Trade, Production Sharing, and the International Transmission of Business Cycles[*]

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Abstract

Countries that are more engaged in production sharing exhibit higher bilateral manufacturing output correlations. We use data on trade flows between US multinationals and their affiliates as well as trade between the United States and Mexican maquiladoras to measure production-sharing trade and its link with the business cycle. We then develop a quantitative model of international business cycles that generates a positive link between the extent of vertically integrated production-sharing trade and internationally synchronized business cycles. A key assumption in the model is a relatively low elasticity of substitution between home and foreign inputs in the production of the vertically integrated good.

1. Introduction

The importance of trade in the propagation of business cycles has received considerable attention in international macroeconomics, dating back to the writings of Kindleberger (1962) and Meltzer (1976). Recent empirical studies have found evidence of a positive link between the bilateral volume of trade and business cycle synchronization (see, for example, Frankel and Rose 1998, Clark and van Wincoop 2001, and Kose and Yi 2006). Various theoretical mechanisms have been examined that generate, under certain conditions, a positive link between international trade and international business cycle comovement, including dependence on foreign inputs, common external shocks such as changes in oil prices, aggregate demand shocks, and other aggregate shocks whose cross-country correlation is related to the extent of international trade (see, for example, Backus, Kydland and Kehoe 1995, Baxter 1995, Stockman and Tesar 1995, Backus and Crucini 2000, Kose and Yi 2006). In this paper, we examine an alternative mechanism. We argue that pairs of countries that are more engaged in production sharing also exhibit higher comovements of business cycles. We measure this positive link in the data and quantify its importance in a model of international business cycles.

Production sharing is defined as trade in intermediate goods that are part of vertically integrated production networks that cross international borders. Communications and transportation technology has evolved to the point that firms find it both feasible and profitable to slice up the production chain into separate parts or stages that can be performed in different locations according to region- or country-specific comparative advantage. Hummels, Ishii and Yi (2001) and Yi (2003) describe this phenomenon in detail.[1]

Such vertical integration creates close interdependencies between different parts of the firm located across national borders. For example, following the attacks on 9/11, border crossings between the United States and Canada were closed and many of the "big three" auto plants stood idle waiting for parts shipments from Canada.[2] The outbreak of the Severe Acute Respiratory Syndrome (SARS) virus in Asia raised widespread concerns about a possible interruption in the production of power supplies for laptop computers. According to

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[1] This division of production processes into separate stages is also referred to as vertical specialization, desintegration or fragmentation of production, and off-shoring. Hummels, Ishii and Yi (2001) argue that production sharing accounts for more than one-third of world export growth between 1970 and 1995.

[2] The effects of 9/11 on US-Canada trade are discussed in a 2002 Council of Foreign Relations report, "America still unprepared - America still in danger," headed by Congressmen Hart and Rudman.

industry analysts, a quarantine of China would have meant "nuclear winter to the semiconductor and electronics industry."[3] Similarly, production of the new Boeing 787 Dreamliner involves a supply chain of 50 suppliers on four continents, with final manufacture taking place at Boeing plants in Everett, Washington. Foreign suppliers account for roughly 70 percent of the parts needed to manufacture the airplane. Boeing makes foreign suppliers aware that failure to deliver a particular component can, and has, resulted in a shutdown of the production line.[4]

Despite these illustrations of global production sharing and cross-border interdependencies, it is difficult to systematically measure the extent of production sharing activities at business cycle frequencies. In this paper, we measure production sharing using trade flows between US multinationals and their foreign affiliates, as well as trade flows between the United States and Mexico through maquiladoras. These imperfect, yet informative, measures of production sharing have been used by other researchers, including Chen, Kondratowicz, and Yi (2005) and Hanson, Mataloni and Slaughter (2005). We summarize the data on the extent of production sharing and its connection to the business cycle as follows. First, trade flows associated with production sharing are more correlated with US manufacturing output than are trade flows that are not associated with production sharing. Second, for a large cross-section of countries that host US affiliates, those with larger production-sharing trade links with the US also have higher manufacturing output correlations with the US. Third, for these countries we find that the share of production sharing in trade is at least as important as the total volume of trade in accounting for bilateral manufacturing output correlations.

We then develop a model of international business cycles to quantify the role of vertically integrated production sharing links in the transmission of the business cycle. Our model extends the framework of Backus, Kydland and Kehoe (1995)–henceforth BKK–to allow for these links in production. A key assumption in the model is that the elasticity of substitution between home and foreign intermediate goods is relatively lower if there is a production-sharing arrangement between locations. In particular, we assume that the location of plants and assembly lines are unresponsive to shocks at business cycle frequencies, creating a tight dependence of the production chain on inputs from a particular source. This complementarity

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[3]See "Analysis: Asia casts shadow over supply chain," EE Times, April 1, 2003.

[4]For a graphic illustration of the global supply chain for the 787, see http://seattletimes.nwsource.com/html/boeingaerospace. For an account of Boeing's relation with its suppliers, see "Supplier visits strengthen Boeing 737 program," http://www.sme.org/cgi-bin/get-newsletter.pl?LEAN&20060815&5&

in the production of the vertically integrated final good mutes substitution effects stemming from aggregate shocks to relative costs across countries.[5] Consistent with our data, the model generates a higher comovement between production-sharing trade flows and output in the source country relative to non-production-sharing trade flows. The model also produces a positive link between the share of production sharing in total trade and output correlations in manufacturing. This link, however, is lower than the positive link generated by the model between overall trade volumes and output correlations in manufacturing industries, with the extent of the difference depending on how production-sharing trade flows are accounted for in measures of trade flows.

Our work is related to a large literature on business cycles and international trade. It differs from Frankel and Rose (1998) and other empirical work that studies the positive link between the share of trade in GDP and output correlations by focusing on the relation between the production-sharing intensity of trade and output correlations in manufacturing. Kose and Yi (2001 and 2006) show that in a standard model of international business cycles, trade has a very small effect on overall cross-country GDP correlations given the small shares of trade in GDP for most countries. We focus on manufacturing industries, which have higher trade shares, and show in our model that increasing the share of trade has a bigger impact on GDP correlations in the presence of production-sharing trade. Our work also relates to studies of international business cycles that examine the impact of differing degrees of substitutability in traded intermediate inputs on business cycles (see, for example, BKK, Ambler, Cardia and Zimmerman 2002, and Heathcote and Perri 2002).[6] Our paper motivates differences in the degree of substitution between inputs based on the extent of production sharing in bilateral trade flows. Other related work that studies macroeconomic models of vertical integration and trade include Yi (2003), focusing on the increase in trade volumes over time, and Bergin, Feenstra, and Hanson (2007), focusing on the higher volatility of production-sharing industries in host, relative to source, economies.[7]

The paper is organized as follows. Section 2 presents some evidence on the link between the extent of production sharing, trade volumes, and business cycle comovement. Section 3

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[5]These substitution effects can imply that an increase in international trade leads to lower international business cycle correlations (see for example Heathcote and Perri 2002 and Kose and Yi 2006).

[6]Drozd and Nosal (2007) study the trade-comovement relation using an alternative framework based on search and matching frictions.

[7]There is also a literature that develops rich models of offshoring and international trade, that abstract from business cycle considerations. See, for example, Antras and Helpman (2004), Grossman and Helpman (2005), Grossman and Rossi-Hansberg (2006), and references therein.

describes the model. Section 4 examines the model's quantitative implications for the link between the volume of international trade, the extent of production sharing, and international business cycles. Section 5 concludes.

2. Some evidence on production sharing, trade and business cycle fluctuations.

This section documents the importance of production sharing in international trade flows and the relation between production sharing and international business cycles. We examine trade flows between US multinational companies and their affiliates and trade flows between the US and Mexican maquiladoras. Trade flows associated with production sharing are more synchronized with output in the US relative to trade flows that are not associated with production sharing. We then examine the link between the volume of bilateral production-sharing trade flows (as a fraction of output and trade) and bilateral output correlations in manufacturing. We find a positive relationship between the share of production sharing and bilateral manufacturing output correlations. When accounting for this positive link, the intensity of production sharing in trade is at least as important as the total volume of trade in output.[8]

Trade between multinationals and their foreign affiliates

The Bureau of Economic Analysis (BEA) reports data on intermediate inputs shipped from US parents to majority-owned affiliates, as well as sales of US affiliates back to the US. This data provides only an imperfect measure of production sharing as not all trade flows from affiliates to parents have US input or process content and, similarly, some trade flows from the parent to the affiliate are final goods without further content added by the affiliate.[9] Moreover, this data captures only intra-firm trade and omits arms-length production-sharing activities. However, the BEA data has been extensively used in the literature as a way of measuring of production sharing. See, for example, Hanson, Mataloni, and Slaughter (2005), and Chen, Kondratowicz and Yi (2005).

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[8]More details on the data used in this section can be found in the Appendix and in the notes of the individual tables and charts.

[9]This is an important consideration for US-Europe trade, as US-owned affiliates regularly ship *final* products that are not intensive in US processes or inputs (for example, exports of cars from Sweden, or pharmaceuticals from Ireland).

Panel A of Table 1 shows the sales of US affiliates located in Canada, Mexico, Europe and Japan to the US, as a share of total affiliate sales. By 2003, a significant fraction $(30-35\%)$ of the sales of affiliates in the NAFTA region are sales back to the US, suggesting that affiliates are part of a vertically integrated production chain, and the goods are ultimately shipped back to the US. In contrast, less than 10% of the sales of European and Japanese affiliates are sales to the US, evidence that the activity of those affiliates is quite different from affiliates in Canada and Mexico.[10]

Panel B shows the ratio of exports from US parents to their affiliates as a fraction of the total sales of affiliates. Again, there is an apparent difference between the activities of affiliates in Canada and Mexico relative to Europe and Japan. Exports of intermediate goods to affiliates account for roughly $20-45\%$ of the total sales volume of affiliates in the NAFTA region, but less than 10% of the sales volume for the aggregate of Europe and Japan. This suggests that much more of the production by US affiliates in Europe and Asia is done where the affiliate is located, with less dependence on intermediate inputs from the US parent.

