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RELATION BETWEEN TRADE AND COMOVEMENT?**

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Can the Standard International Business Cycle Model Explain the Relation Between Trade and Comovement?

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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 both asset market structures the model can generate stronger correlations for pairs of countries that trade more, but the increased correlation falls far short of the empirical findings. Even when we control for the fact that most country pairs are small with respect to the rest of the world, the model continues to fall short. We also conduct additional simulations that allow for increased trade with the third country or increased TFP shock comovement to affect the country pair's business cycle comovement. These simulations are helpful in highlighting channels that could narrow the gap between the empirical findings and the predictions of the model.

JEL Classification code: F4

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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), Baxter and Kouparitsas (2004), 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 doubling of the median (across all country pairs) bilateral trade intensity is associated with an increase in the country pair's GDP correlation of about 0.06. These empirical results are all statistically significant, and they suggest that increased international trade may lead 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

¹Anderson, 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) and Imbs (2004) find that international trade plays a relatively moderate role in transmitting business cycles across countries.

²FR, p. 1015-1016. While several papers (which we cite in fn. 12) have looked at the relationship between trade and business cycle comovement, their focus was not on explaining the recent cross-sectional empirical research.

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. 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 inappropriate 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 (2003) 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 "country pair"), and the third country is calibrated to the other 19 countries, taken together (the "rest of the world"). We choose four country pairs, all of which are close to the median bilateral trade

intensity and GDP correlation. We solve and simulate our model under a variety of transport costs between the two small countries. Following the empirical research, we compute the change in GDP correlation per unit change in the log of bilateral trade intensity. We find that under either set of market structures, the model can match the empirical findings qualitatively, but it falls far short quantitatively. In our baseline experiment, the model explains at most 1/10 of the responsiveness of GDP comovement to trade intensity found in our updated FR regressions.

A key reason for the model’s weak performance is that the trade intensity for each of our benchmark country pairs is small to begin with. A typical country does not trade much with any other country: the median trade intensity in our sample is 0.0023, or approximately 1/4 of one percent of GDP. For trade intensities close to the median, a doubling or tripling is not a large increase in level terms. Moreover, we perform simulations indicating that what matters for the model is the change in trade intensity levels, not logs. Consequently, we re-estimate the FR regressions using trade intensity levels. We also compute the responsiveness of GDP comovement to trade intensity levels implied by our model and compare it to the new coefficient estimates. Now the model performs better. For the best benchmark country pair, the model implies that a one-percentage-point increase in trade intensity (roughly 1 percent of GDP) would increase their GDP correlation by about 0.036, which is more than 1/4 of the empirical findings. Nevertheless, for the other country pairs the model continues to fall short by more than an order of magnitude.

While the model performs even better when we employ a lower Armington elasticity of substitution, there is still a sufficient gap between the model and the empirical findings that it is suggestive of a trade-comovement puzzle. This puzzle would be 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. Our trade-comovement puzzle 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 puzzle is about a “slope.”

We conduct two further experiments that might help explain the gap between the model and the empirical findings. In one experiment, we vary all transport costs, not just those between the country pair, but we attribute all of the correlation changes to changes in the country pair’s bilateral trade. This experiment yields a slope that is closer to, and in some cases, exceeds, the

empirically estimated slopes. We also find that the empirical association between trade and total factor productivity (TFP) comovement is almost as strong as the association between trade and GDP comovement. We conduct an experiment in which as we vary transport costs and trade, the correlation of TFP shocks changes in a way that is consistent with our regressions. Now there are two channels affecting GDP correlation: the pure trade channel and an indirect channel operating through TFP comovement. Not surprisingly, the model does a much better job in this experiment. Both of our experiments provide guidance for future empirical and modeling work on resolving this puzzle.

In Section 2, we update the Frankel-Rose regressions to study the empirical relationship between trade and business cycle comovement. Next, we describe our three-country model and its parameterization. Our quantitative assessment of the model is conducted in section 4. Section 5 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 (hereafter “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 comovement, Hodrick-Prescott (HP) filtered and (log) first-differenced correlations of real GDP between the two countries. Summary statistics of the trade and comovement data are presented in Table 1a, and the data for HP-filtered GDP are illustrated in Figure 1. While the data look “cloudy,” there is also a fairly clear positive slope.³

We estimate two (cross-section) regressions. In the first, we follow FR by running instrumental variables (IV) estimation on the log of trade intensity:

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

where i and j denote the two countries. In the second, we run the regression on the levels of $Trade_{ij}$:

$$Corr_{ij} = \beta_0 + \beta_1 Trade_{ij} + \epsilon_{ij} \quad (2)$$

³Baxter and Kouparitsas (2004) produce a similar figure using data from developed and developing countries.

As mentioned in the introduction, the regressions using the log of trade intensity imply that an increase in a country pair’s trade intensity from 0.002 to 0.004 is associated with the same change in its GDP correlation as an increase in its trade intensity from 0.02 to 0.04. This would appear to be counterfactual, which motivates our second regression, in which trade intensity is measured in level terms. We employ a GMM instrumental variables 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 consistent with those in the empirical literature. In the logs regression, the slope coefficient estimate implies that a country pair with twice the trade intensity as another country pair will have a 0.063 (HP-filtered GDP) or 0.054 (log first-differenced GDP) higher GDP correlation, all else equal. FR’s estimates with HP-filtered GDP imply that a doubling of trade intensity is associated with a 0.033 higher GDP correlation. The slope coefficient from our levels regression implies that a doubling of the median trade intensity, i.e., an increase of 0.0023, is associated with an increase in GDP correlation of about 0.029 (HP-filtered GDP) or 0.026 (log first-differenced GDP). Note that these numbers are about half as large as what is implied from the logs regression. We also examined two other measures of trade intensity, the sum of each country’s imports from each other divided by the sum of their total imports, and bilateral imports divided by total imports of the smaller of the two countries. The results are very similar to those obtained with our benchmark measure of trade intensity.⁴

3 The Model

Our model extends the basic two-country, free trade, complete market BKK (1994) framework by having three countries and transportation costs and by allowing for international financial autarky (zero international asset markets).⁵ We first describe the preferences and technology. Then, we

⁴The motivation for the second measure comes from the idea that a high GDP correlation seems to arise from a large bilateral trade share (of total trade) by the smaller of the two countries. For the first measure and for the HP-filtered data (the first-differenced results are very similar), a doubling of the median trade intensity is associated with an increase in GDP correlation of 0.08 (logs) and 0.035 (levels). For the second measure, a doubling of the median trade intensity is associated with an increase in GDP correlation of 0.08 (logs) and 0.051 (levels).

⁵Heathcote 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 (1999), all examine the effects of transport costs; and Zimmermann (1997) employs a three-country model. To our knowledge, no previous paper has

describe the characteristics of the asset markets. Unless stated otherwise, 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:

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

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 sector that produces a traded intermediate good and a sector that produces a non-traded final good. Each country is completely specialized in producing an intermediate good. We suppress time subscripts except where necessary.

The Intermediate Goods Sector

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

$$y_i = z_i k_i^\theta n_i^{1-\theta}, \quad 0 < \theta < 1; \quad i = 1, 2, 3 \quad (4)$$

where y_i denotes (per capita) intermediate good production in country i ; z_i is the productivity shock; k_i is capital input. θ denotes capital's share in output. Firms in this sector rent capital and hire labor in order to maximize profits, period by period:

$$\max_{k_i, n_i} p_i y_i - r_i k_i - w_i n_i \quad (5)$$

$$\text{subject to } k_i, n_i \geq 0; \quad i = 1, 2, 3$$

where w_i (r_i) is the wage (rental rate), and p_i is the f.o.b. or factory gate price of the intermediate good produced in country i .

included all three features.

The market clearing condition in each period for the intermediate goods producing firms in country i is:

$$\sum_{j=1}^3 \pi_j y_{ij} = \pi_i y_i \quad (6)$$

where π_i is the number of households in country i , and determines country size. y_{ij} denotes the quantity of intermediates produced in country i and shipped to each agent in country j .

