Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement*

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Abstract

This paper examines the mechanisms through which bilateral trade linkages affect business cycle comovement using an industry-level panel dataset of manufacturing production and trade. We establish that higher bilateral trade in an individual sector increases both the comovement within the sector between trading countries, as well as the comovement between that sector and the rest of the economy of the trading partner. The estimated magnitudes imply that transmission *across* sectors is responsible for nearly 90% of the total impact of higher bilateral trade on the business cycle correlation. We also demonstrate that vertical linkages in production are an important force behind the overall impact of trade on business cycle synchronization. The elasticity of comovement with respect to bilateral trade is significantly higher in industry pairs that use each other as intermediate inputs in production. Our estimates indicate that vertical production linkages account for some 19% of the total impact of bilateral trade on business cycle correlation.

JEL Classifications: F15, F4

Keywords: Business cycle comovement, trade, industry-level data, vertical linkages

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1 Introduction

By almost any measure, the world economy exhibits ever stronger international linkages. Both trade and capital flows grew dramatically as a share of world GDP over the last few decades. In addition, goods trade has become more vertical, as intermediates in production account for an increasing share of world trade (Hummels, Ishii and Yi 2001). Recent years have also seen newer forms of cross-border economic integration, such as offshoring and outsourcing of different parts of the production chain (Amiti and Wei 2005).

As economic globalization proceeds apace, what can we say about its effects on international business cycles? The seminal paper by Frankel and Rose (1998) established what has become a well-known empirical regularity: country pairs that trade more with each other experience higher business cycle correlation. While the finding has been confirmed by a series of subsequent studies (Clark and van Wincoop 2001, Baxter and Kouparitsas 2005, Calderon, Chong and Stein 2007), the mechanisms underlying this effect are still not well understood. In light of the rapidly changing nature of global trade, understanding these mechanisms is becoming increasingly important for macroeconomic policy. For instance, Tesar (2006) analyzes business cycle synchronization of the EU accession countries in a model of cross-border production sharing.

This paper uses industry-level data on production and trade to examine the importance of various channels through which sectoral trade flows affect the aggregate comovement. In order to do this, we estimate the impact of bilateral trade on comovement within each pair of sectors that constitute the economy. Doing so allows us to probe deeper into the mechanics of the trade-comovement link. First, we establish whether the Frankel-Rose effect holds not just for the aggregate economy but for each pair of individual sectors. Second, we investigate whether vertical linkages across industries can help explain the impact of trade on comovement at the level of an individual pair of sectors. To measure the extent of vertical linkages, we use Input-Output matrices to gauge the intensity with which individual sectors use others as intermediate inputs in production. We then condition the impact of bilateral trade on the strength of bilateral linkages between each pair of sectors.

Our main results can be summarized as follows. First, the Frankel-Rose effect is present at the sector level: sector pairs that experience more bilateral trade exhibit stronger comovement. Second, we find strong evidence that vertical production linkages are important. In sector pairs that use each other heavily as intermediate inputs, a given increase in bilateral trade results in higher comovement. That is, bilateral trade is more important in creating comovement in sectors characterized by input-output linkages. Having established these two results, we then calculate how important the various sector-level linkages are in generating aggregate comovement. To do that, we write the aggregate correlation as a function of sector-pair level correlations, and carry out the usual thought experiment of increasing bilateral trade between two countries. This produces the increase in aggregate correlation that comes from adding up the changes in sector-pair correlations due to trade. It turns out that this experiment matches well the magnitude of the Frankel-Rose effect as implied by the canonical aggregate regression.

More interesting is the breakdown of the overall effect into the various components. First, a number of recent studies find that intra-industry trade is especially important in accounting for the increased comovement between trading countries (see, e.g., Fidrmuc 2004, Koo and Gruben 2006, Calderon et al. 2007). Our estimation lets us break down the aggregate impact into the component coming from intra-industry comovement (which we call the Within-Sector component), and the inter-industry comovement (the Cross-Sector component). The results are surprising. The Within-Sector component accounts for only 10% of the impact of bilateral trade on aggregate business cycle correlation. By contrast, the Cross-Sector component accounts for the remaining 90% of the total effect. What is the intuition for this result? It turns out that the same increase in bilateral trade changes the correlation within a sector by twice as much as the correlation across sectors. At first glance, such a difference bodes well for the finding that intra-industry trade is particularly important in generating aggregate comovement. However, an average sector is quite small in our sample relative to the aggregate. As a result, the impact of a within-sector increase in correlation on the aggregate is moderated by its average small size. Correspondingly, the increase in the correlation of a particular sector with the rest of the economy is that much more important for the same reason: since an average sector is small, its complement is quite large.

Second, we investigate the relative importance of vertical linkages in generating aggregate comovement. In order to do that, we break down the change in correlation between each individual sector pair into the component that is due to the Input-Output linkages and the remaining main effect. It turns out that vertical linkages explain 19% of the overall impact of bilateral trade on aggregate comovement. Finally, we establish whether the vertical linkages are more important for the intra- of inter-industry comovement. It turns out that the Within-Sector component, that is responsible for only 10% of the overall effect, accounts for some 37% of the vertical linkage effect. That is, vertical linkages are especially important in intra-industry trade.

To carry out the empirical analysis, we combine the sectoral output data from the OECD-STAN database for 19 OECD countries during the period 1970–97 with the bilateral sectoral trade series from the World Trade Database (Feenstra et al. 2005). The use of sector-level data allows us to estimate the empirical importance of individual channels through which international trade affects business cycle comovement, as well as exploit variation in sectoral characteristics. In addition, the four-dimensional dataset indexed by exporter, importer, and sector-pair allows the inclusion of a rich set of fixed effects in order to control for many possible unobservables and resolve most of the omitted variables and simultaneity concerns in estimation. In particular, the country fixed effects control for any potential omitted variable that varies at country level, such as country-specific shocks (fiscal, monetary, and productivity), level of development, or quality of institutions. Sector fixed effects will do the same for sector-specific variation correlated across countries, such as sector-specific shocks and factor intensity. In addition to country and sector fixed effects, we utilize importer×exporter fixed effects that control for a variety variables that varying at the country-pair level, such as bilateral distance, monetary or fiscal policy synchronization, sectoral similarity, and many others.

This paper is part of a growing literature on the role of trade in business cycle transmission. Fidrmuc (2004), Koo and Gruben (2006), and Calderon et al. (2007) find that intra-industry trade, as measured by the Grubel-Lloyd index, accounts for most of the Frankel-Rose effect. Imbs (2004) shows that in addition to bilateral trade, similarity in sectoral structure and financial linkages are also important. By contrast, Baxter and Kouparitsas (2005) find sectoral similarity does not have a robustly significant effect on cross-country output correlations. Our paper is the first to examine both comovement and vertical linkages at the industry level, providing a richer picture of the underlying effects and transmission mechanisms. In particular, the vertical linkage results highlight the key role for industrial structure in transmitting shocks via trade. Moreover, our estimates reveal that vertical linkages are especially important within sectors. Thus, our paper arguably provides a bridge between the results of Imbs (2004) and Baxter and Kouparitsas (2005), by highlighting the interaction between countries' trade and the similarity of their industrial structure in explaining business cycle synchronization. Finally, the evidence on vertical linkages in this paper complements recent DSGE analyses (Kose and Yi 2001, Burstein, Kurz and Tesar 2007, Huang and Liu 2007, Arkolakis and Ramanarayanan 2006) that model these effects.[1]

The rest of the paper is organized as follows. Section 2 describes the empirical strategy and data. Section 3 presents the regression results, while section 4 describes the quantitative impact of the various channels on aggregate comovement. Section 5 concludes.

[1] Using data on U.S. multinationals, Burstein et al. (2007) find that trade between affiliates — the measure of production sharing used in that paper — is robustly correlated to bilateral comovement of manufacturing GDP at the country level.

2 Empirical Strategy and Data

2.1 Sector-Level and Aggregate Comovement

Let there be two economies, c and d, each comprised of $\mathcal{I}$ sectors indexed by i and j. The aggregate growth in the two countries, y^c and y^d, can be written as:

$$y^c = \sum_{i=1}^{\mathcal{I}} s_i^c y_i^c$$

and

$$y^d = \sum_{j=1}^{\mathcal{I}} s_j^d y_j^d,$$

where y_i^c is the growth rate of sector i in country c, and s_i^c is the share of sector i in the aggregate output of country c. The business cycle covariance between these two countries is then equal to:

$$\text{Cov}\left(y^c, y^d\right) = \text{Cov}\left(\sum_{i=1}^{\mathcal{I}} s_i^c y_i^c, \sum_{j=1}^{\mathcal{I}} s_j^d y_j^d\right) = \sum_{i=1}^{\mathcal{I}} \sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \text{Cov}\left(y_i^c, y_j^d\right). \tag{1}$$

Since all of the empirical work in this literature is carried out on correlations, and because, conceptually, correlations are pure measures of comovement, we take one extra step and rewrite the identity in terms of correlations:

$$\rho^{cd} = \frac{1}{\sigma^c \sigma^d} \sum_{i=1}^{\mathcal{I}} \sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \rho_{ij}^{cd}. \tag{2}$$

In this expression, σ^c and σ^d are the standard deviations of aggregate growth in the two countries, while σ_i^c and σ_j^d are the standard deviations of the growth rates in individual sectors i and j in countries c and d respectively.