Finally, Panel C provides a measure of the production-sharing intensity of trade by calculating for each country or region the ratio of affiliate sales of manufactured goods to the US parent as a share of total manufacturing exports to the US. The figures suggest that the production-sharing intensity of trade is higher within NAFTA (roughly 50% for Canada, 25% for Mexico), than for Japan (roughly 2%) and Europe (roughly 15%).[11] [12]

Maquiladora trade

Data on manufacturing and trade of Mexican maquiladoras provides information on the extent of production sharing between the US and Mexico at business cycle frequencies. The Maquiladora Program was established in 1965 to help relieve high unemployment in the northern region of Mexico. Foreign-owned firms were granted the right to set up production

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[10] This pattern is also documented in Ekholm et. al. (2007), who distinguishing export-platform FDI (i.e. affiliate sales to the host or third countries) from vertical integration motivated FDI.

[11] Table 1 focuses on production-sharing relationships between US parent firms and their foreign affiliates. European firms engage in similar production sharing arrangements with their affiliates in Eastern Europe (see Tesar 2006). Data based on Austrian and German firms with foreign affiliates in a subset of East European countries (Czech Republic, Hungary, Poland and Slovakia) suggests production sharing figures comparable to those in Table 1 Panel C, ranging from 0.42 to 0.55 for Austria and from 0.15 to 0.65 for Germany.

[12] Results in Table 1 are consistent with the information in USITC (various issues), which reports the share of domestic content in US imports based on tax-exemption data from Harmonized Tariff Schedule 9802. The coverage of this data has declined recently, with the reduction in tariff barriers lowering the incentive to report domestic content of imports.

in the region and to import materials and equipment duty-free under the proviso that the goods would be re-exported. Not all maquiladoras are majority owned by US corporations, so this data complements the information in Table 1 based on US multinational data only. The maquiladoras are an important source of employment and export-oriented growth for Mexico, with their exports accounting for half of all non-oil exports from Mexico and one-third of manufacturing employment.[13] The US is the predominant trading partner with maquiladoras, accounting for roughly 90% of total maquiladora exports in 1998 (Bendesky et. al. 2003).

Table 1 shows that including maquiladoras trade significantly increases the measures of production sharing between US and Mexico described above. For example, in Panel C we observe that the production sharing intensity of trade increases from roughly 25% to 55% when maquiladoras are included.[14]

To quantify the operations of maquiladoras, Panel A in Figure 1 displays the ratio of imports by maquiladoras as a fraction of their exports, for the period $1993 - 2005$. The average value of the ratio is roughly 0.75. This suggests that for every 75 cents of imported intermediate inputs, 25 cents of Mexican value is added to the product, and one dollar is re-exported.

Time variation in the import/export ratio provides some information on the elasticity of substitution between imported intermediate inputs and Mexican value added contributed by maquiladoras. In particular, we can compare changes in the import/export ratio to changes in the relative price of imported inputs to Mexican value added. If the elasticity of substitution between imported inputs and exports is equal to one, then the import/export ratio should be unresponsive to changes in the relative price, as the share of imported inputs in gross output remains constant. If the elasticity of substitution is less (greater) than one, then an increase in the relative price of imported intermediate inputs relative to Mexican value added should lead to an increase (decrease) in the import/export ratio, as the share of imported inputs in gross output increases.

We approximate the relative price of imported inputs to Mexican value added using the producer-price-index-based US-Mexico real exchange rate (PPI-based RER), constructed as the ratio of the Mexican to US producer price index for manufactured goods, both expressed

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[13]Sources: Bank of Mexico and OECD

[14]In 2002, 52.5 percent of maquiladoras were owned by US corporations. In generating the shares in Table 1, we assume that 47.5 percent of maquiladora output reflects vertical integration with the US that is not captured in the BEA multinational data. Source: InfoMex.

in the same currency. Our choice of bilateral RER is motivated by the fact that the US accounts for 90% of trade with maquiladoras. The PPI-based RER is displayed in Panel C, Figure 1. Panels A and C reveal a positive comovement between the import/export ratio of maquiladoras and the PPI-based RER. For example, the large real depreciation of the Mexican peso in 1995 (an increase in the PPI-based RER) is accompanied by an increase in the import/export ratio. The correlation between the log of the import/export ratio and the PPI-based RER (deviations from a quarterly HP trend) is 0.77. This is consistent with an elasticity of substitution (at high frequencies of the data) lower than one between imported inputs and value added in the production sharing sectors.

For comparison purposes, Panel B reports the import/export ratio for non-maquiladora manufacturing. Note that this ratio does not have a simple interpretation based on imported inputs/ gross output (as it did for the maquiladoras), given that goods exported and imported by Mexico can be very different within non-maquiladora industries. Panels B and C reveal a negative relation between this ratio and the PPI-based RER. For example, in 1995, the real depreciation of the Mexican peso is associated with a large decline in the import/export ratio. The correlation between the log of the import/export ratio and the PPI-based RER is −0.72, which is significantly less than the correlation using the maquiladora data. We interpret the difference between these two correlations as evidence that firms engaged in production sharing (in this case maquiladoras) exhibit a lower elasticity of substitution between home and foreign inputs relative to other firms.[15]

Production sharing and international business cycles

We now provide some evidence that trade flows associated with production sharing are more closely related to the economic activity in the source country relative to trade flows not associated with production sharing. We also document a positive link between the share of production sharing in bilateral trade flows, and bilateral manufacturing output correlations. Our analysis is based on the measures of production sharing discussed above (US multinational trade with affiliates and trade with Mexican maquiladoras).

The two panels of Table 2 examine the relationship between US manufacturing output, as measured by real manufacturing value added from the BEA, with both affiliate and

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[15]The higher inferred elasiticity of substitution in non-maquiladoras could also reflect differences in consumption cyclicality of US and Mexico imports, especially during the 1995 Mexican crisis. In our model we abstract from these considerations.

maquiladora trade flows. Table 2a focuses on the relationship between annual US manufacturing output and trade flows with 39 countries over the 1983-2003 period.[16] We estimate the relationship between US manufacturing output, total affiliate sales to the US from country j, and total exports from country j excluding affiliate sales to the US. For both annual HP-filtered and first-differenced series, sales of US affiliates back to the US (our measure of production sharing) are more strongly related to US manufacturing output than are exports net of US affiliate sales back to the US. Affiliate sales to the US for our sample of countries has a correlation with US manufacturing output of roughly 0.15 (significant at the 1 percent level), while the correlation with exports net of US affiliate sales back to the US is roughly 0.05 (and insignificant). The data reject the hypothesis that the coefficient on affiliate sales is less than the coefficient on non-affiliate exports to the US (columns 3 and 4 of the table). These results are roughly unchanged if we use current dollar values instead of real dollar values, and if we use alternative measures of US output, such as total GDP and measures of industrial production. The results are robust to the use of country fixed effects.

We next examine the relationship between US manufacturing output and maquiladora and non-maquiladora manufacturing exports. Table 2b reports the correlation of each form of exports with real US manufacturing value added, using annual HP-filtered and first-differenced series. The results support the view that US manufacturing output is more tightly correlated with maquiladora exports from Mexico (correlation of 0.8) than with non–maquiladora exports (correlation of about 0.5); the two estimates are also statistically different from each other. The maquiladora correlations with US manufacturing output complement the affiliates-based results in panel A. The results are roughly unchanged if we use current dollar values or quarterly data.[17]

Bilateral output correlations are a common measure of the degree of business cycle co-movement. Frankel and Rose (1998) and Kose and Yi (2006) find a positive relationship between trade flows and bilateral output correlations. We extend their analysis by asking whether production sharing also contributes to the comovement of business cycles. To do this, we examine the link between bilateral output correlations and measures of the share of production sharing in trade and the share of trade in output. Since production sharing

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[16]In Table 2a we use total affiliates trade due to the large number of missing values in the manufacturing affiliates data during the 1980s.

[17]The Bank of Mexico only provides maquiladora data for total exports and not by destination. The results in Table 2b are robust to the substitution of non-maquiladora exports with US manufacturing imports from Mexico less maquiladora exports.

is more concentrated in manufacturing industries, we focus on output and trade in manufactured goods. The set of countries includes US trading partners with production sharing data. The figures we present also include countries engaged in intra-European production sharing based on survey data reported in Marin (2005).[18] The output correlations between the United States and its trading partners are calculated using annual measures of real manufacturing value added over the period 1983-2005 (the correlations with Eastern European countries are limited to the period 1995-2003, due to data availability).

Figure 2a shows the relationship between manufacturing bilateral output correlations and the extent of production sharing, here measured as the ratio of current dollar sales of foreign affiliates back to the source country as a share of current dollar manufacturing output in the host country. The figure suggests a positive relationship between bilateral manufacturing output correlations and the ratio of affiliate sales to host country output.[19] Table 3 quantifies this relationship for the US and its trade partners. The second column in Table 3a displays a slope coefficient of 0.94 that is significant at the five percent level.[20]

We now investigate whether this relationship is mostly accounted for by the total volume of exports, or by production sharing per se. To do this we decompose affiliate sales from host country j to source country i relative to host country output as follows:

$$\frac{affilsales_{ij}}{mftgVA_j} = \left(\frac{affilsales_{ij}}{mftgEXP_{ij}}\right)\left(\frac{mftgEXP_{ij}}{mftgVA_j}\right), \tag{2.1}$$

where $mftgVA_j$ denotes manufacturing value added in country j, and $mftgEXP_{ij}$ denotes manufacturing exports from country j to country i.

The first component on the right hand side of equation (1) represents affiliate sales to the source country as a share of manufacturing exports to the source country (in the model, this will be referred to as s_2^P). Seen earlier in Table 1, this metric captures the intensity of production-sharing trade in total bilateral trade flows. The second component is the share of manufacturing exports to the source country in host-country manufacturing output (in

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[18]Specifically, Figure 2 and Table 3 consider trade flows between the US and 15 Western European countries, a EU 15 aggregate, Argentina, Austrialia, Brazil, Canada, Chile, Colombia, Costa Rica, Dominican Republic, India, Japan, Malaysia, Mexico, New Zealand, Phillippines, Singapore, South Korea, Switzerland, Thailand, and Venezuela. Figure 2 also includes trade flows between Germany, Austria, and four Eastern-European countries (Czech Republic, Hungary, Poland and Slovakia).