The total number of households in the world is normalized to 1:

$$\sum_{i=1}^3 \pi_i = 1 \quad (7)$$

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 i exports y_{ij} units to country j , $g_{ij}(y_{ij})^2$ units are lost in transit, where g_{ij} is the transport cost parameter for country i 's exports to country j . That is, only:

$$(1 - g_{ij}y_{ij})y_{ij} \equiv m_{ij} \quad (8)$$

units are imported by country j . We think of $g_{ij}y_{ij}$ 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 y_{ij} . Below, we discuss our transport technology further.

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. To be more specific, the final goods production function in country j is given by:

$$F(y_{1j}, y_{2j}, y_{3j}) = \left[\sum_{i=1}^3 \omega_{ij} [(1 - g_{ij}y_{ij})y_{ij}]^{1-\alpha} \right]^{1/(1-\alpha)} \quad (9)$$

$$= \left[\sum_{i=1}^3 \omega_{ij} m_{ij}^{1-\alpha} \right]^{1/(1-\alpha)} \quad (10)$$

$$\omega_{1j}, \omega_{2j}, \omega_{3j} \geq 0; \quad \alpha \geq 0; \quad j = 1, 2, 3$$

where ω_{1j} denotes the Armington weight applied to the intermediate good produced by country 1 and imported by country j (m_{1j}). We assume that $g_{ii} = 0$ and that $g_{ij}y_{ij} = g_{ji}y_{ji}$. In other words, there is no cost associated with intra-country trade, i.e., $m_{22} = y_{22}$, and iceberg transport costs between two countries do not depend on the origin of the goods. $1/\alpha$ is the elasticity of substitution between the inputs.

Final goods producing firms in each country j maximize profits, period by period :

$$\max_{m_{1j}, m_{2j}, m_{3j}} q_j \left[\sum_{i=1}^3 \omega_{ij} m_{ij}^{1-\alpha} \right]^{1/(1-\alpha)} - p_{1j}m_{1j} - p_{2j}m_{2j} - p_{3j}m_{3j} \quad (11)$$

where q_j is the price of the final good produced by country j , and p_{ij} is the c.i.f. (cost, insurance, and freight) price of country i 's good imported by country j . Note that $p_{jj} = p_j$. The non-traded good in country 1 is the numeraire good; hence, $q_1 = 1$.

As in Ravn and Mazzenga (1999), we can use the first order conditions from 11 to calculate the price of an imported good i relative to j 's own good:

$$\frac{p_{ij}}{p_j} = \frac{\omega_{ij}}{\omega_{jj}} \left(\frac{y_{jj}}{m_{ij}} \right)^\alpha \quad (12)$$

Also, because $\partial F/\partial y_{ij} = (\partial F/\partial m_{ij})(1 - 2g_{ij}y_{ij})$, we know that:

$$p_i = (1 - 2g_{ij}y_{ij})p_{ij} \quad (13)$$

Comparing 8 and 13, it is easy to see that the c.i.f. price multiplied by imports exceeds the f.o.b. price multiplied by exports:

$$p_{ij}m_{ij} - p_i y_{ij} = p_{ij}(1 - g_{ij}y_{ij})y_{ij} - p_i y_{ij} = y_{ij}(p_{ij}(1 - g_{ij}y_{ij}) - p_i) > 0 \quad (14)$$

In other words, if we think of the transportation costs as arising from transportation services provided to ship goods between countries, with the quadratic costs arising because the transportation “technology” is decreasing returns to scale, then, in a perfect competition setting, there are positive profits. That is, the firms providing the transportation services pay the exporting firm the factory gate or f.o.b. price of the good, and then receive the c.i.f. price from the final goods firm in the importing country. We think of a single representative shipping firm that chooses y_{ij} to maximize the leftmost expression of 14. We assume that households in the exporting country own this firm, whose profits are distributed as dividends to the households.

Capital is accumulated in the standard way:

$$k_{jt+1} = (1 - \delta)k_{jt} + x_{jt}, \quad j = 1, 2, 3 \quad (15)$$

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

$$c_{jt} + x_{jt} = F(y_{1jt}, y_{2jt}, y_{3jt}), \quad j = 1, 2, 3 \quad (16)$$

3.3 Asset Markets

We consider two asset market structures, (international) financial autarky and complete markets. Under financial autarky, there is no asset trade; hence, trade is balanced period by period. As mentioned above, Heathcote and Perri (2002) have shown that international business cycle models with financial autarky yield a closer fit to some key business cycle moments than the same models under complete markets. Also, financial autarky is the natural “other extreme” relative to complete markets.⁶ The following budget constraint must hold in each period:

$$q_{it}(c_{it} + x_{it}) - r_{it}k_{it} - w_{it}n_{it} - R_{it} = 0, \quad \forall t = 0, \dots, \infty; \quad i = 1, 2, 3 \quad (17)$$

where R_{it} is profits that the transportation firms distribute as dividends to the household ($= \sum_{j=1}^2 (p_{ijt}m_{ijt} - p_{it}y_{ijt})$). In addition to dividends, the household obtains income from its labor and from the capital it owns. The household spends its income on consumption and investment goods. The complete markets framework, i.e., complete contingent claims or fully integrated international asset markets, is the usual benchmark. There is a single lifetime budget constraint:

$$E_0 \left[\sum_{t=0}^{\infty} \sum_s q_{ist}(c_{ist} + x_{ist}) \right] = E_0 \left[\sum_{t=0}^{\infty} \sum_s (r_{ist}k_{ist} + w_{ist}n_{ist} + R_{ist}) \right] \quad (18)$$

where the subscript s indexes the state of nature. Households maximize 3 subject to either 17 or 18.

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 6 and 16, are satisfied in every period.*

⁶A third asset structure that is popular involves one-period risk-free bonds. However, recent research by Heathcote and Perri (2002), Baxter and Crucini (1995), and others suggests that, when productivity shocks are stationary, a bond economy typically implies results very similar to those of a complete markets economy.

3.5 Calibration and Solution

Our goal is to quantitatively assess whether our three-country international RBC model can generate the high responsiveness of GDP comovement to bilateral trade intensity found in the data. To tie our simulations as closely as possible to the empirical work in section 2, we view the world as consisting of the 21 OECD countries in our sample. Two of the countries in our model are calibrated to two of the OECD countries (the “country pair”), and the third country of our model is calibrated to an aggregate of the other 19 countries (the “rest of the world” or “ROW”). There are 210 such three-country combinations; we select four combinations to serve as our benchmarks. We focus on country combinations whose bilateral trade intensity and GDP correlation are 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.

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 percent 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 annual interest rate of approximately 4 percent. 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 (hereafter, “Armington elasticity”).

The two key elements of the calibration are the Armington aggregator weights ω_{ij} , and the productivity shocks. For each set of three countries (the designated country pair and the rest of the world), there are nine weights. The weights are set so that when all bilateral transport costs are 15 percent, the model’s deterministic steady state implies import shares equal to the actual import shares, and intermediate goods output equals final goods output in each country. We use 15

percent transport costs because the research of Baier and Bergstrand (2001), Hummels (2001), Yi (2003), and others suggests that in the 1980s and 1990s, transport costs plus tariffs for developed countries were around 7 percent to 15 percent, and because we allow for unmeasured trade frictions, such as border-crossing regulations, as well. We estimate the productivity shocks using the data of the benchmark country pairs and the ROW. We begin by calculating Solow residuals using data 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 AR(1) shock process. Further details about the parameterization of the Armington aggregator weights and the productivity shocks are given in the Appendix and in Appendix Table 1.

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 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.⁷

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

$$\frac{2\left(\frac{\pi_2}{\pi_1}\right)y_{12}}{\left[\left(y_{11} + \left(\frac{\pi_2}{\pi_1}\right)y_{12} + \left(\frac{\pi_3}{\pi_1}\right)y_{13}\right) + p_{12}\left(y_{21} + \left(\frac{\pi_2}{\pi_1}\right)y_{22} + \left(\frac{\pi_3}{\pi_1}\right)y_{23}\right)\right]} \quad (19)$$

where p_{12} is country 1's terms of trade with country 2 (the price of country 2's good in terms of country 1's good).⁸ In the special 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.