Until now, the literature has examined the left-hand side of this identity, the correlation of countries' aggregate growth ρ^{cd}. Using sector-level data, this paper instead examines the impact of sector-level trade on the correlation between individual sectors in the two economies, ρ_{ij}^{cd}. As we show in the paper, this allows us to develop a much richer picture of the mechanics of trade's impact on aggregate comovement.

In particular, we estimate the following specification, using comovement and trade data for each sector-pair:

$$\rho_{ij}^{cd} = \alpha + \beta_1 \text{Trade}_{ij}^{cd} + \mathbf{u} + \varepsilon_{ij}^{cd}. \tag{3}$$

In the benchmark estimations, the left-hand side variables are correlations computed on almost 30 years of annual data, helping reduce the measurement error. Trade_{ij}^{cd} is one of four possible trade intensity measures, constructed as described in Section 2.3.

All specifications include various configurations of fixed effects $\mathbf{u}$. The observations are recorded at the exporter×sector×importer×sector level, rendering possible the use of a variety of fixed effects. The baseline specifications control for importer, exporter, and sector effects. These capture the average effect of country characteristics on comovement across trading partners and sectors, such as macro policies, country-level aggregate volatility, country size and population, and the level of income. Sector effects capture any inherent characteristics of sectors, including, but not limited to, overall volatility, tradability, capital, skilled and unskilled labor intensity, R&D intensity, tangibility, reliance on external finance, liquidity needs, or institutional intensity. We also estimated the model with exporter×sector and importer×sector effects. These control for the average comovement properties of each sector within each country across trading partners. Finally, we also control for country-pair and sector-pair effects. The country-pair effects capture the average linkages for each country pair, such as bilateral distance, total bilateral trade and financial integration, monetary and fiscal policy synchronization, and sectoral similarity, among others. Sector-pair effects absorb the average comovement for a particular pair of sectors in the data. Note that when we use country-pair effects, the coefficient on trade is identified purely from the variation in bilateral trade volumes *within each country pair across industry pairs.*

Some papers in the literature focus on the impact of intra-industry trade in particular on the aggregate comovement. A typical finding is that intra-industry trade, captured by the aggregate Grubel-Lloyd index for each country pair, is solely responsible for the result that trade between two countries increases comovement. In order to isolate the impact of intra-industry trade, we estimate a variant of equation (3) in which we allow the coefficient on the trade variable to differ when it occurs within the industry:

$$\rho_{ij}^{cd} = \alpha + \beta_1 \text{Trade}_{ij}^{cd} + \beta_2 \mathbf{1}\left[i = j\right] \text{Trade}_{ij}^{cd} + \mathbf{u} + \varepsilon_{ij}^{cd}, \tag{4}$$

where $\mathbf{1}\left[\cdot\right]$ is the indicator function. That is, we allow the coefficient on trade to be different for those observations in which $i = j$.

2.2 Vertical Linkages and Transmission of Shocks

We then investigate further the nature of transmission of shocks at the sector level. We would like to understand whether vertical production linkages help explain the positive elasticity of the output correlation — within and across sectors — with respect to trade in a sector. The explanation behind this link relies on the vertical nature of the production chain. Here, a positive shock (either demand or supply) to a sector in one country increases that sector's demand for intermediate goods in production, and thus stimulates output of intermediates in the partner country (Burstein et al. 2007, Huang and Liu 2007, Kose and Yi 2001).

We exploit information from the Input-Output (I-O) matrices about the extent to which sectors use each other as intermediates in production. Our hypothesis is that the positive link between trade and comovement will be stronger in sector pairs that use each other as intermediates in production. To establish this effect, we estimate the following specification:

$$\rho_{ij}^{cd} = \alpha + \beta_1 \text{Trade}_{ij}^{cd} + \gamma_1 \left(\text{IO}_{ij} \text{Exports}_i^{cd} + \text{IO}_{ji} \text{Exports}_j^{dc} \right) + \mathbf{u} + \varepsilon_{ij}^{cd}, \tag{5}$$

where IO_{ij} is the (i, j)th cell of the I-O matrix. It captures the value of intermediate inputs from sector i required to produce one dollar of final output of good j. It is interacted with the trade variable Exports_i^{cd}, which is the value of exports in sector i from country c to country d. That is, exports of good i from country c to country d will increase comovement by more with sectors j that use i heavily as an intermediate. Correspondingly, IO_{ji} is the value of intermediate j required to produce one dollar of final good i. Therefore, comovement between sector i in country c and sector j in country d will be more affected by exports of j from d to c, Exports_j^{dc}, whenever i uses j intensively as an intermediate (IO_{ji} is high). Note that we constrain the coefficient (γ_1) to be the same regardless of the direction of trade. This is because indices c and d are completely interchangeable, so there is no economic or technological reason why the coefficients on $\text{IO}_{ij}\text{Exports}_i^{cd}$ and $\text{IO}_{ji}\text{Exports}_j^{dc}$ should be different. In addition, the coefficient magnitudes in the unconstrained regressions were quite similar, and the F-tests could not reject equality in most specifications.[2]

Once again, to focus attention on intra-industry trade, the final specification we estimate allows the coefficients to be different when trade is intra-industry:

$$\begin{aligned} \rho_{ij}^{cd} = \alpha &+ \beta_1 \text{Trade}_{ij}^{cd} + \gamma_1 \left(\text{IO}_{ij}^{cd} \text{Exports}_i^{cd} +_2 \text{IO}_{ji} \text{Exports}_j^{dc} \right) + \beta_2 \mathbf{1} [i = j] \, \text{Trade}_{ij}^{cd} \\ &+ \gamma_2 \left(\mathbf{1} [i = j] \, \text{IO}_{ij} \text{Exports}_i^{cd} + \mathbf{1} [i = j] \, \text{IO}_{ji} \text{Exports}_j^{dc} \right) + \mathbf{u} + \varepsilon_{ij}^{cd}. \end{aligned} \tag{6}$$

2.3 Data and Summary Statistics

Data on sectoral production, quantity indices, employment, and prices come from the OECD-STAN Database. We use the version that reports data according to the 3-digit ISIC Revision 2 classification. There are 28 manufacturing sectors in total, plus the information on total manufacturing. The resulting dataset is a panel of 19 countries. Though the panel is unbalanced, the country, sector, and year coverage is reasonably complete in this

[2]It could also be that variation in elasticities of substitution among varieties within a sector also has an effect on the elasticity of sectoral comovement with respect to trade. We checked for the presence of this effect using the estimated elasticities of substitution from Broda and Weinstein (2006). There was no relationship between sectoral variation in our coefficients and the elasticity of substitution.

sample. We calculate correlations of the growth rates of real value added per worker. The real value added series uses sector-specific deflators. We combine information on sectoral production with bilateral sectoral trade flows from the World Trade Database (Feenstra et al. 2005). This database contains trade flows between some 150 countries, accounting for 98% of world trade. Trade flows are reported using the 4-digit SITC Revision 2 classification. We convert the trade flows from SITC to ISIC classification and merge them with our production data. The final sample is for the period 1970–97, giving us roughly three decades.

We employ four indicators of bilateral trade intensity. Following Frankel and Rose (1998), our measures differ from one another in the scale variable used to normalize the bilateral trade volume. In particular, the first two measures normalize bilateral sectoral trade with output, either at the aggregate or sector level:

$$\text{Trade}_{ij}^{cd} = \frac{1}{T}\sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{Y_t^c + Y_t^d} \qquad \text{(Measure I)}$$

$$\text{Trade}_{ij}^{cd} = \frac{1}{T}\sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{Y_{i,t}^c + Y_{i,t}^d} \qquad \text{(Measure II)}$$

where $X_{i,t}^{cd}$ represents the value of exports in sector i from country c to country d, Y_t^c is the GDP of country c and $Y_{i,t}^c$ is the output of sector i in country c in period t.