[19]Given the sensitivity of Mexico-US output correlations to the inclusion of the 1994-1995 Mexican crisis, we report two values for this correlation. One is based on data over the period 1983-2003, and the other is based on data over the period 1996-2003.

[20]The results in Table 3 are roughly unchanged if we include intra-Europe pairs of countries, and if we exclude either of the two Mexico observations.

the model, this will be referred to as s_2^X). This captures the importance of trade relative to manufacturing economic activity in the host country. This decomposition allows us to separate the effect of production sharing on bilateral output correlations from the effect of the volume of trade.

Figure 2b shows a positive relationship between bilateral manufacturing output correlations and the production sharing intensity of trade. The corresponding OLS coefficient from Table 3a column 3 is 0.85, significant at the 5 percent level. Figure 2c shows the relationship between bilateral correlations and the second term in the decomposition, the volume of trade. The point estimate for the relationship between output correlations and the volume of trade is equal to 0.29, which is lower than the estimate for the affiliate share of manufacturing exports. Table 3b includes both terms of the decomposition in the same regression. The coefficient on the production sharing intensity of trade is larger than the coefficient on the volume of trade, which is insignificant. The hypothesis that the two coefficients are identical is rejected and the results are robust to the exclusion of outliers.

Frankel and Rose (1998), Kose and Yi (2006), and others perform a regression similar to that in Table 3a to estimate the relationship between bilateral correlations and trade volumes. While both our regressions and theirs find a positive coefficient on trade volumes, our coefficients are smaller. Our regressions differ in two respects. First, because we are not attempting to identify a causal relationship between openness and business cycles, but rather to describe moments in the data, we do not follow Frankel and Rose (1998) and Kose and Yi (2006) in utilizing instrumental variables to proxy for the bilateral trade relationship. Second, our measures of trade openness differ. While they define the trade openness measure as the ratio of the sum of bilateral exports and imports over the sum of the two countries' GDP for all industries (not solely manufacturing), we measure openness as the ratio of exports from country j to the US over manufacturing GDP (or value added) of country j. Our definition leads to higher ratios (placing total US GDP in the denominator significantly reduces these ratios), and implies smaller regression coefficients on s_2^X relative to those reported in Frankel and Rose (1998) and Kose and Yi (2006).[21]

We conclude this section by summarizing our main findings. First, the degree of production sharing differs significantly across US trading partners. Second, trade flows associated with production sharing are more correlated with US output than trade flows not associated

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[21] For our data and set of countries, we can roughly reproduce the results in Kose and Yi (2006) if we use their measures of openness.

with production sharing. Third, the fraction of exports associated with production sharing is at least as important as the total volume of trade in accounting for a positive synchronization of manufacturing output across countries. Our results are based on imperfect measures of the extent of production sharing at business cycle frequencies. Future work will have to resolve how robust these conclusions are to alternative measures of production sharing.

We next turn to a simple quantitative model to study the effects of trade composition on international business cycles.

3. Model of Production Sharing and Business Cycles

In this section, we construct a two-country model to study the role of production sharing in the transmission of business cycles across countries. In our model we assume that each country specializes in the production of an intermediate good. These intermediate inputs are then combined to produce two composite manufactured goods, a vertically integrated good (the production-sharing good) and a horizontally differentiated good. Both countries consume the differentiated composite good, but only country 1 consumes the vertically integrated composite good. One can think of the model as describing the production and trade linkages between the US and Mexico. Both the US and Mexico consume the horizontally differentiated goods, while the production-sharing good is produced jointly by the US and Mexico but it is ultimately sold to consumers in the US.

The production technology for the two manufactured composites differ in the elasticity of substitution between local and foreign inputs. We assume that there is a relatively high elasticity of substitution between home and foreign inputs in the production of the horizontally differentiated good (e.g. home and foreign auto parts that are readily substitutable). On the other hand, the vertically integrated composite is assembled under a relatively low substitution elasticity between local and foreign intermediate goods, and can be understood as a production sharing arrangement with low short-run substitution between inputs or processes. One stage of production is carried out in country 1, and another stage in country 2. The model is designed to capture, in a very simple way, the essence of production sharing at business cycle frequencies, with little substitution in processes across countries. We abstract from interesting long-run issues such as the location of the vertical production chain and substitution between alternative offshore locations.[22] The model nests the "stan-

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[22]Ruhl (2004) and Ramanarayanan (2006) study rich models of trade with heterogeneous firms where the

dard" model of international business cycles in BKK when the production sharing sector is made arbitrarily small - in this case the model depicts standard trade flows in horizontally differentiated varieties.

This model allows us to vary the importance of production sharing and examine its implications for business cycle transmission. We show that, consistent with our empirical findings, exports used in the production of the vertically integrated good are more tightly linked to aggregate fluctuations in country 1, in comparison with exports used in the production of the horizontally differentiated good. Conversely, horizontally differentiated exports are more closely tied to aggregate fluctuations in country 2 than vertically integrated exports. It then follows that business cycles are more synchronized between pairs of countries with a higher share of international trade in inputs utilized in the production of vertically integrated goods, than between pairs of countries where trade is dominated by inputs used to produce horizontally differentiated goods.

We first describe the details of the model, and then explore in a calibrated version of the model the quantitative importance of trade and production sharing in the international transmission of business cycles.

We measure time in discrete periods and index each period by $t = 1, 2, 3, ...\infty$. Countries are indexed by $i = 1, 2$ and have a population of L_i individuals. Preferences of the representative agent in country i are characterized by an expected utility function of the form

$$U_i = \max E_0 \sum_{t=0}^{\infty} \beta^t u \left(c_{it}, 1 - n_{it} \right) , \tag{3.1}$$

where c_i and n_i are per capita consumption and employment in country i, and

$$u \left(c, 1 - n \right) = \frac{1}{(1 - \sigma)} \left[c^\mu \left(1 - n \right)^{1-\mu} \right]^{1-\sigma} .$$

Each country specializes in the production of one intermediate good. Per capita output of the intermediate good z_i requires inputs of domestic labor n_i, and capital k_i, and is affected by country-specific aggregate productivity (its average is A_i), which changes stochastically over time. The production function of the intermediate good is given by

$$z_{it} = A_i e^{s_{it}} \left(n_{it} \right)^\alpha \left(k_{it} \right)^{(1-\alpha)} . \tag{3.2}$$

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presence of fixed costs and irreversibilities lead to low trade elasticities at business cycle frequencies and high trade elasticities in response to permanent trade reforms.

The parameter α denotes the share of labor in value added. The vector of aggregate productivity shocks $s_t = (s_{1t}, s_{2t})$ follows the process $s_{t+1} = Ps_t + \varepsilon_{t+1}$, where P is a symmetric 2x2 matrix characterized by the parameters P_{11} and P_{12}, and ε_t is distributed normally and independently over time, with mean 0 and variance Σ.

We assume that all trade occurs at the level of intermediate goods. Local and imported intermediate goods are combined in each country to create two types of manufactured composites: the horizontally differentiated composite, denoted by x, and the vertically integrated composite, denoted by v.

Production of composite x_i combines local and imported intermediate goods according to the following Armington aggregator:

$$x_{it} = \left[\theta_i^{1-\rho} (x_{iit})^\rho + (1 - \theta_i)^{1-\rho} (x_{ijt})^\rho \right]^{\frac{1}{\rho}} , \; i = 1, 2, \; j \neq i \tag{3.3}$$

The first subscript in x_{ijt} denotes the country where the input is used to assemble x, and the second subscript denotes the source country where this intermediate input is originally produced. The parameter $1 - \theta_i$ reflects the importance of imported intermediate goods in the production of composite x_i. We assume that the elasticity of substitution, $1/(1 - \rho)$, between inputs in the production of good x is relatively high.

The vertically integrated composite, v, is only consumed in country 1, and is produced according to

$$v_{1t} = \left[\lambda^{1-\zeta} (v_{11t})^\zeta + (1 - \lambda)^{1-\zeta} (v_{12t})^\zeta \right]^{\frac{1}{\zeta}}. \tag{3.4}$$

The parameter $1 - \lambda$ measures the importance of imported intermediate goods provided by country 2.

Good v_1 can be thought of as the product of a multinational enterprise in conjunction with its foreign affiliate. Alternatively, we can also think of v_{12} as the inputs provided by firms in country 2 that are not necessarily under the control of a firm in country 1 (e.g.: maquiladoras). To capture a key feature of production sharing, we assume that inputs into the production of good v are complementary, relative to the production of good x. That is, the elasticity of substitution in the vertically integrated composite, $1/(1 - \zeta)$, is smaller than $1/(1 - \rho)$.

Two alternative assumptions can be made about the international flow of intermediate goods required to assemble v_1. Under the first assumption, v_{11} is initially shipped to country 2, v_{12} is added to produce v_1, and then v_1 is shipped back to country 1. Alternatively, v_{12} is

shipped from country 2 to country 1, and combined with v_{11} in country 1 to produce v_1. The trade balance and equilibrium allocations are identical under either specification.[23] However, gross trade flows in the model depend on this assumption and we are interested in how those flows commove with output and other macro variables. Given the uncertainty regarding the extent that inputs from the source country v_{11} are shipped back and forth with its trading partners, in the quantitative analysis we report results for the two extremes (v_{11} is excluded, and v_{11} is included in the export measures).

Each country produces a final manufactured (or tradeable) good y_i^T. In country 1 the final manufactured good y_i^T combines x_i and v according to

$$y_{1t}^T = (x_{1t})^\omega (v_{1t})^{1-\omega} \ , \tag{3.5}$$

where ω is the weight of the horizontally differentiated composite. We assume that country 2 does not engage in production sharing with other countries, so $y_{2t}^T = x_{2t}$.