⁷In 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 17.

⁸Following 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.

4 Quantitative Assessment of the Effects of Trade on Comovement

For each benchmark country pair, we simulate the model by varying transport costs between the two countries in a range from zero to 35 percent. Each transport cost implies a particular steady-state trade intensity.⁹ Given our benchmark Armington elasticity of 1.5, this range of transport costs generates trade intensities that vary by a factor of four in each of our benchmark country pairs, which is about one standard deviation from the median trade intensity in the data. In level terms, the range in trade intensities generated by free trade and by transport costs of 35 percent is 0.002 for Australia-Belgium (low) and 0.007 for France-U.S. (high). For each transportation cost, we simulate the model 1000 times over 35 years, and then apply the Hodrick-Prescott filter.¹⁰ We calculate the average of the GDP correlations across all simulations.

Comparing across transport costs, we calculate the change in GDP correlation per unit change in steady-state trade intensity. In other words, we undertake the model analogue of the regressions from section 2. The model-generated “slope” is compared against the empirical estimates from section 2.¹¹

⁹An alternative approach to create variation in trade intensities is to vary the Armington aggregator weights holding the transport costs constant. We have a slight preference for our approach as the transport costs can be exogenous variables in our framework, while the Armington aggregator weights are parameters. However, in certain settings, such as complete markets without capital accumulation, Betts and Kehoe (2001) show that these two approaches are equivalent in the sense that for every calibration of non-zero transport costs, there exist Armington weights at zero transport costs that “result in an equivalent model” (p. 26). In practice, there can be a difference between the two approaches. For example, in a setting with two identical countries, financial autarky, and free trade, altering the Armington weights so that the import share declines from 0.30 to 0.15 implies a decrease in the GDP correlation from 0.34 to 0.29. Setting the Armington weights so that the free trade import share is 0.30, and then raising transport costs until the import share falls to 0.15 implies a decrease in the GDP correlation from 0.35 to 0.26. This example suggests that variation of transport costs could generate moderately greater implied slopes than variation of the Armington weights.

¹⁰In an earlier version of this paper (Kose and Yi (2002)), we conducted simulations involving three identical countries. These simulations highlighted the effects of different asset markets, import shares, elasticities of substitution, and country sizes. For some of the simulations, we also used a first difference filter, as in Clark and van Wincoop (2001). The trade-comovement implications were virtually identical to those generated by the HP filter.

¹¹As a reminder, the exercises we undertake are cross-section exercises, not time series exercises. In particular, they are designed to conform to the cross-section regressions of FR and others. For recent time series work on the transmission of business cycles via international trade, see Prasad (2001) and Schmitt-Grohe (1998).

4.1 Main Results

In our baseline experiment, we examine the impact of trade on output comovement under complete markets and financial autarky. We then extend the analysis by lowering the Armington elasticity. Last, we consider two additional transmission channels: 1) allowing for all transport costs, not just transport costs between the two small countries, to change, and 2) allowing for the cross-country correlation of productivity shocks to change as the transport costs change.

Baseline Experiment

In our first and primary set of experiments, we fix the transport costs between each small country and the ROW at 15 percent. We then vary transport costs between the two small countries. Table 2 presents the bilateral trade intensities and GDP correlations under complete asset markets and under international financial autarky for 0 percent and 35 percent transport costs. Consider the complete market results in the top panel of the table. For the Belgium-U.S. country pair, the trade intensity increases by a factor of four, from 0.0013 to 0.005, as transport costs fall from 35 percent to 0. Under complete markets, the GDP correlation rises from 0.323 to 0.329, an increase of 0.006. The implied slope using the log of the trade intensity is 0.0043, which is less than 1/20 of our estimated slope of 0.091 (log case) in Table 1. Consequently, with this benchmark country pair and across these particular transport costs, the model explains only about 5 percent of the estimated slope.

The complete markets results in the top panel also show that for the other benchmark country pairs, even smaller results are obtained. For one country pair, Finland-Portugal, increased trade is associated with essentially no change in GDP correlation. This is due to the two opposing forces that operate under complete markets. On the one hand, 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 comovement. Second, there is a “trade-magnification” force: greater trade linkages leads to greater business cycle comovement because, loosely speaking, of the usual supply and demand linkages mentioned previously. From the tables we can infer that for the Finland-Portugal case, the two forces essentially cancel.¹²

¹²Our finding that the model with complete asset markets can produce essentially no 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 including BKK (1992), Zimmermann (1997), Kose and Yi (2001, 2002), and Mazzenga and Ravn (2002). On the other hand, see Head (2002) for an international business cycle model based on monopolistic

Under financial autarky, the resource-shifting channel cannot operate, so the only force at work is the trade-magnification force discussed above. Consequently, it is natural to suppose that the model-implied slopes would be closer to the estimated slope. This is the case, as the right-hand side of the top panel of Table 2 shows. For the Belgium-U.S. country pair, for example, the GDP correlation rises from 0.3113 to 0.3247 as transport costs fall from 35 percent to 0, an increase of 0.0134. This increase is more than double the increase in the complete market case. The implied slope, again using the log of the trade intensity, is 0.0098, which is slightly more than 1/10 of our estimated slope. The implied slopes for the other three country pairs are all smaller than the Belgium-U.S. slope. Relative to complete markets, the France-U.S. country pair showed the greatest increase; the implied slope is about 5.6 percent of our estimated slope, which is 10 times higher than under complete markets. Hence, while financial autarky does generate higher implied slopes than complete markets, the model is still off by an order of magnitude or more.¹³

While the primary goal of this section is to provide a quantitative assessment of the model, we believe it is useful at this point to provide a more thorough intuition on how the trade-magnification force works, especially because this is the force that generates greater comovement through increased trade.¹⁴ One country's GDP is correlated with another's to the extent that its TFP, capital, and labor are correlated with the other country's TFP, capital, and labor. Capital is essentially fixed in the short run. The TFP processes are exogenous and remain unchanged in our baseline experiment. Consequently, the increase in GDP correlation due to lower transport costs must stem primarily from increases in the two countries' employment correlation.

The employment correlation, in turn, is driven by TFP shocks. Consider a pair of countries. A positive TFP shock to one country, "One," will raise output of One's intermediate good. Output of the intermediate good rises further because employment in One rises. In addition, the relative price of One's intermediate good falls, i.e., One's terms of trade increase. This makes labor in the other country, "Two," effectively more productive, thus raising labor demand and employment in Two. It turns out that the decrease in Two's (increase in One's) terms of trade is larger under free trade than under transport costs. Hence, under free trade the employment and output response in Two is larger, leading to greater output comovement with One. Figure 2 illustrates this for a special competition. In this model, under complete markets, lower transport costs lead to higher output comovement.

¹³For both complete markets and financial autarky, we calculated the model's implied slope when transport costs fall from 35 percent to 20 percent, from 20 percent to 10 percent and from 10 percent to 0. The results are essentially the same. For example, for Belgium-U.S. under financial autarky, the slopes are 0.005, 0.014, and 0.023, respectively.

¹⁴We thank one of the referees for suggesting much of the following intuition.

case of our model in which all three countries are identical in size and in which the Armington elasticity is 0.5.¹⁵

The last part of the intuition addresses why Two's terms of trade fall by more under free trade than under transport costs. There are two channels operating. The first channel begins with the idea that world demand for One's good is the sum of One's demand and Two's demand. One's demand is less responsive to changes in prices (steeper demand curve) because any price changes have both a substitution effect and an income effect. A positive TFP shock in One leads to a decline in the price of its good. Demand rises because of substitution effects, but this increase is partially offset by the adverse income effect owing to the worsened terms of trade. Two's demand for One's good, on the other hand, is driven mainly by the substitution effect. This means Two's demand curve is flatter. As the world moves to free trade, Two's share of world demand for One's good increases; this means the overall world demand curve becomes flatter, which would lead to a smaller fall in Two's terms of trade.