The two alternative intensity measures normalize bilateral sector-level trade volumes by the overall trade in the two countries:

$$\text{Trade}_{ij}^{cd} = \frac{1}{T}\sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{(X_t^c + M_t^c) + (X_t^d + M_t^d)} \qquad \text{(Measure III)}$$

$$\text{Trade}_{ij}^{cd} = \frac{1}{T}\sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{(X_{i,t}^c + M_{i,t}^c) + (X_{i,t}^d + M_{i,t}^d)} \qquad \text{(Measure IV)}$$

where $X_{i,t}^c$ ($M_{i,t}^c$) is the total exports (imports) of sector i of country c, and X_t^c is the total manufacturing exports of country c. In all of our regressions, the intensity measures are averaged over the sample period and their natural logs are used in estimation.

Appendix Table A1 reports the list of countries in our sample, the average correlation of manufacturing output per worker between the country and other ones in the sample, and the average of the total manufacturing trade relative to GDP over the sample period. The differences between countries in the business cycle comovement and trade openness are pronounced. For instance, the average correlation of Korea's manufacturing output with the rest of the sample is almost nil while the Netherlands' average is around 0.4. The share of trade in GDP ranges from 12% in the United States to 87% in Belgium.

Appendix Table A2 presents the list of sectors used in the analysis and some descriptive statistics, such as the average correlation of output per worker growth of each sector between country pairs, and the average of the total trade of each sector of a country to its GDP. The average within-sector bilateral correlation, at 0.086, is almost three times lower than that of total manufacturing output. However, there are also differences in correlations across sectors. For example, the average bilateral correlation of the Paper and products sector is around 0.28 while the correlation for the Beverages sector is almost zero. The average cross-sector correlation is 0.048, or about half the size of the within-sector correlation. There are also large differences in the degree of openness across sectors.

Figure 1 reports the scatterplot of bilateral GDP correlations against bilateral total manufacturing correlations in our sample. The relationship is close, with the correlation coefficient of 0.52 and Spearman rank correlation of 0.51. Appendix Table A3 reports the canonical Frankel-Rose regression with GDP correlations on the left-hand side along with a specification that uses manufacturing correlations instead. The two give nearly identical results, in both the coefficient magnitudes and the R^2's. It is clear that by focusing on manufacturing only, we will not reach results that are misleading for the overall economy. Figure 2 reports the scatterplot of bilateral correlations of the total manufacturing value added per worker against the four measures of trade openness. As had been found in the large majority of the literature, there is a strong positive association between these variables.

The I-O matrices come from the U.S. Bureau of Economic Analysis. We use the 1997 Benchmark version, and build a Direct Requirements Table at the 3-digit ISIC Revision 2 level from the detailed Make and Use tables and a concordance between the NAICS and the ISIC classifications. As defined by the BEA, the (i, j)th cell in the Direct Requirements Table gives the amount of a commodity in row i required to produce one dollar of final output in column j. By construction, no cell in this table can take on values greater than 1. This is the table we use in estimation.

Figure 3 presents a contour plot of the I-O matrix. Darker colors indicate higher values in the cells of the matrix. Two prominent features stand out. First, the diagonal elements are often the most important. That is, at this level of aggregation, the most important input in a given industry tends to be that industry itself. This is a prominent feature of the data, which we will attempt to take into account in estimation. Second, outside of the diagonal the matrix tends to be rather sparse, but there is a great deal of variation in the extent to which industries use output of other sectors as intermediates. To get a sense of the magnitudes involved, Appendix Table A2 presents for each sector the "vertical intensity," which is the diagonal element of the I-O matrix. It is clear that sectors differ a great deal in the extent to which they use themselves as intermediates, with vertical intensity ranging from 0.011 in Miscellaneous petroleum and coal products to 0.374 in Non-ferrous metals. Its mean value across sectors is 0.128. We also present what we call "upstream intensity," which is the sum of the columns in the I-O matrix (excluding the diagonal term). Upstream intensity captures the total amount of intermediates from other sectors required to produce one dollar of output in each sector. We can see that there is a great deal of variation in this variable as well. It ranges from 0.036 in Petroleum refineries to 0.406 in Footwear, with a mean of 0.224. Note that in our estimation we will of course exploit variation in the I-O matrix cell-by-cell.

The I-O matrix we use in baseline estimation reflects the input use patterns in the United States. Therefore our approach, akin to Rajan and Zingales (1998), is to treat IO_{ij} as a technological characteristic of each sector pair, and apply it across countries uniformly. How restrictive is this assumption? Fortunately, we can check this using the GTAP4 database, which contains information on I-O matrices for many countries. We do not use it in the baseline estimations because it contains information on only 17 distinct manufacturing sectors. However, we can use it to check whether the I-O matrices look radically different among the countries in the sample. It turns out that the I-O matrices are quite similar across countries. For instance, the correlation of the diagonal elements of the I-O matrix (vertical intensity) between the U.S. and the U.K. is 0.91. Taking vertical intensities of all 19 countries in the sample, the first principal component explains 40% of the variation, suggesting that the diagonals of the I-O matrices are quite similar across countries. Same could be said for the upstream intensity, as defined above. The correlation between sector-level upstream intensity between the U.S. and the U.K., for instance is 0.75, and the first principal component explains 60% of the variation in upstream intensity across the countries in the sample. Finally, we estimated all specifications using the average of the I-O matrices across the countries in the sample, and the results were robust.

3 Results

Table 1 presents the results of estimating equation (3). There are four panels, one for each measure of trade linkages. Column (1) reports the simple OLS regression without any fixed effects. Column (2) adds country and sector effects, while column (3) includes country×sector effects. Finally, column (4) is estimated using country-pair and sector-pair effects. Standard errors for all estimates reported in this paper are clustered at the country-pair level.

There is a positive relationship between the strength of bilateral sectoral trade linkages and comovement of sectoral business cycles across countries. Although the trade intensity coefficients tend to become less significant with the inclusion of more stringent fixed effects, they are significant at the 1% level in all cases except one, in which the level of significance is 5%. It is notable that the magnitude of the coefficient is roughly ten times lower than in the aggregate Frankel-Rose specifications. The two specifications are not directly comparable, however, as they capture distinct economic phenomena. In addition, we show below that the estimated sector-level coefficient magnitudes are in fact fully consistent with the observed aggregate impact.

As we described above, some of the recent literature focuses on the role of intra-industry trade in particular. To isolate whether trade has a special role for within-sector correlations, we estimate equation (4), in which the coefficient on the trade variable is allowed to be different for observations such that $i = j$. That is, bilateral trade is allowed to affect the correlation of Textiles in the U.S. with Textiles in the U.K. differently than the correlation of Textiles in the U.S. with Apparel (or Machinery) in the U.K. Table 2 presents the results. It is clear that the coefficient on the within-sector trade is about twice the size of the coefficient on cross-sector trade, and always significantly different at the 1% level. There is indeed something about the within-sector transmission of shocks through trade. In estimating the next specification, we attempt to understand the sources of this difference, while in the calculation of aggregate impact, we assess its quantitative importance for the aggregate comovement.

3.1 Vertical Production Linkages, Trade, and Comovement

Next, we estimate the role of vertical production linkages in explaining comovement within sector pairs. Table 3 presents the results of estimating equation (5). Once again, there are four panels that use different measures of trade intensity. Column (1) reports the simple OLS regression without any fixed effects. Column (2) adds country and sector effects, while column (3) includes country×sector effects. Finally, column (4) is estimated using country-pair and sector-pair effects.

There is a highly statistically significant relationship between trade intensity interacted with I-O linkages and cross-sector comovement under all specifications. The positive coefficient implies that sector pairs that use each other heavily as intermediates experience a higher elasticity of comovement with respect to bilateral trade intensity. Note also that the main effect of trade is also highly significant, though the point estimates are lower than when I-O linkages are not accounted for. That is, vertical linkages are a significant determinant of comovement as well as of the role of trade in increasing comovement. But they are clearly not the whole story. Section 4 calculates how much of trade's impact on aggregate comovement can be explained by vertical linkages.

Finally, Table 4 reports estimation results for equation (6). These establish whether the impact of I-O linkages is different for within-sector comovement compared to cross-sector comovement. This might be especially important in light of our earlier observation that the diagonal elements of the I-O matrix tend to me much larger than the off-diagonal elements. The four panels and configurations of fixed effects are the same as in the previous table. The results here are somewhat ambiguous. In the first three specifications, the within-sector coefficient on the trade-I-O interaction is significantly greater than the cross-sector coefficient on this interaction term, but the difference is negligible in magnitude. When we include country-pair and sector-pair effects – our preferred specification – it turns out that the coefficient is negative, but the difference is not statistically significant. In our view, the more important result is that once the I-O interaction is included, the main effect of trade is no longer robustly significantly different between the within- and the cross-sector observations. In our preferred specifications the coefficient is tiny and not statistically significant. That is, once the intermediate input linkages are taken into account – and these tend to be more important with within-sector observations – the elasticity of comovement with respect to trade is no different for intra- and inter-industry observations.