The final manufactured good y_i^T is combined with a non-tradeable good y_i^N (these can be understood as nontraded services) to produce the final good y_i which can be either consumed, or invested. The final good y_i is produced according to

$$y_{it} = \left(y_{it}^T\right)^\gamma \left(y_{it}^N\right)^{1-\gamma} \ . \tag{3.6}$$

The resource constraint for the final good in each country is

$$y_{it} = c_{it} + i_{it} \text{ for } i = 1, 2 \tag{3.7}$$

where

$$i_{it} = k_{it+1} - (1 - \delta) k_{it} \ . \tag{3.8}$$

The resource constraint for intermediate goods in country 1 is

$$L_1 z_{1t} = L_1 x_{11t} + L_2 x_{21t} + L_1 v_{11t} + L_1 y_{1t}^N \tag{3.9}$$

Intermediate goods from country 1 are either used locally to produce x_1, v_1, or y_1^N, or exported to produce x_2. The resource constraint for intermediate goods in country 2 is

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[23]To give a concrete example of the two versions of trade flows, imagine the production of a laptop computer. Under assumption 1, the US ships components to the offshore production location, the laptop is assembled abroad and is then shipped back to the US for final sale. Under assumption 2, the laptop is shipped from the offshore production site to the US, but the final stage of the process (e.g. packaging, installation of software, etc.) occurs in the US before being sold to US consumers. Both types of assembly are likely to occur in practice, so our assumptions should be viewed as characterizations of extreme cases.

$$L_2 z_{2t} = L_2 x_{22t} + L_1 x_{12t} + L_1 v_{12t} + L_2 y_{2t}^N. \tag{3.10}$$

Intermediate goods from country 2 are either used locally to produce x_2 and y_2^N, or exported to produce x_1 and v_1.

We define manufacturing output as $z_{it}^T = z_{it} - y_{it}^N$. The volume of exports as a fraction of manufacturing output in country i, abstracting from time subscripts, is denoted by s_i^X. In country 1, this share is $s_1^X = (L_2 x_{21}) / (L_1 z_1^T)$, and in country 2 it is $s_2^X = L_1 (x_{12} + v_{12}) / (L_2 z_2^T)$. The share of country 2 exports accounted for by production sharing is given by $s_2^P = v_{12} / (x_{12} + v_{12})$. Hence, country 2's share of production sharing in manufacturing GDP is $s_2^P s_2^X$.

In defining these measures of trade we have assumed that v_{11} is not shipped from country 1 to country 2, and thus v_{11} is not included in export measures. We also consider the case in which v_{11} is included in exports (assuming that v_{11} is shipped back and forth between countries) when constructing s_1^X, s_2^X and s_2^P.

Note that lowering ω, keeping constant the total volumes of trade s_1^X and s_2^X, raises the share of production sharing in s_2^P. When $\omega = 1$, we have $s_2^P = 0$, and the model reduces to the standard, two-country, two-good model of BKK.

To isolate the role of international trade in international business cycles, we assume the availability of complete contingent claims that permit agents to diversify country-specific risk across states of nature. We exploit the fact that equilibrium allocations are Pareto optimal and maximize $L_1 U_1 + L_2 U_2$, subject to the technology and resource constraints described above. By choosing a suitable set of initial wealth levels, the competitive equilibrium allocations are identical to the ones obtained by solving this planner's problem. Furthermore, prices can be computed from marginal rates of substitution across goods. The numeraire is the price of z_1, and we denote by p_t the relative price of z_2.

Using the resource constraints, gross domestic product in country 1 (in terms of intermediate good z_1) is equal to $L_1 z_{1t}$ and the following national accounts identity holds

$$L_1 z_{1t} = P_{1t}^y L_1 (c_{1t} + i_{1t}) + TB_{1t} , \tag{3.11}$$

where P_{it}^y denotes the price of the final good in country i, and the trade balance TB_1 is

$$TB_{1t} = L_2 x_{21t} - L_1 p_t x_{12t} - L_1 p_t v_{12t}. \tag{3.12}$$

Analogously, in country 2 the national accounts identity is

$$L_2 p_t z_{2t} = L_2 P_{2t}^y (c_{2t} + i_{2t}) + TB_{2t} \ , \tag{3.13}$$

where the trade balance TB_2 is

$$TB_{2t} = L_1 p_{2t} v_{12t} + L_1 p_{2t} x_{12t} - L_2 x_{21t} \ . \tag{3.14}$$

The price of the final good is given by

$$P_{1t}^y = \kappa_1 \left[\theta_1 + (1 - \theta_1) p_t^{\rho/(\rho-1)} \right]^{\frac{\gamma\omega(\rho-1)}{\rho}} \left[\lambda + (1 - \lambda) p_t^{\zeta/(\zeta-1)} \right]^{\frac{\gamma(1-\omega)(\zeta-1)}{\zeta}} \tag{3.15}$$

in country 1, and

$$P_{2t}^y = \kappa_2 \left[\theta_2 (p_t)^{\rho/(\rho-1)} + (1 - \theta_2) \right]^{\frac{\gamma(\rho-1)}{\rho}} (p_t)^{1-\gamma} \tag{3.16}$$

in country 2, with $\kappa_2 = \left[\gamma^\gamma (1 - \gamma)^{1-\gamma} \right]^{-1}$ and $\kappa_1 = \kappa_2 \left[\omega^{\gamma\omega} (1 - \omega)^{\gamma(1-\omega)} \right]^{-1}$.

Sectoral differences in transmission mechanism

To gain some intuition for the transmission mechanism of trade in our model, it is helpful to examine the first-order conditions for the allocation of intermediate goods in the two sectors. Optimality in the use of intermediate goods in country 1 implies

$$\frac{1 - \theta_1}{\theta_1} \frac{x_{11t}}{x_{12t}} = p_t^{\frac{1}{1-\rho}} \tag{3.17}$$

in the assembly of composite x_1, and

$$\frac{1 - \lambda}{\lambda} \frac{v_{11t}}{v_{12t}} = p_t^{\frac{1}{1-\zeta}} \tag{3.18}$$

in the assembly of composite v_1.

A comparison of equations (3.17) and (3.18) makes clear that for a given change in p, the model produces larger reallocations between x_{11} and x_{12} than between v_{11} and v_{12} if $\rho > \zeta$. This is the key mechanism that causes country 2's exports in the vertically integrated composite (v_{12}) to be more correlated with country 1's output than country 2's exports in the horizontally integrated composite (x_{12}). Of course, another key determinant of these correlations is the comovement between the two composites x_1 and v_1, for which we need to fully solve the model.

Note also that optimality in the production of the horizontally differentiated composite in country 2 implies:

$$\frac{\theta_2}{1-\theta_2}\frac{x_{21t}}{x_{22t}} = p_t^{\frac{1}{1-\rho}} \tag{3.19}$$

If prices are more volatile when production sharing accounts for a higher fraction of trade, then substitution between domestic (x_{22}) and imported (x_{21}) intermediate goods in country 2 partly offsets the positive cross-country comovement in total manufacturing outputs.

To assess the quantitative importance of this form of business cycle transmission, we turn to a parametrized version of our model that is solved numerically.

4. Quantitative Analysis

Parameter values

We first discuss the choice of standard parameters in models of international business cycles: β, μ, σ, δ, and α. We follow BKK in setting the period length to one quarter, and choosing $\beta = 0.99$, $\sigma = 2$, $\mu = 0.36$, $\alpha = 1/3$, and $\delta = 0.025$. We set $\gamma = 0.2$ so that the share of tradeable output in GDP is roughly equal to that observed for manufacturing industries in OECD countries between 1990 and 2006. We set the elasticity of substitution between home and foreign intermediate inputs in the production of the differentiated manufactured good x, $[1/(1-\rho)]$, equal to the standard value of 2. To isolate the pure effect of international trade on international business cycle synchronization, we abstract from international spillovers of aggregate productivity $(P_{12} = 0)$ and assume that shocks to aggregate productivity are uncorrelated across countries $(\sigma_{12} = 0)$.[24] We follow BKK and set the persistence of the shocks P_{11} equal to 0.91. We normalize, without loss of generality under our strategy of targeting bilateral export shares discussed below, $A_1 = L_1 = L_2 = 1$. We choose A_2 so that in steady-state $p = 1$.

The remaining parameters are $\{\zeta, \lambda, \theta_1, \theta_2, \omega\}$, which are not conventional from the point of view of standard models of international business cycles.

We first discuss our choice of parameters λ and ζ in the production function of the vertically integrated composite. We set $\lambda = 0.75$, so that the share of country 1's intermediate input (v_{11}) in the vertically integrated composite (v) coincides with the average share of US imports in Mexican maquiladora gross output over the period 1993-2006 (as described in

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[24]Our model can generate a non-zero cross-country correlation of measured total factor productivity, if input variation is undermeasured at business cycle frequencies.

Section 2). In our benchmark calibration we choose ζ so that the the elasticity of substitution between home and foreign intermediate inputs in the vertically integrated good is equal to 0.05. Given the obvious importance of this parameter, we also evaluate the model assuming a higher elasticity of substitution in the production of the vertically integrated composite.

Finally, we choose θ_1, θ_2, and ω to generate different combinations of steady-state values for the volume of trade as a fraction of manufacturing output in each country (s_1^X and s_2^X), and the fraction of exports of country 2 accounted for by production sharing (s_2^P). We do not calibrate our model to replicate features of each individual country in Section 2 because we do not have direct evidence on the extent to which source country inputs v_{11} are included in bilateral trade flows. Instead, we consider all possible combinations of values of s_1^X, s_2^X, and s_2^P in the following grids: $s_1^X \in \{0.01, 0.05, 0.15\}$, $s_2^X \in \{0.01, 0.05, 0.15, 0.30, 0.45, 0.60\}$ and an evenly-spread 7-point grid for s^P between 0.05 and 0.9.[25] We can then examine how the transmission of international business cycles changes across this range of parameter values.

In our benchmark experiments, we assume that v_{11} is not shipped between countries, and hence is not included in the measures of exports and imports of both countries when constructing these shares. We also consider the other extreme that v_{11} is shipped between countries — recall that this alternative procedure does not have an impact on the equilibrium allocations, but only on the measures of trade.

For each set of parameter values, we solve the model via a standard log-linearization method. We then randomly draw 150 periods of the productivity shock vector ε_t, feed them into the model, and compute several moments of interest from the artificially generated data. We repeat this procedure 1500 times, and finally average the statistics across simulations to produce the numbers we report in the tables.

