	0.00137	0.3262	0.0082
Australia	Belgium	35%	0.00192	0.1202	
		0%	0.00162	0.1575	0.0373
Finland	Portugal	35%	0.00203	0.2700	
		0%	0.00176	0.2922	0.0222
France	U.S.	35%	0.00342	0.3488	
		0%	0.00363	0.3558	0.0071

APPENDIX TABLE 1
ESTIMATED PRODUCTIVITY SHOCK PROCESS AND IMPORT SHARES

Belgium U.S.

A Matrix (Matrix of AR1 Productivity Shocks)

	Belgium	U.S.	ROW
Belgium	0.513	0.352	0.074
U.S.	-0.168	0.823	-0.464
ROW	-0.252	0.197	0.771

Symmetric A Matrix

	Belgium	U.S.	ROW
Belgium	0.668	-0.191	0.074
U.S.	-0.191	0.668	0.074
ROW	-1.232	-1.232	0.771

Standard Deviation of Residuals

	Belgium	U.S.	ROW
	0.016	0.018	0.011

Correlation of Residuals

	Belgium	U.S.	ROW
Belgium			
U.S.	0.368		
ROW	0.577	0.684	

Matrix of Import Shares

To \ From	Belgium	U.S.	ROW
Belgium	0.359	0.047	0.594
U.S.	0.002	0.899	0.099
ROW	0.024	0.074	0.901

Australia Belgium

A Matrix (Matrix of AR1 Productivity Shocks)

	Australia	Belgium	ROW
Austral.	0.731	-0.143	-0.317
Belgium	0.197	0.436	0.421
ROW	0.108	-0.303	0.783

Symmetric A Matrix

	Australia	Belgium	ROW
Austral.	0.584	-0.168	-0.317
Belgium	-0.168	0.584	-0.317
ROW	0.310	0.310	0.783

Standard Deviation of Residuals

	Australia	Belgium	ROW
	0.018	0.016	0.013

Correlation of Residuals

	Australia	Belgium	ROW
Austral.			
Belgium	0.248		
ROW	0.461	0.516	

Matrix of Import Shares

To \ From	Australia	Belgium	ROW
Austral.	0.830	0.002	0.168
Belgium	0.003	0.359	0.638
ROW	0.014	0.047	0.940

Finland Portugal

A Matrix (Matrix of AR1 Productivity Shocks)

	Finland	Portugal	ROW
Finland	0.669	-0.189	0.396
Portugal	-0.244	0.562	1.018
ROW	-0.071	-0.133	0.829

Symmetric A Matrix

	Finland	Portugal	ROW
Finland	0.615	-0.196	0.396
Portugal	-0.196	0.615	0.396
ROW	-0.193	-0.193	0.829

Standard Deviation of Residuals

	Finland	Portugal	ROW
	0.031	0.029	0.013

Correlation of Residuals

	Finland	Portugal	ROW
Finland			
Portugal	0.125		
ROW	0.339	0.496	

Matrix of Import Shares

To \ From	Finland	Portugal	ROW
Finland	0.721	0.003	0.277
Portugal	0.002	0.649	0.349
ROW	0.035	0.019	0.946

France U.S.

A Matrix (Matrix of AR1 Productivity Shock

	France	U.S.	ROW
France	0.581	0.241	0.020
U.S.	-0.296	0.762	-0.293
ROW	0.025	0.268	0.432

Symmetric A Matrix

	France	U.S.	ROW
France	0.672	0.194	0.020
U.S.	0.194	0.672	0.020
ROW	-4.552	-4.552	0.432

Standard Deviation of Residuals

	France	U.S.	ROW
	0.012	0.018	0.012

Correlation of Residuals

	France	U.S.	ROW
France			
U.S.	0.438		
ROW	0.670	0.694	

Matrix of Import Shares

To \ From	France	U.S.	ROW
France	0.792	0.022	0.186
U.S.	0.004	0.899	0.097
ROW	0.038	0.072	0.890

Note: Data sources include Penn World Tables, version 6.0; and the IMF's Direction of Trade Statistics