The second channel works in the opposite direction. As the world moves toward free trade, the importance of the income effect for One's response to its own productivity shocks rises. This is because the income effect is realized to the extent the country purchases imported goods. One's demand curve becomes steeper; this contributes to a steeper world demand curve, which, all else equal, would lead to a steeper fall in Two's terms of trade (in response to a positive TFP shock in One). Our interpretation of the second panel of Figure 2 is that this second channel dominates the first channel. Summarizing, then, owing to composition of demand effects, the terms of trade response to a positive TFP shock is larger under free trade than under transport costs. This raises the effective marginal product of labor in the other country by more, leading to a greater increase in employment and GDP and, hence, greater GDP comovement.

Returning to the quantitative analysis, a key reason for the small explanatory power of the model is that the trade intensity for each of our benchmark country pairs is small to begin with. A typical country does not trade much with any other country. This implies that a large percentage increase in trade intensity may not be a large increase in trade intensity levels. In the Belgium-U.S. case above, the increase in trade intensity by a factor of four translates into an increase in the

¹⁵We essentially employ a three-country, financial autarky version of the model in Kose and Yi (2001). In particular, the productivity shocks follow a vector AR(1) process with the diagonal elements equal to 0.717, and the off-diagonal elements set to 0.033. The standard deviation of the error term is 0.013, and the error correlations are all 0.255. The Armington weights are set so that the import share of GDP is 0.15 in steady state.

trade intensity level of only 0.0037, or approximately 0.4 percent of GDP. Put differently, while a log trade specification may fit the data well, as mentioned in section 2, it is difficult to see how a model would imply that an increase in trade intensity from 0.002 to 0.004 has the same effect on GDP comovement as an increase in trade intensity from 0.02 to 0.04. Indeed, drawing from the Belgium-U.S. case under financial autarky, the model-implied slopes when transport costs fall from 35 percent to 30 percent, from 20 percent to 15 percent and from 5 percent to 0, are 0.0026, 0.012, and 0.026, respectively. At lower levels of transport costs, trade intensity levels are higher, so a given percentage change in trade intensity translates into a larger absolute change; the fact that the model-implied slope is 10 times higher when transport costs are around 5 percent compared to when they are 35 percent indicates that the model is driven more by level changes, rather than logarithmic changes, in trade intensity.

Hence, to put the model on a better footing, we calculate the change in GDP correlation per unit change in the trade intensity level and compare that against our estimated coefficient on the level of trade intensity. We are, in a sense, controlling for the fact that for country pairs that trade a small amount, large percentage increases in trade do not translate into large level increases. The bottom panel of Table 2 presents the results from the “level” calculations for both complete markets and financial autarky. They show that the explanatory power of the model is indeed greater. For example, with the Belgium-U.S. country pair and under financial autarky, the model-implied slope is 3.6, which is more than 1/4 of the estimated slope of 12.6, and more than double the explanatory power calculated from the log slopes. Based on the logic above, it would be expected that the country pairs with lower trade intensity would show a larger increase in explanatory power than country pairs with higher trade intensity. Indeed, this is the case, as a comparison of Finland-Portugal with France-U.S. illustrates.

Table 2 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, regardless of the market structure and whether the log or level slopes are used. 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 countries’ GDPs.) In general equilibrium, the greater impact on the world economy will eventually be transmitted back to the two countries, generating greater comovement.

Nevertheless, even under financial autarky and using the level slopes, it is still the case that the best country pair, Belgium-U.S., explains less than 30 percent of the estimated slope. For the

other three country pairs, the model still falls short by more than an order of magnitude.

Low Elasticity Experiment

Heathcote and Perri (2002) make a case that the Armington elasticity is less than 1. Lower Armington elasticities make the countries' intermediate goods behave more like complements and less like substitutes, in the Armington aggregator. This would be expected to raise comovement, as well as the responsiveness of comovement to changes in trade intensity. The latter would arise to the extent that lower transport costs lead to larger terms of trade movement in response to a TFP shock. Figure 3 illustrates the impulse response of the terms of trade and country 2's output for the same case as Figure 2, but with a high Armington elasticity, 3. A comparison of the two figures shows that under a low Armington elasticity, the increase in the terms of a trade response to a TFP shock in moving from 35 percent transport costs to free trade is larger than under a high Armington elasticity.

We re-run our primary set of experiments with the elasticity Heathcote and Perri use, 0.9. Table 3 reports the results under complete markets and financial autarky, and computing both log and level slopes. The table shows that using lower Armington elasticities does indeed improve the fit of the model; however, it still falls short for both market structures and even with the levels slopes. Under complete markets, for example, the country pair with an implied levels slope closest to the estimated levels slope is Belgium-U.S., but the model slope is only about 21 percent of the estimated slope. For the other three country pairs, the model is still more than an order of magnitude off. Under financial autarky, the Belgium-U.S. simulation performs considerably better, yielding an implied model levels slope that is 67 percent of the estimated levels slope. This is by far the best fit of all of our simulations. However, again, in the other three country pairs, the model explains 25 percent or less of the empirical estimates.¹⁶

4.2 Two Additional Experiments

Our results suggest that the large gap between the model's predictions and the empirical evidence is certainly suggestive of a *trade-comovement puzzle*. However, in all of our experiments until now, we have focused only on the channels directly linking bilateral trade to bilateral GDP correlations. In

¹⁶While 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 (2003), Obstfeld and Rogoff (2001), and Yi (2003), for example. Hence, with respect to the volume of trade, the low elasticity is counterfactual.

this section, we report on two experiments designed to see if additional channels can help improve the fit to the data. The first experiment examines a scenario in which all transport costs, not just those involving the country pair in question, change. However, we attribute all of the increase in GDP correlation only to trade between the country pair. The second experiment stems from the fact that TFP correlation is closely related to bilateral trade intensity. In this experiment, we allow for the correlation of TFP shocks to change when transport costs change.

All Transport Costs Change

Many of the European countries in our sample share the same trading partners. Also, for almost all countries, the U.S. is an important trading partner. It is possible, then, that the GDP of two small countries is highly correlated because both trade heavily with the U.S. and other countries. This channel would complement the direct bilateral channel. If pairs of countries with higher bilateral trade intensity also tend to trade extensively with common trading partners, then it is possible that the empirical estimates of the effect of trade on GDP correlation suffer from a positive omitted variable bias.¹⁷ We assess the possibility that the empirical estimates are upwardly biased by running simulations in which transport costs between all three countries change simultaneously and by continuing to focus on the relationship between the two small countries' bilateral trade intensity and their 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. 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 country pair's trade intensity).

Table 4 reports our results under financial autarky.¹⁸ The panel shows clearly that when all

¹⁷If there is a bias, one way to rectify this would be to construct a bilateral measure of intensity of trade with common trading partners and to re-estimate equation (1) including this variable in addition to the trade intensity variable. However, it is likely that any such measure would be endogenous and would need to be instrumented for. It is unclear what instruments would be correlated with this measure but uncorrelated with GDP comovement. Among the cross-section and panel empirical papers, to our knowledge only Fidrmuc (2004) attempts to control for common third-party trade. He enters a dummy variable for whether the pair of countries belongs to the EMU. He finds that the EMU countries tend to have higher comovement, all else equal.

¹⁸Under complete markets the responsiveness of GDP correlation to decreases in transport costs is non-monotonic, rising when transport costs are high, but then declining when transport costs are low. We infer that the resource-shifting channel associated with complete markets is more important at lower transport costs. Three of our four benchmark country pairs implied a negative relation between GDP comovement and trade (comparing free trade and 35% transport costs).