Results

In this section we study the model's implications for business cycle synchronization. To quantify the degree of business cycle synchronization, we focus on the cross-country correlation of quarterly HP-filtered fluctuations in output in the tradeable sector z_{it}^T, which we denote as $corr_{z^T}$. We focus on correlations for tradeable sectors because our model is designed to study the role of trade in business cycle synchronization and abstracts from

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[25]In a steady-state with balanced trade and $p = 1$, we can back out the values of θ_1, θ_2 and ω that are consistent with the assumed trade shares s_1^X, s_2^X, and s_2^P, using the three following expressions: (i) $s_1^X = \omega(1 - \theta_1) + (1 - \omega)(1 - \lambda)$, (ii) $s_2^X = 1 - \theta_2$, and (iii) $s_2^P s_1^X = (1 - \omega)(1 - \lambda)$.

considerations that are important for understanding correlations of total GDP, such as cross-country and cross-sector comovement of aggregate shocks. We examine, for our range of parameter values, how $corr_{z^T}$ varies with the share of trade in country 2's tradeable output s_2^X, and with the share of production sharing in country 2's exports, s_2^P. We first fix the share of trade in country 1's tradeable output (s_1^X) at 5%, and vary s_2^X and s_2^P separately. We then consider regressions of the form discussed in Section 2 using artificial data generated by the model where we jointly vary s_1^X, s_2^X, and s_2^P at the levels of the grids defined above.

Result 1: *Fixing s_2^P, $corr_{z^T}$ is increasing in s_2^X and fixing s_2^X, $corr_{z^T}$ is increasing in s_2^P.*

Figure 3, panel A, displays the relation between s_2^X (x-axis) and $corr_{z^T}$ (y-axis) for different values of s_2^P. Each vertical cluster of dots represents the range of $corr_{z^T}$ for various levels of s_2^P, holding the overall level of trade in country 2 (s_2^X) constant. We focus first on the impact of trade volume on bilateral correlations. The plot shows that for any level of s_2^P there is a positive relationship between the correlation and the volume of trade. For example, for $s_2^P = 5\%$ (represented by the lowest dot in each vertical cluster), an increase in s_2^X from 1% to 30% (moving along the x-axis) raises $corr_{z^T}$ from 0.03 to 0.1.

To understand how an increase in trade volume, all else constant, leads to higher output correlations, consider a positive productivity shock in country 1. For simplicity, here we abstract from the vertically integrated composite by assuming $\omega = 1$. Firms in country 1 produce more final output, which requires imports from country 2, x_{12}. This increase in the demand for country 2 output is partly offset by the increase in its relative price, p, inducing a substitution in country 2 from x_{22} to x_{21}. Overall, the increase in demand from country 1 dominates the substitution effect in country 2, so z_{1t}^T and z_{2t}^T are positively correlated, and the correlation increases as we raise the volume of trade.[26]

Figure 3, panel B, illustrates the impact of an increase in production sharing on bilateral correlations. Each vertical cluster of dots represents the range of $corr_{z^T}$ for various levels of s_2^X. For each level of s_2^X, the plot reveals a positive relation between s_2^P and $corr_{z^T}$. For example, fixing $s_2^X = 30\%$ (the fourth lowest set of dots in the figure for each level of s_2^P) an increase in s_2^P from 5% to 60% raises $corr_{z^T}$ from 0.1 to 0.16. The relatively lower elasticity of substitution in the production of the vertically integrated composite plays an important

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[26]Note that as p increases there is also substitution away from nontradeable goods in country 2, y_2^N, which leads to an overall decline of output in country 2, and a negative cross-country correlation between total GDPs z_1 and z_2.

role in this positive link between s_2^P and $corr_{z^T}$. If we assume instead that the elasticity of substitution is equal for the vertically integrated and horizontally differentiated composites, $(\zeta = \rho = 0.5)$, an increase in s_2^P from 5% to 60% leaves $corr_{z^T}$ roughly unchanged.

To flesh out the intuition for the importance of production sharing in generating positive cross-country correlations in output, consider again an increase in aggregate productivity in country 1. This generates an increase in the supply of both the horizontally differentiated and the vertically integrated composites in country 1. This raises the demand for imports x_{12} and v_{12} from country 2, as well as the relative price of country 2. This increase in p leads to a lower substitution effect in the vertically integrated composite when $\zeta < \rho$, so v_{12} increases more than x_{12} — see (3.17) and (3.18). A higher value of s_2^P raises the steady state level of v_{12} relative to x_{12}, and leads to a larger increase of z_2^T in response to the aggregate shock. Note that as we increase s_2^P, the positive transmission of the aggregate shock is partly offset by the fact that p rises more (i.e.: lower elasticities of substitution lead to larger movements in relative prices), and hence the substitution effects on x_{22} and x_{12} away from z_2^T are larger.

An increase in s_2^P has a similar impact on international business cycle comovements as a reduction in the elasticity of substitution between the home and the foreign good in a standard two- good model such as BKK. For example, if we assume $s_2^P = 0$, $s_1^X = 5\%$, and $s_2^X = 15\%$, then $corr_{z^T}$ falls from 0.21 to 0.06 as we raise the elasticity of substitution $1/(1-\rho)$ from 1/10 to 2. In our model, we generate variation in this elasticity of substitution through variation in the importance of production sharing in bilateral trade flows.

Note that the model also has implications for the comovement between country 2's exports to country 1 and country 1's manufacturing output. When $\zeta < \rho$, the correlation between fluctuations in production sharing exports from country 2 to country 1 (v_{12}) and fluctuations in z_1^T is roughly 1. The correlation between exports of the horizontally differentiated composite (x_{12}) and country 1 output is smaller, equal to 0.4. The fact that exports associated with production sharing are more tightly linked to economic activity in country 1 than exports not associated with production sharing, is consistent with the observations in the data discussed in Section 2.

Result 2: a) The positive relation between s_2^X and $corr_{z^T}$ is increasing in s_2^P. Similarly, b) the positive relation between s_2^P and $corr_{z^T}$ is increasing in s_2^X.

To understand b), note that in Figure 3, panel B, the slope between s_2^P and $corr_{z^T}$ is higher for higher levels of s_2^X . The higher is the share of exports in output, the more

important is the role of production sharing in shaping $corr_{z^T}$. A similar logic applies for a). The slope between s_2^X and $corr_{z^T}$ is higher for higher levels of s_2^P. A higher share of production sharing in trade leads to stronger complementarities, so an increase in trade induces higher comovements in business cycles. Hence, to understand the link between the volumes of trade and business cycle synchronization, it is important to distinguish between trade in vertically integrated inputs and trade in horizontally differentiated inputs.

From results 1 and 2, it becomes apparent that we need to jointly vary s_1^X, s_2^X and s_2^P in order to quantify the role of s_2^X and s_2^P in shaping $corr_{z^T}$. To do this, we generate artificial data from the model under all the possible combinations of $\{s_1^X, s_2^X, s_2^P\}$ as defined by the grids above. We then consider the following univariate regressions:

$$corr_{z^T} = \alpha + \beta^i X^i + e_{12i} \text{ , for } X^i = s_2^X s_2^P \text{ , } s_2^X \text{ , and } s_2^P. \tag{4.1}$$

Note that, due to the independence of s_2^X and s_2^P, $\beta^{s_2^X}$ and $\beta^{s_2^P}$ are identical to those obtained in a bivariate regression in which s_2^X and s_2^P are simultaneously included as right hand side variables.

Table 4 reports the results from these regressions. The first three columns are calculated under the assumption that v_{11} is not included in the measure of exports when constructing s_2^X and s_2^P. The last three columns are calculated under the assumption that v_{11} is shipped back and forth between countries, and hence is included in exports in both countries when constructing s_2^X and s_2^P. Row 1 displays the results under the benchmark parameterization. The remaining rows on the tables performs sensitivity analysis with respect to key model parameters.

Result 3: The regression coefficients on s_2^X and s_2^P are both positive, with the former being larger than the latter.

Row 1 in Table 4 shows that in the baseline model, $\beta^{s_2^X} = 0.43$ and $\beta^{s_2^P} = 0.13$ when v_{11} is excluded from the export measures.[27] This positive relation between the volume of trade, the production-sharing intensity of trade, and tradeable output correlations, results in a strong positive relation between the latter and the share of production-sharing exports in tradeable output ($\beta^{s_2^X s_2^P} = 0.69$).

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[27] If instead of focusing on tradeable output cross-country correlations $corr_{z^T}$, we examine cross-country correlations of the employment used to produce this tradeable output, we obtain regression coefficients $\beta^{s_2^x}$ and $\beta^{s_2^P}$ that are roughly three times larger. The relative magnitudes of $\beta^{s_2^x}$ and $\beta^{s_2^P}$ remain roughly unchanged.

Note that, as discussed under our *Result 2*, the extent of production sharing shapes the positive link between the volume of trade and bilateral correlations. In the context of our current regression, if we set $s_2^P = 0.05$ and vary s_1^X and s_2^X according to the grids defined above, we obtain $\beta^{s_2^X} = 0.3$. In contrast, if we set $s_2^P = 0.9$, we obtain $\beta^{s_2^X} = 0.6$. By varying s_2^P between 0.05 and 0.9 we obtain $\beta^{s_2^X} = 0.43$ in our baseline regression.

If country 1's production sharing inputs v_{11} flow back and forth between countries and are thus included in the export measures, then the model implies $\beta^{s_2^X} = 0.17$, and $\beta^{s_2^P} = 0.13$. The lower coefficient on $\beta^{s_2^X}$ in this case can be understood as follows. If v_{11} is included in the measures of exports, then increasing the weight of the vertically integrated composite also increases the share of exports in GDP (even though s_2^X exclusive of v_{11} remains constant). This results in more variation in s_2^X, for the same GDP correlations (recall that these do not vary as we change the measurement of exports), which implies a lower coefficient on s_2^X. Note that the positive link between the production sharing intensity of trade and tradeable GDP correlations $\beta^{s_2^P}$ is quite insensitive to the inclusion of v_{11} in the export measures.