To assess robustness of these results, in addition to the various fixed effects configurations and the four measures of trade intensity that we use, Appendix Tables A4 through A7 repeat the analysis above for correlations computed on HP-filtered data rather than on growth rates. It is evident from these tables that the results are by and large the same when using HP-filtered data.

4 The Impact of Sector-Level Trade on Aggregate Comovement

The preceding section estimates the impact of bilateral sectoral trade on sector-level comovement, focusing in particular on two aspects of this relationship: intra-industry trade and intermediate input linkages. In this section, we use these estimates to quantify the relative importance of each of these on aggregate comovement.

The identity in equation (2) relates the correlation of aggregate output growth ρ^{cd} between two countries c and d to the correlations ρ_{ij}^{cd} between each pair of individual sectors i and j in those two countries. A change in these bilateral sector-pair correlations leads to the change in the aggregate correlation equal to:

$$\Delta\rho^{cd} = \frac{1}{\sigma^c\sigma^d}\sum_{i=1}^{\mathcal{I}}\sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \Delta\rho_{ij}^{cd}. \tag{7}$$

As we note in Section 2, σ^c and σ^d are the standard deviations of the aggregate manufacturing growth in countries c and d; σ_i^c and σ_j^d are the standard deviations of the growth rate of individual sectors in each economy; and s_i^c and s_j^d are the shares of sectors i and j in aggregate output of countries c and d, respectively. Since aggregate correlation is simply additive in all of the bilateral sector-pair correlations, this expression is an exact one rather than an approximation.

The empirical analysis above estimates the impact of bilateral trade on ρ_{ij}^{cd}. Thus, we can compute the change in the aggregate volatility brought about by a symmetric increase in bilateral trade between these two countries. According to the estimates of the baseline equation (3),

$$\Delta\rho_{ij} = \beta_1 \times \Delta\text{Trade}_{ij}^{cd}. \tag{8}$$

The value of $\Delta\text{Trade}_{ij}^{cd}$ corresponds to moving from the 25^{th} to the 75^{th} percentile in the distribution of bilateral trade intensity in the sample. This is equivalent to going from the level of bilateral manufacturing trade as a share of GDP of 0.085% (Spain-Japan) to 0.5% (U.S.-U.K.). The thought experiment is a symmetric rise in bilateral trade in all sectors for a given country pair. Thus, the exercise is meant to capture mainly the consequences of cross-sectional variation in bilateral trade intensity between countries, and maps most precisely to the existing literature, which examines aggregate trade and correlations. Note that since the trade variables are taken in logs, we are evaluating the impact of an identical proportional increase in trade in all sectors, rather than an absolute increase.

Plugging $\Delta\rho_{ij}$ from equation (8) in place of $\Delta\rho_{ij}^{cd}$ in equation (7) yields the corresponding change in the aggregate correlation between each country pair, $\Delta\rho^{cd}$. Note that this comparative static is carried out under two assumptions. The first is that the change in bilateral trade we consider here does not affect sector-level and aggregate volatilities (σ_i^c's and σ^c's). This assumption may not be innocuous if, for example, bilateral trade for a given country-pair also represents a large share of total trade for one or both countries. If the change in bilateral trade is large enough to substantially affect the overall trade openness, we show in di Giovanni and Levchenko (2007) that it will affect both industry-level and aggregate volatility. However, in our sample of countries it is rarely the case that bilateral trade between any pair of countries accounts for a substantial share of the country's overall trade. In addition, the regression models include various combinations of country and sector-level fixed effects that absorb the trade-volatility relationship at the country level. The second assumption is that bilateral trade does not affect the similarity of the two countries' industrial structure (i.e. the $s_i^c s_j^d$ terms). A previous version of the paper estimated this effect and found it to be quantitatively tiny, so we do not treat it here. The result that the impact of bilateral trade on sectoral similarity is small has also been reported by

Imbs (2004). Though there two channels do not appear to be quantitatively important, they must be kept in mind when interpreting our comparative statics. To be precise, the results below report the impact of bilateral trade on aggregate comovement *due exclusively to changes in sector-pair level comovement.*

We report the mean value of $\Delta\rho^{cd}$ across the 171 country pairs in our data in the first row of Table 5. Note that this calculation gives different values across country pairs because we use actual values of s_i^c, s_j^d , σ_i^c, σ_j^d, σ^c, and σ^d for each country and sector in this calculation. The standard deviations of aggregate and sector-level growth rates are computed over the entire sample period, 1970–97, and the shares of sectors in total output are averages over the same period. On average in this sample, the standard deviation of aggregate manufacturing output is $\bar{\sigma}^c = \bar{\sigma}^d = 0.0317$, while the average standard deviation of a sector is $\bar{\sigma}_i^c = \bar{\sigma}_j^d = 0.0870$. The mean share of an individual sector in total manufacturing is $\bar{s}_i^c = \bar{s}_j^d = 0.034$. Since this calculation uses an estimated coefficient β_1, the table reports the mean of the standard error of this estimate in parentheses. Not surprisingly, because β_1 is highly statistically significant, the change in the aggregate correlation implied by our estimates is highly significant as well.

Our calculation implies that in response to moving from a 25th to the 75th percentile in bilateral trade openness, aggregate correlation increases by 0.076, which is equivalent to 0.32 standard deviations of aggregate correlations found in the sample. How does the total effect we obtain by adding up the changes in individual sector-pair correlations compare to the change in comovement obtained from the aggregate Frankel-Rose regression for the manufacturing sector? Using the estimates in column (1) of Appendix Table A3, we calculate that the same change in bilateral trade when applied to these estimates results in an increase in bilateral correlation of 0.076. This matches perfectly the increase obtained through very different means in this section. Note that there is no inherent reason that these two sets of estimates should match perfectly, as the sector-pair-level estimation uses a much more stringent array of fixed effects than is possible in the canonical Frankel-Rose regression.

The more interesting results concern the relative importance of within- and cross-sector trade in the total estimated impact of trade reported above. To that end, we use the coefficient estimates in equation (4), to break down the change in correlation depending on whether trade occurs in the same sector or not:

$$\begin{aligned} \Delta\rho_{ij} &= \beta_1 \times \Delta\text{Trade}_{ij}^{cd} \\ \Delta\rho_{ii} &= (\beta_1 + \beta_2) \times \Delta\text{Trade}_{ij}^{cd}. \end{aligned} \tag{9}$$

Combining these expressions with equation (7), we decompose the overall effect of trade openness on comovement into the Within-Sector component and the Cross-Sector component:

$$\Delta\rho^{cd} = \underbrace{\frac{1}{\sigma^c\sigma^d}\sum_{i=1}^{\mathcal{I}} s_i^c s_i^d \sigma_i^c \sigma_i^d \Delta\rho_{ii}}_{\text{Within-Sector Component}} + \underbrace{\frac{1}{\sigma^c\sigma^d}\sum_{i=1}^{\mathcal{I}}\sum_{j\neq i}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \Delta\rho_{ij}}_{\text{Cross-Sector Component}} \quad (10)$$

The second row in Table 5 reports the results. The Within-Sector component contributes only about 0.008 to increased aggregate correlation, accounting for about 10% of the total estimated effect. The Cross-Sector component contributes the remaining 90%. These results are that much more striking because the estimated coefficient on within sector trade, $(\beta_1 + \beta_2)$, is double the magnitude of the cross-sector trade, β_1. Nonetheless, the Within-Sector trade accounts for only a small minority of the total impact. This goes against the conclusions of aggregate-level studies such as Koo and Gruben (2006), or Calderon et al. (2007) that argue for the importance of intra-industry trade for aggregate comovement. If intra-industry trade matters, we demonstrate that it is not because it increases comovement within the same sectors. What is the intuition for this result? Our estimates show that bilateral trade between two countries increases comovement both within sectors and across sectors. However, a typical individual sector is quite small relative to the economy. As we report above, the typical share of an individual sector in total output is less than 4%. Thus, there is limited scope for the increased correlation between, say, the Textile sector in the U.S. and the Textile sector in the U.K. to raise aggregate comovement. However, we also find that more trade in Textiles raises the correlation between Textiles in the U.S. and every other sector in the U.K. Since the sum of all other sectors except Textiles is quite large, the cross-sector correlation has much greater potential to increase aggregate comovement.