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 percent to 0 raises the Australia-Belgium trade intensity from 0.00093 to 0.00248.¹⁹ The lower transport costs raise the GDP correlation from 0.0939 to 0.1645. The implied log slope is 0.0716, which is 79 percent of our estimated slope of 0.091. Hence, compared to the baseline experiment, the explanatory power of the model for this benchmark case has increased 90-fold! In level terms, the model does even better. In fact, now the model does too well. The implied slope of 45.4 is almost four times greater than the estimated slope. Compared to the baseline results, the level slope improvement is also a factor of 90. While the Australia-Belgium case is the extreme case among our four country pairs, the Belgium-U.S. and Finland-Portugal cases also generate level slopes that are 70 percent or more of the estimated slope, and the Belgium-U.S. case generates a log slope that is close to 50 percent of the estimated slope.

Comparing Table 4 with Table 2 also shows that the two benchmark cases with the largest increase in slopes relative to the baseline experiment are the ones in which both countries in the country pair are very small. The two benchmark cases that include the U.S. have considerably less improvement. This is consistent with our previous discussion. For country pairs with very small countries like Australia and Belgium or Finland and Portugal, our results suggest that 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.

We note that from the point of view of the existing empirical research, our experiment was an extreme one, because in our model, all trade is with either the other country in the country pair or with a *common third country*. Our results could be interpreted as the upper bound of what might be estimated in a regression that does not control for this transmission channel. With this caveat, our results suggest that it may be important for the empirical research to control for the intensity of trade with common trading partners.

*TFP Shock Correlation Changes as Transport Costs Change*²⁰

In our baseline experiments, we vary only transport costs and examine its effect on GDP co-

¹⁹This is a smaller increase than in the first experiment but is consistent with the insight from Anderson and VanWincoop (2003) 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.

²⁰We are grateful to one of the referees for suggesting the experiments in this section.

movement. In particular, the correlation of TFP shocks is held fixed. We do this to make our model simulations conform to the conditions underlying the empirical research. Nevertheless, there may be another source of omitted variable bias in that increased trade integration could be associated with increased TFP correlation. Recent evidence from the trade and growth literature certainly supports this idea, at least for data at lower frequencies.²¹ Moreover, our own data support this idea too. We re-run the regressions from section 2, except we replace GDP correlation with TFP correlation. The coefficient in the levels regression is 13.08 (3.03).²² This is actually slightly larger than the estimated coefficient in the GDP correlation regressions.²³ This suggests that increased trade is indeed associated with increased TFP comovement or some force that looks like TFP comovement.

We thus undertake an experiment in which, as transport costs decline, the correlation between the TFP shocks in the two countries increases by an amount consistent with what is predicted by the TFP regressions.²⁴ By doing so, we are essentially comparing pairs of countries that trade heavily with each other and have high TFP shock correlations against countries that trade little with each other and have low TFP shock correlations. Consequently, as in the previous experiment, there are two forces driving comovement: a direct effect from higher trade and an indirect effect resulting from trade’s effect on TFP shock correlations. As before, we also attribute all changes in the GDP correlation to variation in trade intensity.

Table 5 presents the results for “level” slope case. Under both complete markets and financial autarky, the model performs much better. In all cases it explains at least 43 percent of the estimated slopes. Under financial autarky, and for the Belgium-U.S. country pair, the model explains 78 percent of the estimated slope. Comparing these results to the bottom panel of Table 2 shows that including for this indirect TFP correlation channel provides a significant boost in the model’s ability to generate slopes close to those estimated in the data.

Hence, like the experiment considered above, this experiment provides an alternative explanation for why the empirical regressions yield a much greater responsiveness of comovement to trade

²¹See Keller (2004) for a survey of international technology diffusion.

²²The coefficient in the logs regression is 0.089 and the standard error on the coefficient is 0.017.

²³We recognize that the apparent increase in TFP correlation associated with increased trade integration could reflect forces such as variable factor utilization over the cycle. In this case, a more appropriate interpretation of our measures of TFP are Solow residuals, which include both TFP and factor utilization.

²⁴Specifically, the decline in transport costs implies an increase in steady-state trade. That increase in trade is associated with a particular increase in TFP correlation, according to the regression estimates. We adjust the correlation of the TFP shocks to produce that increase in the TFP correlation.

than our baseline exercise. It suggests that both the empirical research and models might want to take this additional channel into account.

5 Conclusion

In this paper we examine whether the standard international business cycle framework can quantitatively replicate the results of recent empirical research that finds a positive association between the extent of bilateral trade and output comovement. We employ 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 is 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 is able to capture the positive relationship between trade and output comovement, but our baseline experiment falls far short of explaining the magnitude of the empirical findings. This is true even when we control for the fact that bilateral trade between countries is typically quite small as a share of GDP and relative to a country's total trade by computing level slopes, as opposed to the log slopes that are typically estimated in the empirical research. 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. In this sense, we have identified a trade-comovement puzzle.

Our trade-comovement puzzle 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.

We conduct two further experiments that might help explain the empirical findings. In one experiment, we vary all transport costs, not just those between the country pair, but we attribute all of the correlation changes to change in the country pair’s bilateral trade. This experiment allows us to obtain a slope that is closer to, and in some cases, exceeds, the estimated slopes. This suggests that the empirical research might benefit from controlling for intensity of third-party trade. In addition, we conduct an experiment in which as transport costs decline, and trade increases, the correlation of TFP shocks increases, as well. With two channels affecting GDP correlation, the pure trade channel and an indirect channel operating through TFP comovement, it is not surprising that the model does a much better job in this experiment. Both of these experiments suggest additional control variables for the empirical research. Our empirical finding that TFP comovement is strongly positively associated with trade suggests a puzzle for model builders, as well. We leave this for future research.

In their empirical work, FR do not control for variables other than bilateral trade intensity. Other researchers, especially Imbs (2004), contend that controlling for sectoral similarity in the regressions leads to smaller coefficients on trade. However, Baxter and Kouparitsas (2004), Calderon, Chong, and Stein (2002), Clark and van Wincoop (2001), and Otto, Voss, and Willard (2001) also control for industrial or sectoral similarity (among other variables) and the coefficients on trade are still statistically significant. An additional empirical finding is that intra-industry trade is more important than inter-industry trade or total trade in driving GDP comovement.²⁵ We would suggest addressing the importance of these sectoral issues from the lens of a dynamic stochastic general equilibrium model. Indeed, there are models that include multiple sectors, including those by Kouparitsas (1998) and Ambler, Cardia, and Zimmermann (2002). Also, Burstein, Kurz, and Tesar (2004) implement a version of a multiple-sector model with production sharing. A further extension would be to replace the Armington aggregator in these models, in which specialization patterns are invariant to changing trade costs, with neoclassical trade theory, in which specialization

²⁵See, for example, Fidrmuc (2004) 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, increased specialization could reduce output comovement.

patterns can endogenously change when trade costs change.

A Appendix: Productivity Shock Process and Import Shares

A.1 Estimating Productivity Shock Process

Our raw data for computing the productivity shocks come 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 an ROW aggregate. The Solow residuals are constructed as follows:

$$Z_{it} = \ln(Y_{it}) - 0.64 \ln(L_{it}) \quad (20)$$

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.

A.2 Calculating Import Shares

We calibrate the Armington aggregator parameters so that under transportation costs of 15 percent the implied steady-state import shares match the actual import shares, and intermediate goods output equals final goods output.²⁶ Specifically, for each set of three countries (the specified country pair and the rest of the world), there are nine aggregator parameters to set. We use two first order conditions from final goods firm j 's maximization problem (six equations in total), where

²⁶In Kose and Yi (2002), we calibrated the aggregator parameters so that the steady-state import shares match the actual import shares under free trade. The results are virtually identical.

the actual import shares enter in the expression in parentheses on the right-hand side below:

$$\left(\frac{p_{ij}}{p_j}\right)^{1-\alpha} = \frac{\omega_{ij}}{\omega_{jj}} \left(\frac{p_j y_{jj}/y_j}{p_{ij} m_{ij}/y_j}\right)^\alpha \quad (21)$$

We also set intermediate goods output equal to final goods output, as in Backus, Kehoe, and Kydland (1992) (three equations), to determine the nine parameters. These nine equations must be solved along with the other steady-state equations of the model.