In the second row, we set $\zeta = \rho = 0.5$, making the production of both composites equally elastic in the home and foreign inputs. Not surprisingly, the coefficient on s_2^P is very close to zero (it is not exactly equal to zero because the composites x_1 and v_1 are not perfectly synchronized). This case, which is essentially the BKK model with trade in horizontally differentiated varieties, produces a positive regression coefficient on s_2^X, with $\beta^{s_2^X} = 0.33$, when v_{11} is excluded from the export measures. In this case the output correlation is driven entirely by the volume of trade.[28]

We conclude that the benchmark model generates a positive link between the share of production sharing in trade and cross-country tradeable output correlations, which is smaller than the positive link between the overall share of trade and cross-country output correlations, with the difference in magnitudes depending on the extent that production sharing inputs from country 1 are shipped back and forth between countries.

Sensitivity Analysis

Rows 3 through 6 examine a variety of sensitivity analyses to changes in the parameter values in the production function of the vertically integrated composite. Rows 3 through 4

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[28]If we instead focus on correlations for total output z_1 and z_2, then we obtain a small negative regression coefficient $\beta^{s_2^X}$ due to the large substitution effects on nontradeable consumption in the presence of fluctuations in p.

relax the extremely high complementarity between home and foreign inputs in the production sharing composite, holding the elasticity in the other composite at 2. In particular, we assume an elasticity of substitution equal to 0.5 and 1, respectively. In both cases the coefficient on production sharing drops, while the coefficient on the export share increases slightly. Row 5 assumes an elasticity of substitution equal to 1 in the vertically integrated composite, and an elasticity of substitution equal to 4 in the horizontally differentiated composite. This perturbation of the model also lowers slightly the positive coefficient on s_2^P. Overall, the model implies a positive link between s_2^P and $corr_{z^T}$ if $\zeta < \rho$.

Row 6 shows that the regression results remain roughly unchanged if we increase the share of country 1 dependence on foreign inputs in the production sharing composite (lower λ), while simultaneously lowering ω to keep s_2^P unchanged.

We also varied the elasticity of substitution between the tradeable and nontradeable final goods in (3.6), as well as the elasticity of substitution between the horizontally differentiated and the vertically integrated composite goods in (3.5) – our benchmark model assumes an elasticity equal to one in both cases. We find that lower elasticities of substitution lead to slightly higher regression coefficients on s_2^P relative to s_2^X. For example, if we reduce the elasticity to 0.5 for both aggregators, then we obtain $\beta^{s_2^X} = 0.40$, $\beta^{s_2^P} = 0.14$ if v_{11} is excluded from the exports measures, and $\beta^{s_2^X} = 0.25$, $\beta^{s_2^P} = 0.13$ if v_{11} is included.

5. Conclusion

The phenomenon of production sharing appears to be an increasingly important component of international trade flows. This paper asks whether production sharing has a significant effect on the transmission of business cycles across national borders. Data on flows between US multinationals and their foreign affiliates, as well as between the United States and Mexican maquiladoras, suggest that trade related to production sharing has a correlation with foreign manufacturing output that is higher than for non-production-sharing trade. The data also suggest that production-sharing intensity is at least as important as trade volume in accounting for bilateral manufacturing output correlations. An important task for future research is to assess the robustness of these empirical findings using detailed data on production sharing, including arms-length transactions, and with more information on the extent of substitutability between inputs and processes.

We develop a stylized-two-country model to study the relationship between business cy-

cles and trade in vertically integrated goods. A key assumption is that home and foreign inputs are less substitutable in the production of vertically integrated goods than in horizontally differentiated goods at business cycle frequencies. The model is consistent with our empirical findings that exports to a particular country used in the production of the vertically integrated good are more tightly linked to the aggregate fluctuations of that country than exports used in the production of the horizontally differentiated good. Our model generates business cycles that are more synchronized between pairs of countries with a higher share of international trade in inputs utilized in the production of vertically integrated goods than between pairs of countries where trade is dominated by inputs used to produce horizontally differentiated goods.

The model is based on a number of simplifying assumptions that deserve further study. In particular, we abstract from longer run substitutability across countries in the location of production-sharing plants. One possible direction for further study is to include fixed costs in the establishment of a production-sharing arrangement. This margin will be operative when shocks are large and persistent (that is, during trade liberalizations, changes in taxation of foreign corporations, etc.). Under this extension, the model has the potential of providing insight into the issue of "footloose" multinationals shifting their production operations across countries at low frequencies, as well as higher-frequency business cycle synchronization between countries.

The model also abstracts from additional forces that can lead to a stronger link between production sharing and international business cycles. It is possible that countries that engage in production sharing are also more likely to experience common shocks, as they specialize in similar industrial sectors. It may also be the case that technology shocks are more easily transmitted from one country to another if firms transcend national borders. Finally, if production sharing tends to be concentrated in sectors that are more affected by cyclical fluctuations (such as, for example, automobile production), the transmission mechanism will also be amplified.

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Data Appendix

Both real and nominal US manufacturing value added data source from the BEA. For years 1980 to 1986 in which no manufacturing value added deflator exists, the deflator is imputed from the GDP deflator. Manufacturing trade data are from the OECD international trade in commodities database. The data on affiliate sales and trade come from BEA's Operations of U.S. Parent Companies Foreign Affiliates data. All values are in dollars and the nominal values for affiliates and maquiladoras are deflated with the US CPI. Mexican PPI, US-Peso exchange rate, and the maquiladora trade data are from the Bank of Mexico. The data source for the US PPI and CPI is the Bureau of Labor Statistics.

Table 1: Extent of Production Sharing by Country or Region

	1977	1982	1989	1994	1999	2003

A. Sales by US Affiliates to the US, as a Share of Total Sales of Affiliates (Manufacturing)

	1977	1982	1989	1994	1999	2003
Canada	0.26	0.29	0.35	0.43	0.43	0.34
Mexico	0.07	0.08	0.29	0.32	0.34	0.31
inc. Maquiladoras		0.19	0.50	0.52	0.56	0.54
Europe	0.02	0.02	0.05	0.04	0.06	0.06
Japan	0.03	0.07	0.05	0.05	0.05	0.04

B. US Exports from Parents to Affiliates/Total Sales of Affiliates (Manufacturing)

	1977	1982	1989	1994	1999	2003
Canada	0.30	0.31	0.28	0.33	0.23	0.18
Mexico	0.15	0.22	0.40	0.39	0.35	0.29
inc. Maquiladoras				0.50	0.49	0.44
Europe	0.06	0.06	0.05	0.05	0.04	0.03
Japan	0.09	0.11	0.10	0.09	0.08	0.07

C. Production Sharing Intensity of Trade, Affiliate Sales to the US/Exports to US (Manufacturing)

	1977	1982	1989	1994	1999	2003
Canada	0.65	0.54	0.54	0.51	0.47	0.47
Mexico	0.14	0.15	0.22	0.26	0.23	0.21
inc. Maquiladoras		0.43	0.54	0.58	0.56	0.55
Europe	0.11	0.09	0.17	0.14	0.17	0.17
Japan	0.00	0.01	0.01	0.02	0.02	0.02

Sources: Data on manufacturing exports from OECD, US affiliates data from the Bureau of
Economic Analysis, and Maquiladora Data from Bank of Mexico.

Table 2: Production Sharing, Exports, and Source Country Output

Table 2a: Relationship between US Manufacturing Value Added, Affiliate Sales, and Exports

$$USmanva_t = \alpha + \beta_1(affilsales_{jt}) + \beta_2(nonaff\ extoUS_{jt}) + \varepsilon_t$$

where $USmanva_t$ denotes US Manufacturing value added, $affilsales_{jt}$ denotes US affiliates' sales from country j to the US, and $extoUS_{jt}$ denotes total exports of country j to the US net of affiliates trade.

Detrending method:	Correlations with US Manu. Value added		p-values corresponding to H_0: $\beta_1 - \beta_2 < 0$	
	affilsales $_{jt}$	*extoUS $_{jt}$*	*No country fixed effects*	*Country fixed effects*
First-differences	0.142***	0.050	0.005	0.009
HP filter	0.148***	0.045	0.005	0.006

*** indicates significance at the 1%, ** at the 5%, and * at 10%

Table 2b: Relationship between US Production, Maquiladora, and Nonmaquiladora Exports

$$USmanva_t = \alpha + \beta_1(maq_t) + \beta_2(nmaq_t) + \varepsilon_t$$

where $USmanva_t$ denotes US manufacturing value added, maq_t denotes manufacturing maquiladora exports , and $nonmaq_t$ denotes non maquiladora manufacturing exports .

Detrending method:	Correlations with US Manu. Value added		p-values corresponding to H_0: $\beta_1 - \beta_2 < 0$	
	maq $_t$	*nmaq $_t$*	*No Time fixed effects*	*Time fixed effects*
First-differences	0.794***	0.531***	0.001	0.001
HP filter	0.855***	0.538***	0.001	0.002

*** indicates significance at the 1%, ** at the 5%, and * at 10%

Sources: The affilate data are annual from 1983-2003, while the maquiladora data from 1980-2005. US manufacturing value-added and affiliates' sales from BEA; Exports to US from OECD International Trade in Commodities datbase; maquiladoras trade from Bank of Mexico. All values are in real US dollars deflated with CPI or BEA value added deflator. The results are roughly unchanged when using nominal values.

The panel in table 2a includes 39 countries: Argentina, Australia, Austria, Brazil, Canada, Chile, China, Colombia, Costa Rica, Czech Republic, Denmark, Dominican Republic, Finland, France, Germany, Greece, Guatemala, Hong Kong, Hungary, India, Ireland, Italy, Japan, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Singapore, South Korea, Spain, Sweden, Switzerland, Thailand, UK, and Venezuela.

Table 3: Production Sharing, Trade, and International Business Cycles

$$\frac{affilsales_{ij}}{mftgVA_j} = \left(\frac{affilsales_{ij}}{mftgEXP_{ij}}\right)\left(\frac{mftgEXP_{ij}}{mftgVA_j}\right)$$

where *affilsalesij* denotes affiliate sales to country i from country j, *mftgVA$_i$* denotes manufacturing value added in country i, and *mftgEXPij* denotes manufacturing exports to country i from j.

Table 3a: Univariate Regressions

$$MftgVAcorr_{ij} = \alpha + \beta(trade_{ij}) + \varepsilon_t$$

where mftgVA*corr$_{ij}$* denotes bilateral manufacturing correlation between countries i and j and trade $_{ij}$ is a measure of the trading relationship between i and j described below.