We now move on to the role of vertical production linkages and bilateral trade in generating comovement between countries. Using our estimates of equation (5), a given change in trade openness produces the following change in sector-pair correlation:

$$\Delta\rho_{ij} = \beta_1 \times \Delta\text{Trade}_{ij}^{cd} + \gamma_1 \times (\text{IO}_{ij} + \text{IO}_{ji}) \times \Delta\ \text{Trade}_{ij}^{cd}. \quad (11)$$

Note that in this case, even though we apply the same change in trade openness, $\Delta\text{Trade}_{ij}^{cd}$, to each sector pair ij, the actual resulting change in correlation will be different across sector pairs, due to input-output linkages IO_{ij} and IO_{ji}. With this in mind, we decompose the total estimated effect of trade on aggregate comovement into what we call the Main

Effect and the Vertical Linkage Effect:

$$\Delta\rho^{cd} = \underbrace{\frac{1}{\sigma^c\sigma^d}\sum_{i=1}^{\mathcal{I}}\sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \beta_1 \Delta\text{Trade}_{ij}^{cd}}_{\text{Main Effect}} + \underbrace{\frac{1}{\sigma^c\sigma^d}\sum_{i=1}^{\mathcal{I}}\sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \left(\text{IO}_{ij} + \text{IO}_{ji}\right)\gamma_1 \Delta\text{Trade}_{ij}^{cd}}_{\text{Vertical Linkage Effect}} \tag{12}$$

The results are reported in the first row of Table 6. The estimates of equation (5) imply that the change in bilateral trade we are considering raises aggregate comovement by about 0.084, which is slightly larger than 0.076 obtained from estimates of equation (3). Applying the reported average standard errors, it turns out that this difference is not statistically significant, however. More interestingly, our estimates show that the Vertical Linkage Effect accounts for 19% of the total impact of increased bilateral trade on aggregate comovement, with the remaining 81% due to the Main Effect.

Finally, we can break down both the Main and the Vertical Linkage Effects into the Within- and the Cross-Sector components using our estimates of equation (6). The last row of Table 6 reports the results. What is remarkable is how different is the behavior of the two effects in Within- and Cross-Sector observations. Above, we found that the Within-Sector component accounts for 10% of the total impact of trade on aggregate volatility. By contrast, the Within-Sector component accounts for almost 37% of the Vertical Linkage Effect (0.007 out of 0.018). Not surprisingly, since the diagonal elements of the I-O matrix tend to be large, there is more scope for vertical transmission of shocks through within-industry trade. Indeed, in this set of estimates, just the Within-Sector component of the Vertical Linkage Effect on its own accounts for 8% of the total increase in comovement, accounting for the bulk of the 10% implied by equation (4). Nonetheless, the lion share of the total impact (75%) is accounted by the Cross-Sector, Main Effect.

Tables 5 and 6 report the mean impacts of trade openness on aggregate volatility in our sample of country pairs. But the change in aggregate correlation is calculated for each country pair, and depends on country-pair characteristics. What can we say about the variation in the estimated impact across countries? Figure 4 reports the histogram of estimated impacts of bilateral trade on aggregate comovement. There is significant variation across country pairs, with the change in correlation ranging from 4% to 16%. Half of the observations are fairly close to the mean impact of 0.076 reported in Table 5: the 25th percentile impact if 0.058, and the 75th percentile 0.090. Table 7 reports the bottom 10 and top 10 country pairs by the estimated impact of trade on comovement. The least pronounced effect of trade is predicted to occur in large and medium-size countries that are close trading partners, such as U.K.-Germany or U.K.-Canada. The highest increase in comovement is predicted for small countries that are far away from each other: 8 of the top 10 pairs involve Austria, and the estimated impact is highest with Mexico, Norway, Portugal, and Korea. It appears, therefore, that the estimated impact of trade is lowest in large diversified economies, and highest in the smallest, least diversified, and most distant trading partners.

What can we say about the relative importance of the vertical transmission channel in this sample? It turns out that among country pairs in our sample, the share of the overall impact due to the vertical transmission channel ranges from 15 to 24% (the mean, reported above, is 19%). The 25th to 75th range is much narrower, however, from 18 to 20%. Thus, the relative importance of the vertical transmission channel does not appear to vary that much across country pairs.

5 Conclusion

This paper studies the mechanisms behind a well-known empirical regularity: country pairs that trade more with each other experience higher business cycle comovement. We start by estimating the impact of trade on comovement not just for each pair of countries, but for each pair of sectors within each pair of countries. It turns out that bilateral trade increases comovement at sector level as well. Next, we investigate the possible transmission channels behind this result. We exploit the information contained in Input-Output tables on the extent to which sectors use others as intermediate inputs, to demonstrate the importance of the vertical transmission channel. The robust finding is that sector pairs that use each other as intermediates exhibit significantly higher elasticity of comovement with respect to trade.

We then go on to quantify the relative importance of the various channels through which trade generates aggregate comovement. Though previous literature identified intra-industry trade as especially important in propagating shocks across countries, we find that the increase in within-sector correlation due to trade accounts for only about 10% of the overall impact, the rest being due to transmission across sectors. When it comes to vertical linkages, we find that they account for 19% of the impact of bilateral trade on aggregate comovement.

How should we interpret these results? On the one hand, the evidence on vertical linkages accords well with the recent quantitative studies that model transmission of shocks through production chains (Burstein et al. 2007, Huang and Liu 2007). On the other hand, we find that some 80% of the overall estimated impact is still "unexplained" by vertical linkages. Thus, our analysis does not fully resolve the puzzle presented by **?**: the role of trade in the transmission of shocks implied by the data is far greater than what what could be generated by a typical international real business cycle model.

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Table 1. Impact of Trade on Comovement at the Sector-Level: Pooled Estimates

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.007**	0.004**	0.003**	0.004**	0.006**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.015	0.065	0.167	0.086	0.011	0.064	0.167	0.085
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.007**	0.004**	0.002*	0.004**	0.008**	0.004**	0.002*	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.016	0.065	0.166	0.086	0.016	0.064	0.167	0.085
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table 2. Impact of Trade on Comovement at the Sector-Level: Within- and Cross-Sector Estimates

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.004**	0.002*	0.004**	0.006**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.004**	0.004**	0.004**	0.004**	0.003**	0.003**	0.003**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Same Sector	0.174**	0.185**	0.187**	–	0.123**	0.129**	0.134**	–
	(0.026)	(0.026)	(0.026)	–	(0.023)	(0.023)	(0.023)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.016	0.066	0.168	0.086	0.012	0.065	0.168	0.085
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.007**	0.004**	0.002*	0.004**	0.008**	0.004**	0.002*	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.003**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Same Sector	0.126**	0.135**	0.136**	–	0.113**	0.105**	0.105**	–
	(0.019)	(0.019)	(0.019)	–	(0.017)	(0.016)	(0.016)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.017	0.066	0.168	0.086	0.017	0.065	0.168	0.085
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table 3. Impact of Trade on Comovement at the Sector-Level: Vertical Linkage Estimates

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003**	0.002*	0.003**	0.006**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.028**	0.029**	0.020**	0.042**	0.033**	0.034**	0.024**	0.042**
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)
Input-Output	0.645**	0.638**	0.472**	–	0.619**	0.583**	0.450**	–
	(0.098)	(0.092)	(0.084)	–	(0.087)	(0.081)	(0.072)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.017	0.066	0.168	0.086	0.014	0.066	0.168	0.086
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003**	0.002*	0.003**	0.008**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.029**	0.029**	0.019**	0.043**	0.040**	0.041**	0.029**	0.045**
	(0.006)	(0.005)	(0.005)	(0.006)	(0.007)	(0.007)	(0.006)	(0.007)
Input-Output	0.498**	0.470**	0.358**	–	0.514**	0.479**	0.376**	–
	(0.070)	(0.067)	(0.061)	–	(0.062)	(0.059)	(0.054)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.018	0.066	0.168	0.086	0.019	0.066	0.168	0.086
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table 4. Impact of Trade on Comovement at the Sector-Level: Vertical Linkages, Within- and Cross-Sector Estimates