We follow Zimmermann (1997) by calculating the import shares, e.g. $\frac{p_{ij} m_{ij}}{y_j}$, for each trading partner of each of the three countries. This is complicated by the fact that imports by ROW countries from other ROW countries are redundant or internal trade in our framework and need to be subtracted from the raw imports data. Then, for each country, we divide the import share of GDP (with ROW imports appropriately adjusted) 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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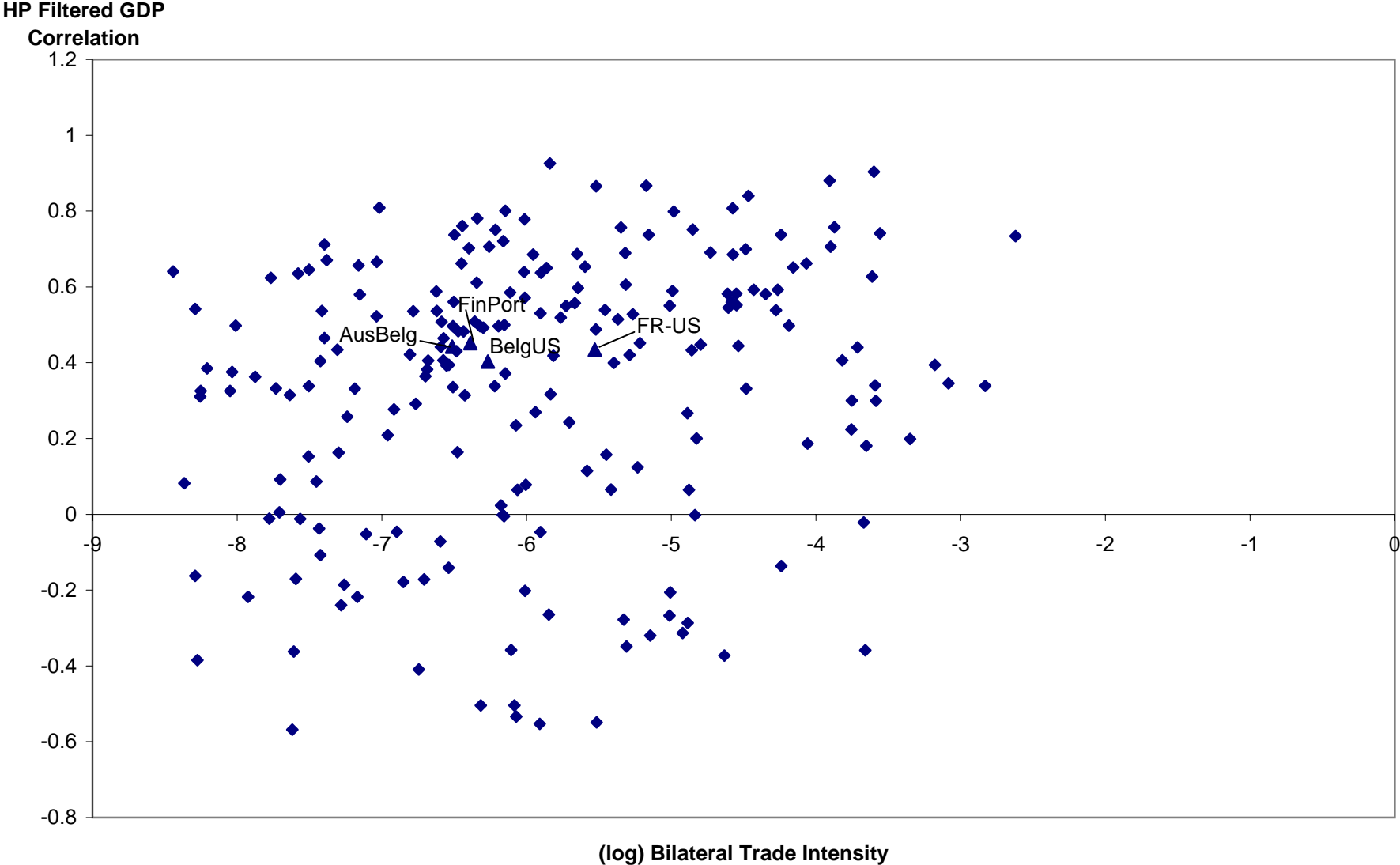
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Figure 1: GDP correlation and Trade Intensity



**Figure 2: Impulse Response to Productivity Shock in Country 1,
International Financial Autarky, Low Elasticity Case (0.5)**

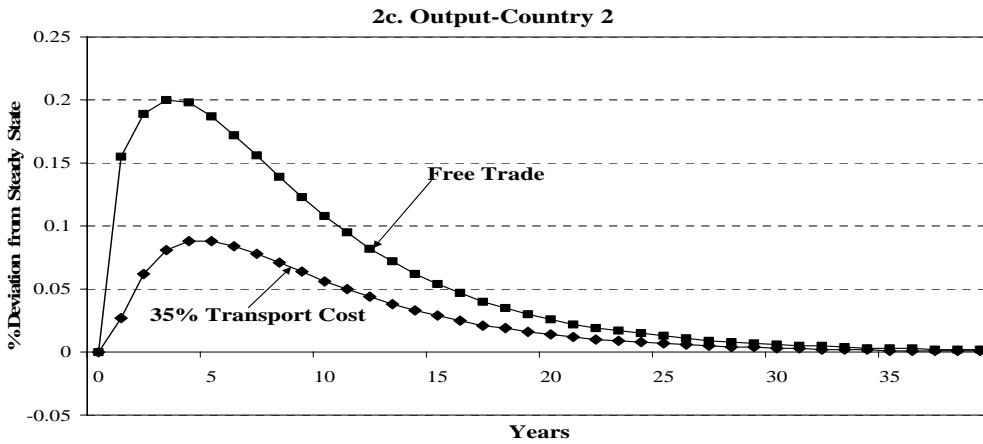
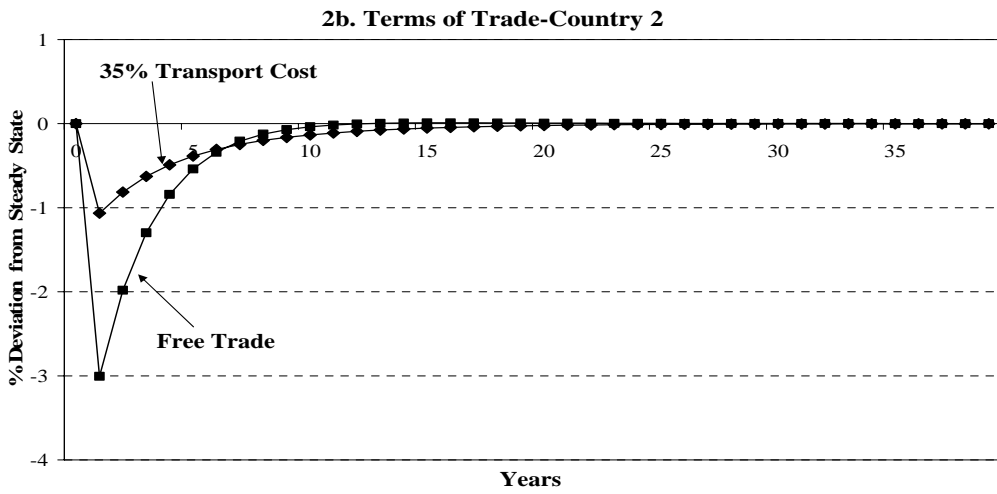
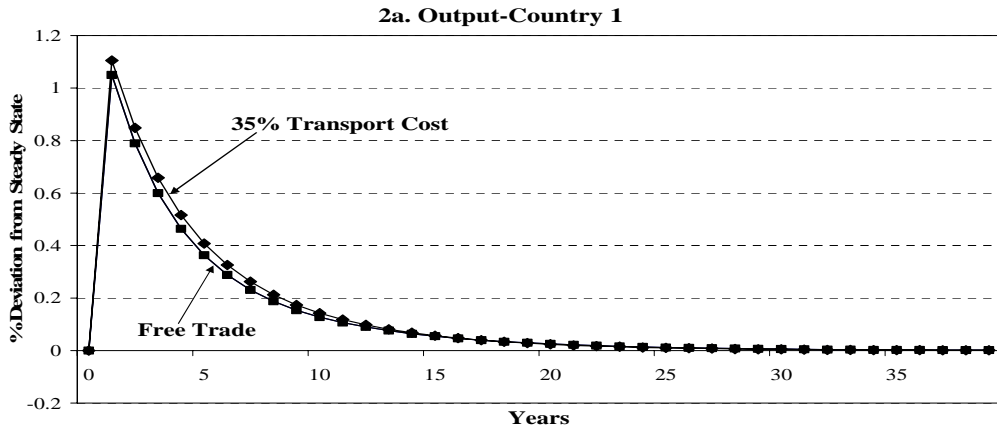