$trade_{ij}$	$\left(\dfrac{affilsales_{ij}}{mftgVA_j}\right)$	$\left(\dfrac{affilsales_{ij}}{mftgEXP_{ij}}\right)$	$\left(\dfrac{mfgEXP_{ij}}{mftgVA_j}\right)$
α	0.177***	0.087	0.170***
	(0.0516)	(0.0720)	(0.0616)
β	0.940**	0.850**	0.290*
	(0.4291)	(0.3679)	(0.1529)
R^2	0.177	0.247	0.115

*** indicates significance at the 1%, ** at the 5%, and * at 10%

Table 3b: Multivariate Regression

$$mftgVAcorr_{ij} = \alpha + \beta_1\left(\frac{affilsales_{ij}}{mftgEXP_{ij}}\right) + \beta_2\left(\frac{mfgEXP_{ij}}{mftgVA_j}\right) + \varepsilon_{ij}$$

α	**β$_1$**	**β2**	**R^2**
0.069	0.746**	0.140	0.247
(0.0755)	(0.3636)	(0.0901)	

*** indicates significance at the 1%, ** at the 5%, and * at 10%

Sources: Data are annual from 1983-2003; Affilates trade data from BEA; exports to US data from OECD International Trade in Commodities datbase. Manufacturing value added correlations are computed by hp-filtering real annual manufacturing value added data from WDI, OECD, and BEA.
 The estimates include 33 country pairings with the US: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, Colombia, Costa Rica, Denmark, Dominican Republic, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Portugal, Singapore, South Korea, Spain, Sweden, Switzerland, Thailand, UK, and Venezuela. The results are roughly unchanged if we include the intra-European country pairings and are robust to the exclusion of outliers.

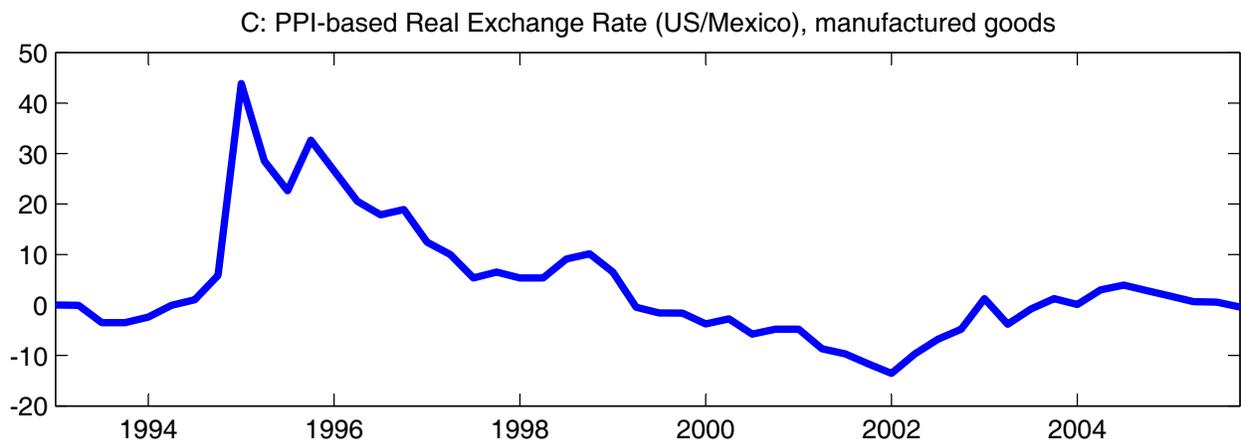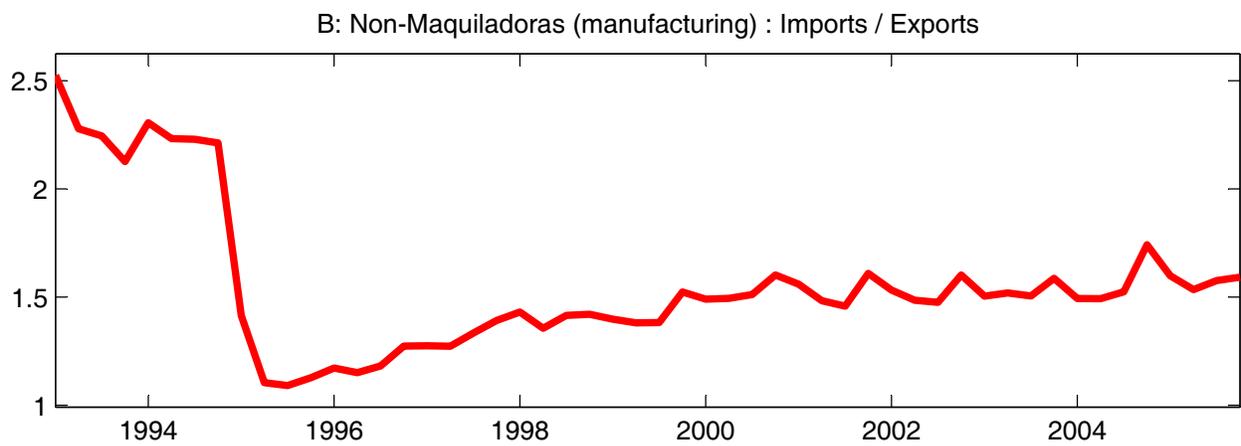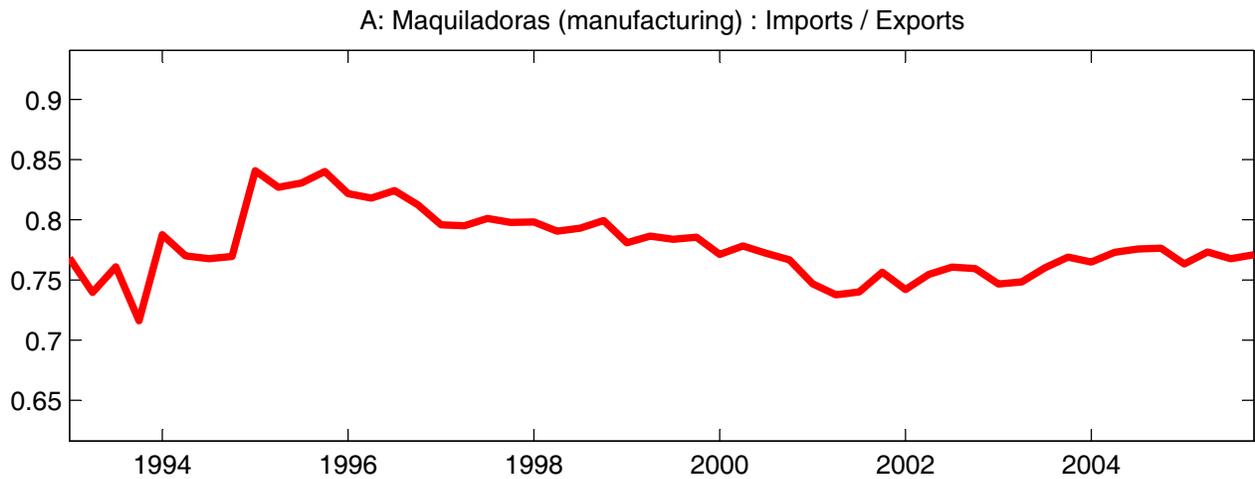# Table 4: Model-Based Production Sharing Decompostion

$$corr_{zt} = \alpha + \beta^i(X^i) + \varepsilon_{12i}$$

$corr_{zt}$ denotes cross-country tradeable output correlation, X^i is a measure of the trading relationship between countries 1 and 2.
Trade measures and correlations generated from grids defined in Calibration description, each combination of grid is denoted by j

	V11 excluded from export measurement			V11 included in export measurement		
	Production sharing / Tradeable GDP 2 $s_2^P s_2^X$	Production share in exports 2 s_2^P	Exports share in Tradeable GDP 2 s_2^X	Production sharing / Tradeable GDP 2 $s_2^P s_2^X$	Production sharing in exports 2 s_2^P	Exports sharing in Tradeable GDP 2 s_2^X
Baseline Model						
	0.69	0.13	0.43	0.17	0.13	0.17
Sensitivity analysis						
$1/(1-\zeta) = 2$	0.37	0.01	0.33	0.09	0.01	0.10
$1/(1-\zeta) = 1$	0.50	0.06	0.38	0.13	0.06	0.13
$1/(1-\zeta) = 0.5$	0.59	0.09	0.42	0.15	0.09	0.15
$1/(1-\rho) = 4, 1/(1-\zeta) = 1$	0.43	0.09	0.28	0.11	0.09	0.11
$\lambda = 0.6$	0.66	0.14	0.40	0.27	0.13	0.25

Details of calibration and model solution are described in the text.