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003**	0.002*	0.003**	0.006**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	-0.001	0.000	0.002*	0.000	-0.003**	-0.002*	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.028**	0.029**	0.012*	0.057**	0.037**	0.038**	0.020**	0.056**
	(0.007)	(0.006)	(0.006)	(0.010)	(0.008)	(0.007)	(0.006)	(0.010)
Log(Trade)×Same Sector×IO	0.008**	0.005**	0.005**	-0.020	0.011**	0.006**	0.006**	-0.019
	(0.002)	(0.001)	(0.001)	(0.014)	(0.002)	(0.002)	(0.002)	(0.014)
Same Sector	-0.011	0.026	0.094**	–	-0.061*	-0.024	0.034	–
	(0.033)	(0.031)	-0.03	–	(0.027)	(0.025)	-0.025	–
Input-Output	0.711**	0.645**	0.355**	–	0.752**	0.650**	0.416**	–
	(0.122)	(0.111)	(0.099)	–	(0.107)	(0.095)	(0.083)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.017	0.067	0.168	0.086	0.015	0.066	0.168	0.086
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003**	0.002*	0.003**	0.008**	0.003**	0.002*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	-0.002*	-0.001	0.001	0.000	-0.002*	-0.002*	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.030**	0.029**	0.012*	0.062**	0.036**	0.045**	0.024**	0.070**
	(0.007)	(0.007)	(0.006)	(0.011)	(0.009)	(0.008)	(0.007)	(0.012)
Log(Trade)×Same Sector×IO	0.011**	0.007**	0.007**	-0.026+	0.015**	0.008**	0.008**	-0.037*
	(0.002)	(0.002)	(0.002)	(0.014)	(0.003)	(0.003)	(0.003)	(0.015)
Same Sector	-0.021	0.016	0.063**	–	-0.022	-0.017	0.023	–
	(0.023)	(0.022)	-0.021	–	(0.017)	(0.017)	-0.018	–
Input-Output	0.567**	0.477**	0.277**	–	0.557**	0.513**	0.339**	–
	(0.087)	(0.080)	(0.072)	–	(0.073)	(0.069)	(0.063)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.018	0.066	0.168	0.086	0.019	0.066	0.168	0.086
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table 5. Impact of Trade on Aggregate Comovement: Baseline and Within vs. Cross-Sector Estimates

Specification	Total Effect	Cross-Sector Component	Within-Sector Component
Baseline: Pooled			
$\Delta\rho_A$	0.076	–	–
	(0.015)	–	–
Separate Within- and Cross-Sector Coefficients			
$\Delta\rho_A$	0.078	0.070	0.008
	(0.015)	(0.0145)	(0.001)
Share of Total		**0.90**	**0.10**

Notes: Calculations based on specification (4) of Tables 1 and 2, respectively. The first row corresponds to the cross-country average impact given by equation (8), while the second row corresponds to the average given by equation (9). The independent variable is Trade/GDP, and country and sector-pair fixed effects are included. Standard errors are in parentheses.

Table 6. Impact of Trade on Aggregate Comovement: Main Effect vs. Vertical Linkage Estimates

Specification	Total Effect	Main Effect		Vertical Linkage Effect	
Baseline: Pooled					
$\Delta\rho_A$	0.084	0.068		0.016	
	(0.015)	(0.015)		(0.002)	
Share of Total		**0.81**		**0.19**	
		Within-Sector Component	Cross-Sector Component	Within-Sector Component	Cross-Sector Component
Separate Within- and Cross-Sector Coefficients					
$\Delta\rho_A$	0.085	0.003	0.064	0.007	0.011
	(0.015)	(0.002)	(0.015)	(0.002)	(0.002)
Share of Total		**0.04**	**0.75**	**0.08**	**0.13**

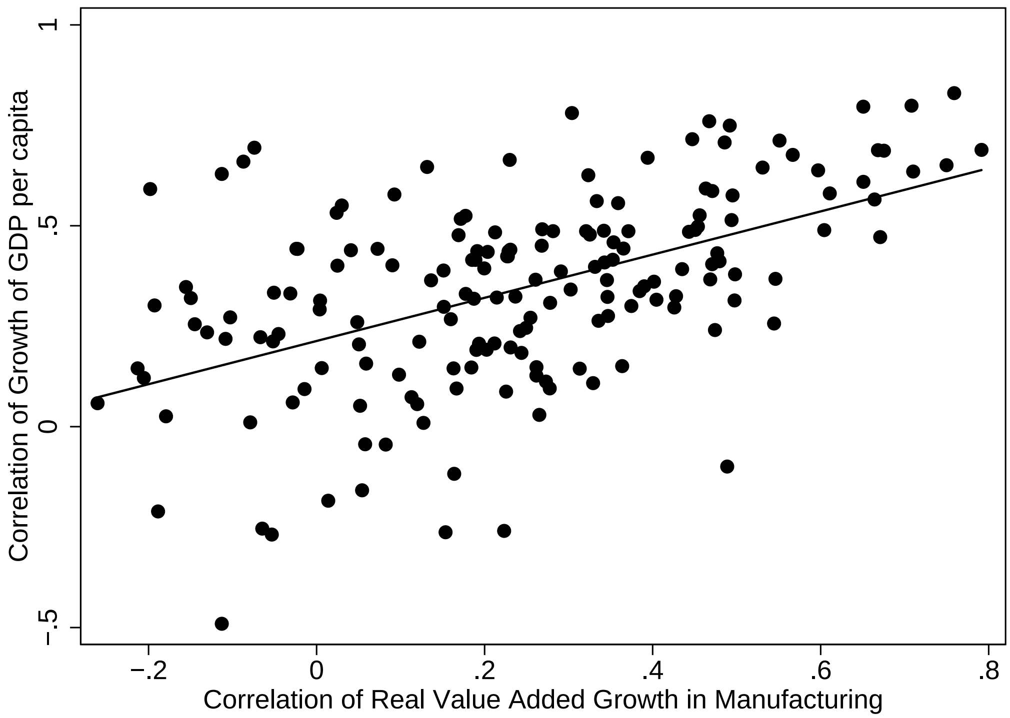
Notes: Calculations based on specification (4) of Tables 3 and 4, respectively. The first row corresponds to the cross-country average impact given by equation (11), while the second row breaks down the average impact into within- and cross-sector components. The independent variable is Trade/GDP, and country and sector-pair fixed effects are included. Standard errors are in parentheses.

Table 7. Bottom and Top 10 Country-Pair Breakdown of Impact of Trade on Aggregate Comovement

Country-Pair	$\Delta\rho_A$
Bottom 10	
U.K.-Canada	0.0399
U.K.-Germany	0.0401
U.K.-Finland	0.0417
Germany-Canada	0.0419
Canada-Finland	0.0435
Germany-Finland	0.0438
U.K.-Italy	0.0438
Italy-Canada	0.0458
U.K.-Netherlands	0.0460
Germany-Italy	0.0460
Top 10	
Portugal-Korea	0.1201
Austria-France	0.1207
Austria-Greece	0.1249
Austria-Spain	0.1290
Norway-Korea	0.1301
Austria-Japan	0.1340
Austria-Mexico	0.1456
Austria-Portugal	0.1483
Austria-Norway	0.1607
Austria-Korea	0.1629

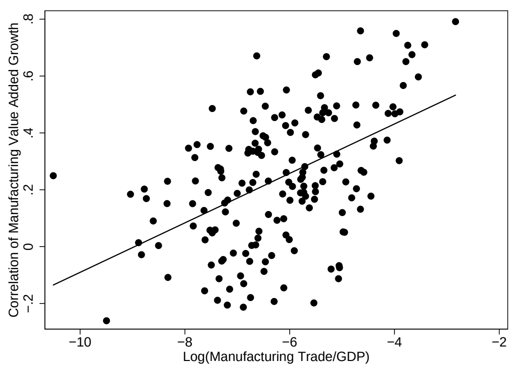
Note: This table lists impact of a change in trade on aggregate comovement for the bottom and top ten country-pairs. It is based on calculations from equation (8) and specification (4) of Table 1.

Figure 1. Correlation of GDP per Capita Growth vs. Correlation of Manufacturing Real Value Added per Capita Growth

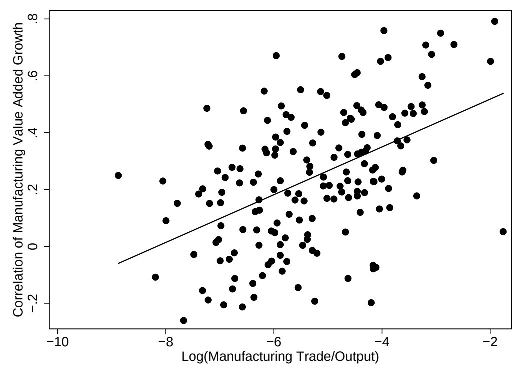


Notes: The x-axis variable is the correlation of manufacturing real value added per worker growth between country pairs. The y-axis is the correlation of GDP per capita growth computed using data from the WDI. In total, there are 171 country pairs in the OECD sample.