Figure 3: Impulse Response to Productivity Shock in Country 1, International Financial Autarky, High Elasticity Case (3)

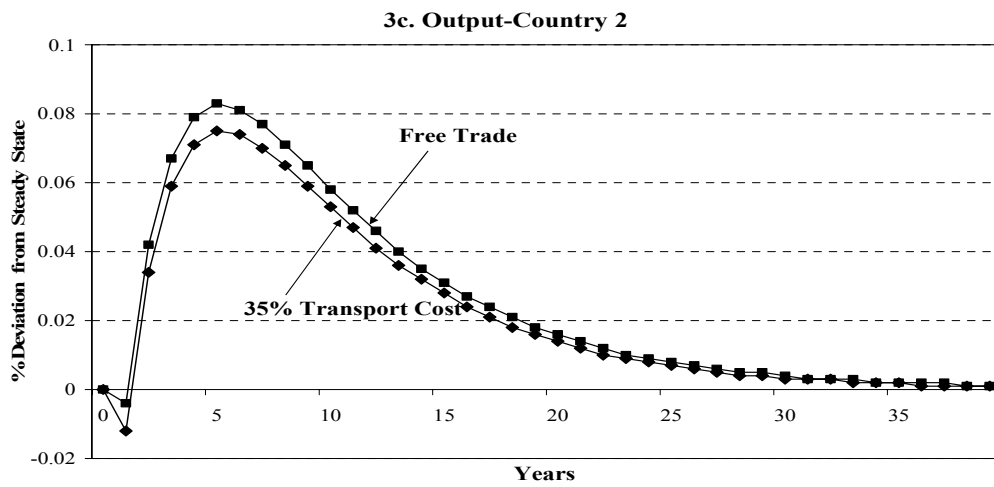
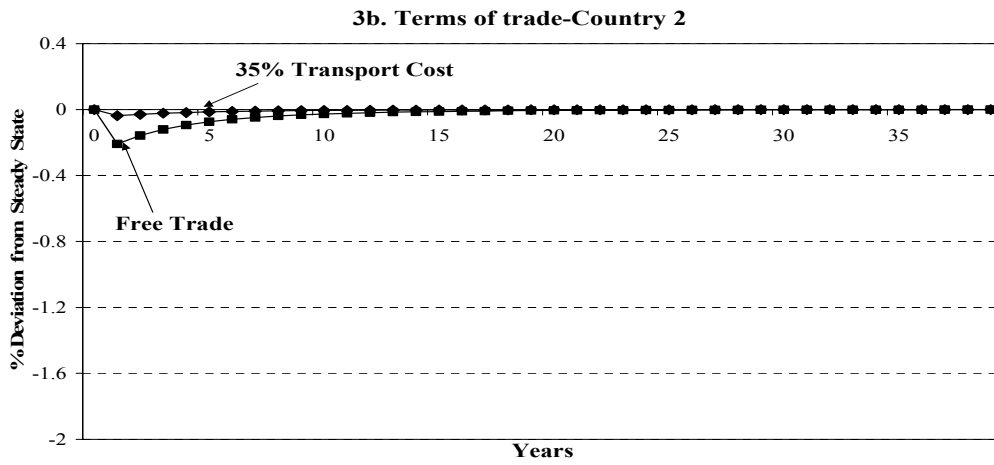
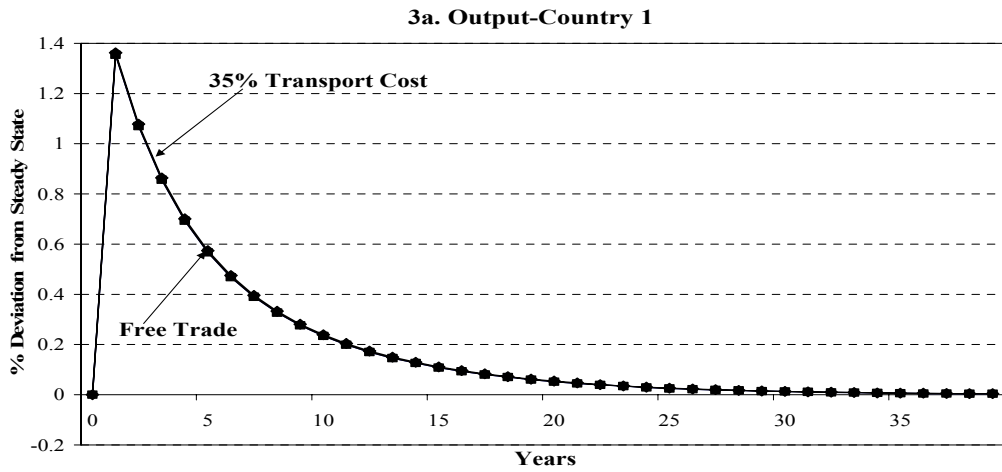


TABLE 1
EMPIRICAL LINK BETWEEN TRADE AND BUSINESS CYCLE COMOVEMENT

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)

	<u>Coefficient on Trade Intensity</u>	
	Logs	Levels
HP-filtered GDP	0.091 (.022)	12.557 (3.760)
Log first-differenced GDP	0.078 (.014)	11.262 (2.859)

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 or level 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
QUANTITATIVE ASSESSMENT OF EFFECTS OF TRADE ON GDP CO-MOVEMENT

Baseline Experiment

Implied slopes based on log of trade intensity

Estimated slope=0.091

Benchmark Country-Pair	Transport Costs	Trade Intensity	COMPLETE MARKETS			FINANCIAL AUTARKY		
			GDP Correlation	Implied slope	Implied slope/ Estimated Slope (percent)	GDP Correlation	Implied slope	Implied slope/ Estimated Slope (percent)
Belgium U.S.	35%	0.00127	0.3235	0.0043	4.7%	0.3113	0.0098	10.8%
	0%	0.00500	0.3294			0.3247		
Australia Belgium	35%	0.00073	0.1450	0.0005	0.5%	0.1339	0.0008	0.9%
	0%	0.00286	0.1456			0.1350		
Finland Portugal	35%	0.00084	0.2506	-4.9E-05	-0.1%	0.2859	0.0008	0.9%
	0%	0.00331	0.2505			0.2870		
France U.S.	35%	0.00249	0.3419	0.0004	0.5%	0.3486	0.0051	5.6%
	0%	0.00974	0.3425			0.3555		

Implied slopes based on level of trade intensity

Estimated slope=12.557

Benchmark Country-Pair	Transport Costs	Trade Intensity	COMPLETE MARKETS			FINANCIAL AUTARKY		
			GDP Correlation	Implied Slope	Implied slope / Estimate Slope (percent)	GDP Correlation	Implied Slope	Implied slope/ Estimated Slope (percent)
Belgium U.S.	35%	0.00127	0.3235	1.576	12.6%	0.3113	3.601	28.7%
	0%	0.00500	0.3294			0.3247		
Australia Belgium	35%	0.00073	0.1450	0.293	2.3%	0.1339	0.527	4.2%
	0%	0.00286	0.1456			0.1350		
Finland Portugal	35%	0.00084	0.2506	-0.027	-0.2%	0.2859	0.441	3.5%
	0%	0.00331	0.2505			0.2870		
France U.S.	35%	0.00249	0.3419	0.079	0.6%	0.3486	0.957	7.6%
	0%	0.00974	0.3425			0.3555		