Figure 1: Real Exchange Rate and Import Content, Mexico

A: Maquiladoras (manufacturing) : Imports / Exports

B: Non-Maquiladoras (manufacturing) : Imports / Exports

C: PPI-based Real Exchange Rate (US/Mexico), manufactured goods

Source: Banco de Mexico and BLS

Figure 2: Output Correlations and Trade Flows

Figure 2a: Production Sharing and Bilateral Manufacturing Output Correlations
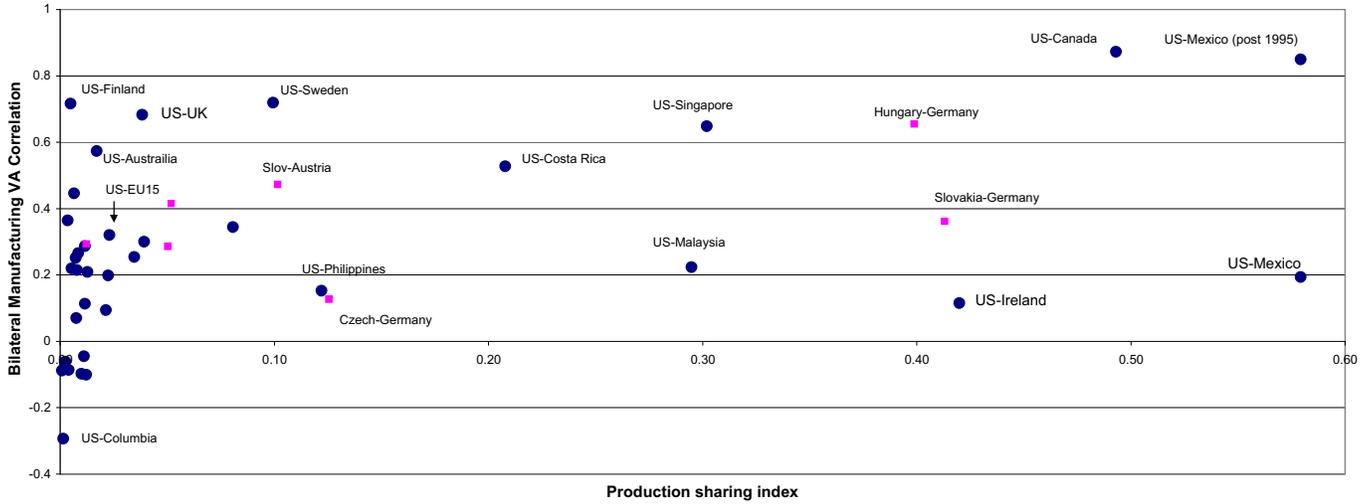

Figure 2b: Production Sharing Intensity of Trade and Bilateral Manufacturing Output Correlations
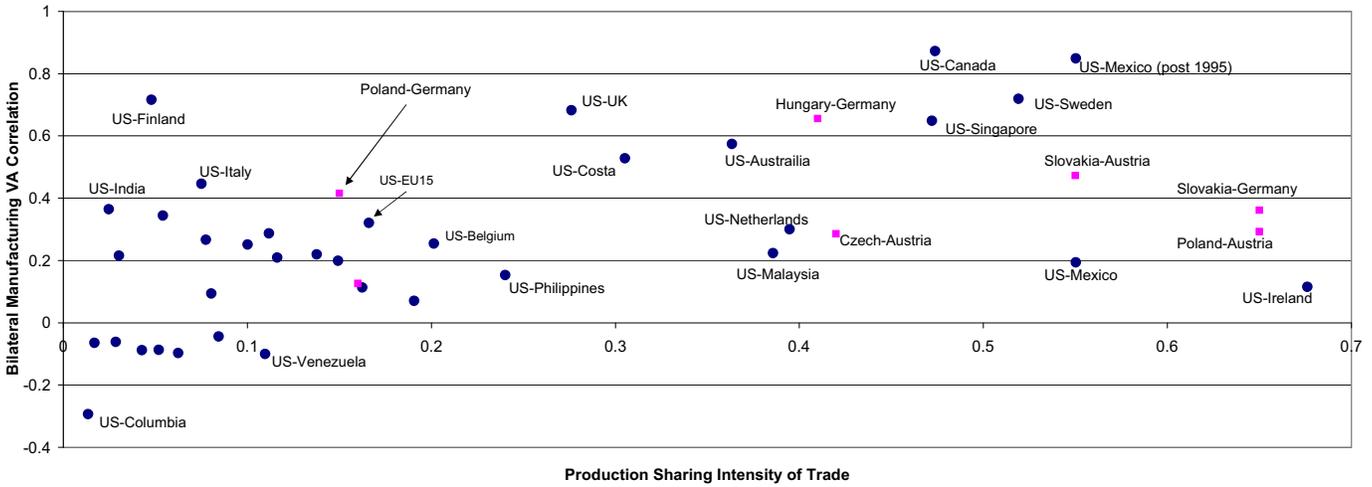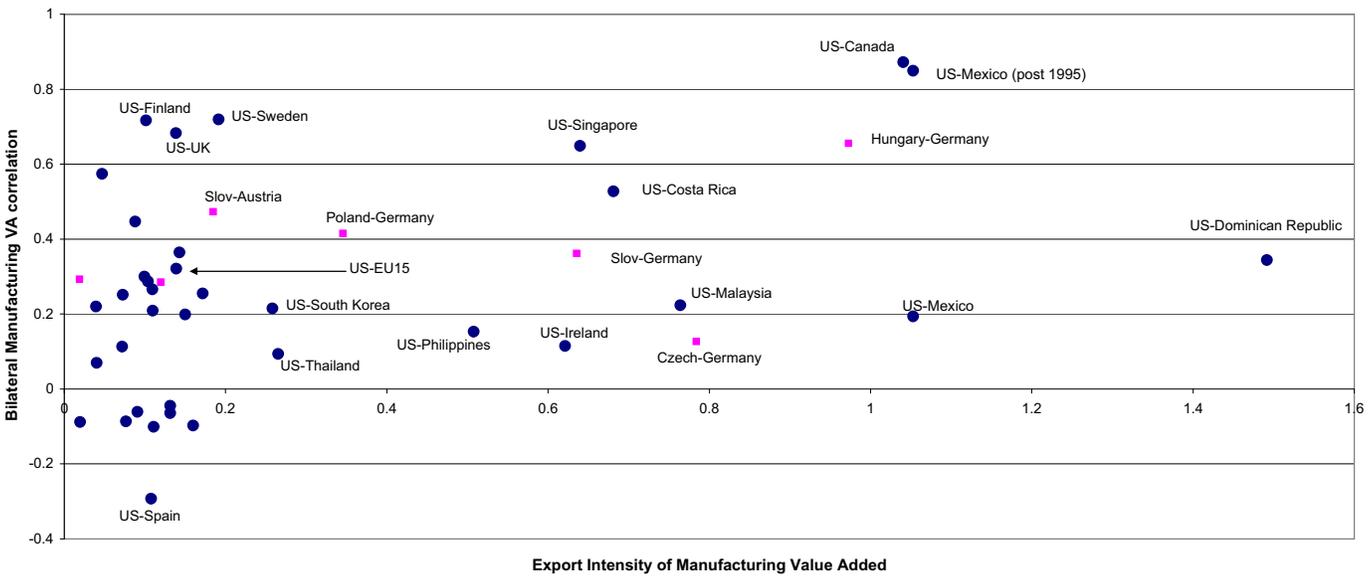

Figure 2c: Bilateral Output Correlations and Export Intensity of Manufacturing

Notes: Production sharing indices for all observations except for East Europe are based on BEA data on flows between US multinationals and their affiliates. The index is calculated for 2003. See text for details. The bilateral output correlations for all observations except for those within Eastern Europe are based on correlations between HP filtered real manufacturing value added from BEA and HP-filtered real manufacturing value added from WDI and OECD for the affiliate host country, over the period 1983-2003

Figure 3: Model Based Bilateral Correlation Results

Figure 3A
Trade Share and Business Cycle Comovement
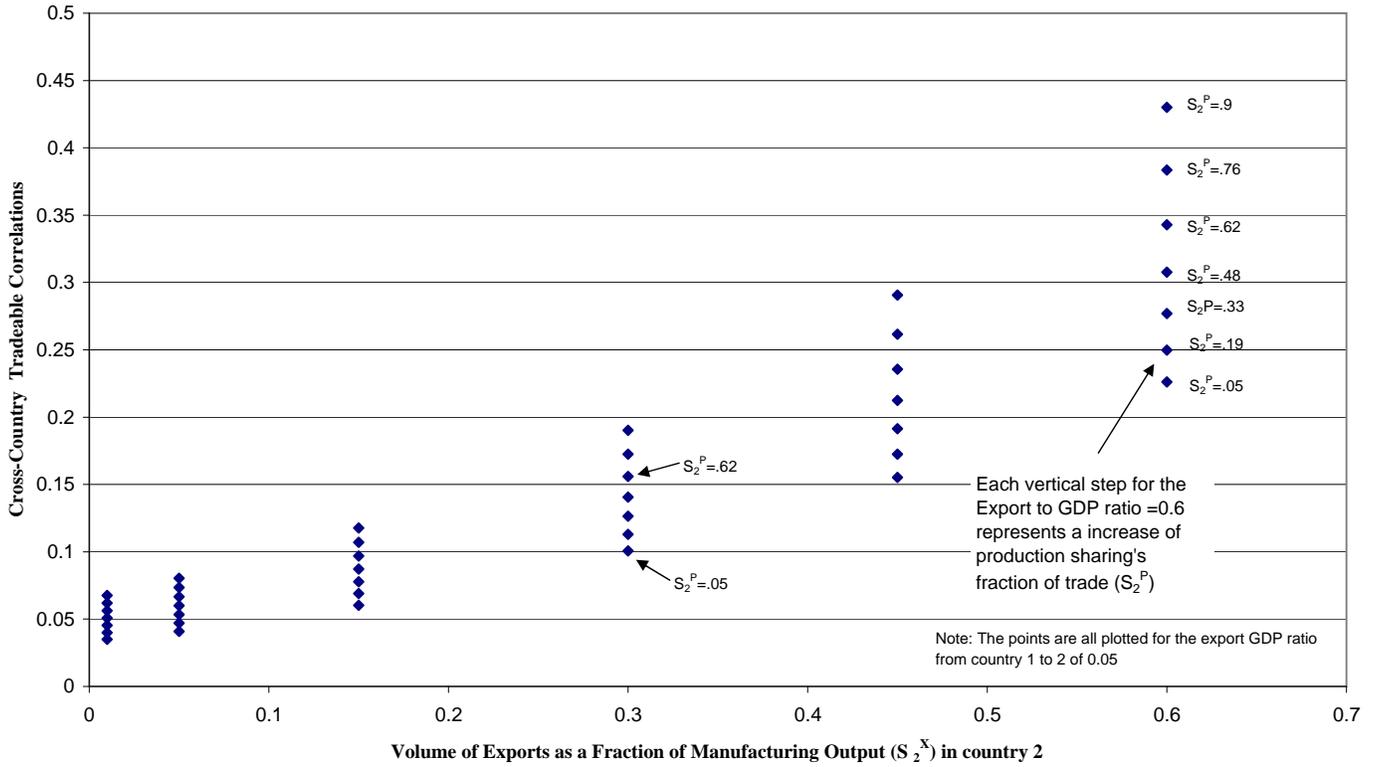
Figure 3B
Production Sharing Composition of Trade and Business Cycle Comovement