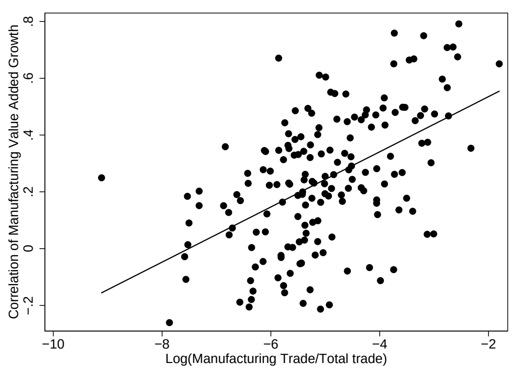
Figure 2. Correlation of Manufacturing Real Value Added per Capita Growth vs. Trade Ratios



(a)



(b)

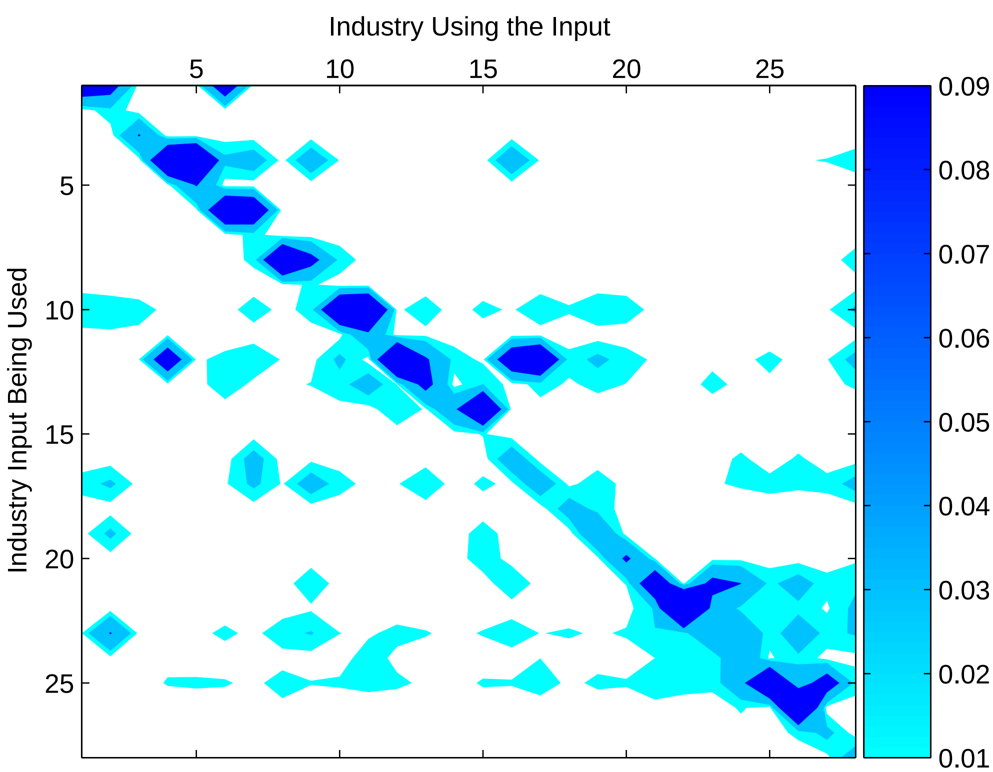


(c)

(d)

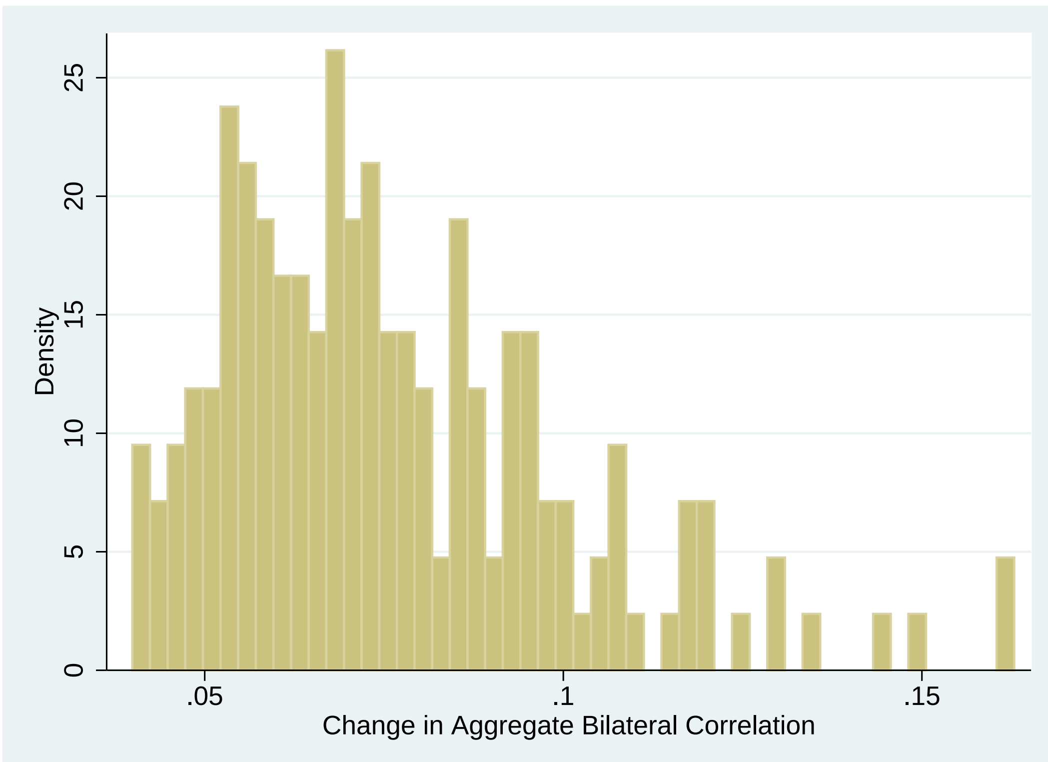
Notes: The y-axis variable for all figures is the correlation of manufacturing real value added per worker growth. The x-axis variables are (a) Log(Manufacturing Bilateral Trade/GDP), (b) Log(Manufacturing Bilateral Trade/Output), (c) Log(Manufacturing Bilateral Trade/Total Trade), and (d) Log(Manufacturing Bilateral Trade/Total Trade within a Sector), respectively.

Figure 3. Contour Representation of the BEA Input-Output Matrix for 28 Manufacturing Sectors



Notes: The figure represents the BEA Input-Output matrix for 28 manufacturing sectors. A darker color implies that an industry is used by another at a higher rate than an industry-pair with a lighter color. The cut-off rates, from light to dark, are 0.01, 0.03, and 0.09, respectively.

Figure 4. Impact of Trade on Bilateral Aggregate Correlation Across Country Pairs



Notes: This figure corresponds to the impact of an average change in bilateral trade intensity on aggregate bilateral correlation for the 171 country pairs in the sample. Calculations are based on specification (4) in Table 1, and correspond to the magnitude calculations in the first row of Table 5.

Table A1. Country Summary Statistics: 1970–97

Country	Average correlation	Trade/GDP
United States	0.335	0.117
United Kingdom	0.321	0.343
Austria	0.263	0.447
Belgium	0.389	0.873
Denmark	0.074	0.425
France	0.359	0.283
Germany	0.366	0.347
Italy	0.371	0.283
Netherlands	0.409	0.688
Norway	0.223	0.365
Sweden	0.229	0.432
Canada	0.325	0.361
Japan	0.230	0.142
Finland	0.144	0.418
Greece	0.208	0.254
Portugal	0.070	0.380
Spain	0.193	0.202
Mexico	0.088	0.183
Korea	0.002	0.424
Average	0.242	0.367

Notes: The first column reports the average correlation of real manufacturing value added growth per worker between a country and the rest of the countries in the sample. Trade/GDP is the average share of manufacturing trade of a country to its GDP over the period.

Table A2. Sector Summary Statistics: 1970–97

ISIC	Sector name	Average ρ_{ii}	Average ρ_{ij}	Trade/ GDP	Vertical Intensity	Upstream Intensity
311	Food products	0.058	0.043	0.026	0.163	0.079
313	Beverages	0.005	0.024	0.004	0.021	0.349
314	Tobacco	0.018	0.000	0.001	0.095	0.046
321	Textiles	0.133	0.062	0.017	0.236	0.230
322	Wearing apparel, except footwear	0.037	0.020	0.014	0.094	0.349
323	Leather products	0.042	0.021	0.003	0.214	0.278
324	Footwear, except rubber or plastic	-0.007	0.017	0.002	0.016	0.406
331	Wood products, except furniture	0.067	0.034	0.008	0.244	0.099
332	Furniture, except metal	0.039	0.033	0.003	0.013	0.352
341	Paper and products	0.277	0.102	0.017	0.228	0.157
342	Printing and publishing	0.092	0.067	0.003	0.073	0.397
351	Industrial chemicals	0.170	0.082	0.032	0.290	0.100
352	Other chemicals	0.161	0.089	0.011	0.120	0.201
353	Petroleum refineries	0.091	0.028	0.015	0.076	0.036
354	Misc. petroleum and coal products	0.015	0.040	0.001	0.011	0.389
355	Rubber products	0.067	0.065	0.004	0.060	0.325
356	Plastic products	0.140	0.074	0.004	0.060	0.340
361	Potttery, china, earthenware	0.091	0.066	0.001	0.050	0.090
362	Glass and products	0.100	0.066	0.003	0.081	0.170
369	Other non-metallic mineral products	0.162	0.077	0.004	0.105	0.110
371	Iron and steel	0.198	0.057	0.020	0.184	0.138
372	Non-ferrous metals	0.076	0.060	0.013	0.374	0.082
381	Fabricated metal products	0.058	0.050	0.014	0.084	0.256
382	Machinery, except eleCtrical	0.104	0.034	0.050	0.076	0.322
383	Machinery, electric	0.056	0.047	0.030	0.242	0.131
384	Transport equipment	0.051	0.024	0.051	0.268	0.269
385	Professional & scientific equipment	0.032	0.033	0.010	0.040	0.255
390	Other manufactured products	0.065	0.032	0.007	0.057	0.312
	AVERAGE	0.086	0.048	0.013	0.128	0.224