Note: **Implied slope** in logs (levels) is calculated as change in GDP correlation per unit log (level) change in trade intensity (between 35% and 0% transport costs)

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

Low Elasticity Experiment

LOG Slopes

Estimated slope=0.091

Benchmark Country-Pair	Transport Costs	Trade Intensity	COMPLETE MARKETS			FINANCIAL AUTARKY		
			GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)	GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)
Belgium U.S.	35%	0.00211	0.3607	0.0080	8.8%	0.3513	0.0251	27.5%
	0%	0.00404	0.3658			0.3676		
Australia Belgium	35%	0.00121	0.1886	0.0011	1.2%	0.1852	0.0020	2.2%
	0%	0.00231	0.1893			0.1865		
Finland Portugal	35%	0.00140	0.2881	0.0019	2.0%	0.3056	0.0017	1.8%
	0%	0.00268	0.2893			0.3067		
France U.S.	35%	0.00412	0.3579	0.0038	4.2%	0.3685	0.0164	18.0%
	0%	0.00789	0.3603			0.3792		

LEVEL Slopes

Estimated slope=12.557

Benchmark Country-Pair	Transport Costs	Trade Intensity	COMPLETE MARKETS			FINANCIAL AUTARKY		
			GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)	GDP Correlation	Implied Slope	Implied slope/ Estimated slope (percent)
Belgium U.S.	35%	0.00211	0.3607	2.681	21.4%	0.3513	8.438	67.2%
	0%	0.00404	0.3658			0.3676		
Australia Belgium	35%	0.00121	0.1886	0.642	5.1%	0.1852	1.173	9.3%
	0%	0.00231	0.1893			0.1865		
Finland Portugal	35%	0.00140	0.2881	0.941	7.5%	0.3056	0.841	6.7%
	0%	0.00268	0.2893			0.3067		
France U.S.	35%	0.00412	0.3579	0.652	5.2%	0.3685	2.827	22.5%
	0%	0.00789	0.3603			0.3792		

Note: **Implied slope** in logs (levels) is calculated as change in GDP correlation per unit log (level) change in trade intensity (between 35% and 0% transport costs)

TABLE 4
QUANTITATIVE ASSESSMENT OF EFFECTS OF TRADE ON GDP CO-MOVEMENT
All Transport Costs Change

FINANCIAL AUTARKY				Log Slopes <i>Estimated slope=</i> <i>0.091</i>		Level Slopes <i>Estimated slope=</i> <i>12.557</i>	
Benchmark Country-Pair	Transport Costs	Trade Intensity	GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)	Implied slope	Implied slope/ Estimated slope (percent)
Belgium U.S.	35%	0.00135	0.2833	0.0447	49.1%	16.45	131.0%
	0%	0.00478	0.3396				
Australia Belgium	35%	0.00093	0.0939	0.0716	78.7%	45.40	361.6%
	0%	0.00248	0.1645				
Finland Portugal	35%	0.00101	0.2770	0.0166	18.3%	9.18	73.1%
	0%	0.00297	0.2950				
France U.S.	35%	0.00265	0.3415	0.0178	19.6%	3.36	26.8%
	0%	0.00934	0.3640				

Note: **Implied slope** in logs (levels) is calculated as change in GDP correlation per unit log (level) change in trade intensity

TABLE 5
QUANTITATIVE ASSESSMENT OF EFFECTS OF TRADE ON GDP CO-MOVEMENT
TFP correlations change

COMPLETE MARKETS					Level Slopes <i>Estimated slope=</i> <i>12.557</i>	
Benchmark Country-Pair	Transport Costs	Trade Intensity	GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)	
Belgium U.S.	35%	0.00127	0.3235	7.99	63.6%	
	0%	0.00500	0.3533			
Australia Belgium	35%	0.00073	0.1450	5.39	43.0%	
	0%	0.00286	0.1565			
Finland Portugal	35%	0.00084	0.2506	7.01	55.8%	
	0%	0.00331	0.2679			
France U.S.	35%	0.00249	0.3419	6.64	52.9%	
	0%	0.00974	0.3900			

FINANCIAL AUTARKY					Level Slopes <i>Estimated slope=</i> <i>12.557</i>	
Benchmark Country-Pair	Transport Costs	Trade Intensity	GDP Correlation	Implied slope	Implied slope/ Estimated slope (percent)	
Belgium U.S.	35%	0.00127	0.3113	9.82	78.2%	
	0%	0.00500	0.3479			
Australia Belgium	35%	0.00073	0.1336	5.59	44.5%	
	0%	0.00286	0.1456			
Finland Portugal	35%	0.00084	0.2859	7.30	58.1%	
	0%	0.00331	0.3040			
France U.S.	35%	0.00249	0.3486	7.32	58.3%	
	0%	0.00974	0.4016			

Note: **Implied slope** in logs (levels) is calculated as change in GDP correlation per unit log (level) change in trade intensity

APPENDIX TABLE 1

ESTIMATED PRODUCTIVITY SHOCK PROCESS AND IMPORT SHARES

<u>Belgium U.S.</u>				<u>Australia Belgium</u>				<u>Finland Portugal</u>				<u>France U.S.</u>			
A Matrix (Matrix of AR1 Productivity Shocks)				A Matrix (Matrix of AR1 Productivity Shocks)				A Matrix (Matrix of AR1 Productivity Shocks)				A Matrix (Matrix of AR1 Productivity Shock			
	Belgium	U.S.	ROW		Australia	Belgium	ROW		Finland	Portugal	ROW		France	U.S.	ROW
Belgium	0.513	0.352	0.074	Austral.	0.731	-0.143	-0.317	Finland	0.669	-0.189	0.396	France	0.581	0.241	0.020
U.S.	-0.168	0.823	-0.464	Belgium	0.197	0.436	0.421	Portugal	-0.244	0.562	1.018	U.S.	-0.296	0.762	-0.293
ROW	-0.252	0.197	0.771	ROW	0.108	-0.303	0.783	ROW	-0.071	-0.133	0.829	ROW	0.025	0.268	0.432
Standard Deviation of Residuals				Standard Deviation of Residuals				Standard Deviation of Residuals				Standard Deviation of Residuals			
	Belgium	U.S.	ROW		Australia	Belgium	ROW		Finland	Portugal	ROW		France	U.S.	ROW
	0.016	0.018	0.011		0.018	0.016	0.013		0.031	0.029	0.013		0.012	0.018	0.012
Correlation of Residuals				Correlation of Residuals				Correlation of Residuals				Correlation of Residuals			
	Belgium	U.S.	ROW		Australia	Belgium	ROW		Finland	Portugal	ROW		France	U.S.	ROW
Belgium				Austral.				Finland				France			
U.S.	0.368			Belgium	0.248			Portugal	0.125			U.S.	0.438		
ROW	0.577	0.684		ROW	0.461	0.516		ROW	0.339	0.496		ROW	0.670	0.694	
Matrix of Import Shares				Matrix of Import Shares				Matrix of Import Shares				Matrix of Import Shares			
To \ From	Belgium	U.S.	ROW	To \ From	Australia	Belgium	ROW	To \ From	Finland	Portugal	ROW	To \ From	France	U.S.	ROW
Belgium	0.359	0.047	0.594	Austral.	0.830	0.002	0.168	Finland	0.721	0.003	0.277	France	0.792	0.022	0.186
U.S.	0.002	0.899	0.099	Belgium	0.003	0.359	0.638	Portugal	0.002	0.649	0.349	U.S.	0.004	0.899	0.097
ROW	0.024	0.074	0.901	ROW	0.014	0.047	0.940	ROW	0.035	0.019	0.946	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