Notes: The first two columns report the average correlation of real sector-level value added per worker growth between a pair of countries, averaged over country pairs within a sector and with all other sectors of the economy, respectively. Trade/GDP is, for each sector, the average (across countries) of the share of sectoral trade of a country to its GDP. Vertical Intensity and Upstream Intensity are calculated from the BEA input-output matrix after aggregating up to the 28 manufacturing sectors for which there is production data. Vertical Intensity is the diagonal term of the I-O matrix. It represents the value of output of the sector needed as an intermediate input to produce a dollar of final output in that same sector. Upstream Intensity is the sum across rows for a given column of the I-O matrix, excluding the diagonal. It represents the value of output of all other sectors needed as intermediate inputs to produce one dollar of final output a given sector.

Table A3. Estimates of the Impact of Total Bilateral Trade on Aggregate Comovement in Real GDP per Capita and Total Manufacturing Real Value Added per Worker

	Aggregate			
	Trade/ GDP	*Trade/ Output*	*Trade/Sector Total Trade*	*Trade/ Total Trade*
	(1)	(2)	(3)	(4)
β	0.042*	0.041*	0.049*	0.049*
	(0.019)	(0.018)	(0.020)	(0.020)
Observations	171	171	171	171
R^2	0.65	0.65	0.65	0.65
	Manufacturing			
	Trade/ GDP	*Trade/ Output*	*Trade/Sector Total Trade*	*Trade/ Total Trade*
	(1)	(2)	(3)	(4)
β	0.043**	0.046**	0.046**	0.046**
	(0.015)	(0.015)	(0.016)	(0.016)
Observations	171	171	171	171
R^2	0.64	0.64	0.64	0.64
$\mu_{c1} + \mu_{c2}$	yes	yes	yes	yes

Notes: Robust standard errors in parantheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variables are the correlations of the growth of real GDP per capita and the growth of real manufacturing value added per capita . All regressors are in natural logs. μ_{c1} and μ_{c2} denote the country fixed effects All specifications are estimated using OLS.

Table A4. Impact of Trade on Comovement at the Sector-Level: Pooled Estimates for HP-Filtered Data

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003*	0.002	0.002**	0.005**	0.002*	0.002	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.007	0.046	0.124	0.075	0.006	0.046	0.124	0.074
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003*	0.001	0.003**	0.007**	0.003*	0.002	0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.008	0.046	0.124	0.075	0.008	0.046	0.124	0.074
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table A5. Impact of Trade on Comovement at the Sector-Level: Within- and Cross-Sector Estimates for HP-Filtered Data

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.005**	0.003*	0.002	0.002*	0.005**	0.002*	0.002	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.004**	0.004**	0.004**	0.004**	0.003**	0.003**	0.003**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Same Sector	0.179**	0.185**	0.185**	–	0.126**	0.128**	0.131**	–
	(0.031)	(0.029)	(0.029)	–	(0.025)	(0.025)	(0.025)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.008	0.047	0.125	0.075	0.007	0.047	0.125	0.075
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.006**	0.003*	0.001	0.002**	0.007**	0.003*	0.001	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.003**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Same Sector	0.128**	0.132**	0.131**	–	0.114**	0.106**	0.106**	–
	(0.022)	(0.021)	(0.021)	–	(0.018)	(0.018)	(0.018)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.009	0.047	0.125	0.075	0.009	0.047	0.125	0.075
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table A6. Impact of Trade on Comovement at the Sector-Level: Vertical Linkage Estimates for HP-Filtered Data

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.005**	0.002*	0.001	0.002*	0.005**	0.002*	0.001	0.002+
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.021**	0.021**	0.015**	0.033**	0.026**	0.025**	0.018**	0.035**
	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Input-Output	0.530**	0.499**	0.398**	–	0.519**	0.463**	0.369**	–
	(0.100)	(0.095)	(0.092)	–	(0.085)	(0.082)	(0.077)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.009	0.047	0.125	0.075	0.008	0.047	0.125	0.075
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.005**	0.002*	0.001	0.002*	0.007**	0.002*	0.001	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×IO	0.021**	0.019**	0.013*	0.032**	0.028**	0.028**	0.021**	0.033**
	(0.006)	(0.006)	(0.005)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Input-Output	0.401**	0.356**	0.286**	–	0.405**	0.369**	0.307**	–
	(0.074)	(0.071)	(0.067)	–	(0.065)	(0.063)	(0.058)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.010	0.047	0.125	0.075	0.010	0.047	0.125	0.075
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.

Table A7. Impact of Trade on Comovement at the Sector-Level: Vertical Linkages, Within- and Cross-Sector Estimates for HP-Filtered Data

	I. Trade/GDP				*II. Trade/Output*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.005**	0.002*	0.001	0.002*	0.005**	0.002*	0.001	0.002+
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.000	0.001	0.002*	0.001	-0.001	0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Log(Trade)×IO	0.017*	0.016*	0.006	0.032**	0.025**	0.024**	0.012+	0.033**
	(0.008)	(0.007)	(0.006)	(0.011)	(0.008)	(0.007)	(0.007)	(0.011)
Log(Trade)×Same Sector×IO	0.008**	0.005**	0.005**	-0.002	0.010**	0.006**	0.006**	-0.001
	(0.002)	(0.002)	(0.002)	(0.017)	(0.002)	(0.002)	(0.002)	(0.018)
Same Sector	0.045	0.080*	0.121**	–	-0.018	0.020	0.060*	–
	(0.042)	(0.039)	-0.037	–	(0.033)	(0.030)	-0.029	–
Input-Output	0.504**	0.417**	0.238*	–	0.581**	0.456**	0.288**	–
	(0.135)	(0.122)	(0.113)	–	(0.111)	(0.101)	(0.091)	–
Observations	131512	131512	131512	131512	131485	131485	131485	131485
R^2	0.009	0.047	0.125	0.075	0.008	0.047	0.125	0.075
	III. Trade/Total Trade				*IV. Trade/Sector Total Trade*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log(Trade)	0.005**	0.002*	0.001	0.002*	0.007**	0.002*	0.001	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Trade)×Same Sector	0.000	0.001	0.002*	0.001	0.000	0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Log(Trade)×IO	0.017*	0.014+	0.004	0.032**	0.016	0.023*	0.010	0.037**
	(0.008)	(0.008)	(0.007)	(0.012)	(0.010)	(0.010)	(0.009)	(0.013)
Log(Trade)×Same Sector×IO	0.011**	0.007**	0.007**	-0.004	0.015**	0.008*	0.008*	-0.010
	(0.003)	(0.002)	(0.002)	(0.017)	(0.004)	(0.003)	(0.003)	(0.018)
Same Sector	0.021	0.056*	0.083**	–	0.023	0.029	0.053*	–
	(0.029)	(0.027)	-0.025	–	(0.023)	(0.022)	-0.022	–
Input-Output	0.400**	0.295**	0.172*	–	0.369**	0.323**	0.215**	–
	(0.097)	(0.089)	(0.081)	–	(0.084)	(0.079)	(0.072)	–
Observations	131512	131512	131512	131512	131512	131512	131512	131512
R^2	0.010	0.047	0.125	0.075	0.010	0.047	0.125	0.075
$\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$	no	yes	no	no	no	yes	no	no
$\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$	no	no	yes	no	no	no	yes	no
$\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$	no	no	no	yes	no	no	no	yes

Notes: Robust standard errors, clustered at the country-pair level, in parentheses. ** significant at 1%; * significant at 5%; + significant at 10%. The sample period is 1970–97. The dependent variable is the correlation of the growth of real value added per worker between sector i and sector j of the country pair. μ_1 and μ_2 are country 1 and 2 fixed effects, respectively. μ_i and μ_j are sector i and j fixed effects, respectively. All regressors are in natural logs.