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The Trade Comovement Puzzle and the Margins of International Trade

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Abstract

Countries that trade more with each other tend to have more correlated business cycles. Yet, traditional international business cycle models predict a much weaker link between trade and business cycle comovement. We propose that the international diffusion of technology through trade in varieties may be driving the observed comovement by increasing the correlation of total factor productivity (TFP). Our hypothesis is that business cycles should be more correlated between countries that trade a wider variety of goods. We find empirical support for this hypothesis. After decomposing trade into its extensive and intensive margins, we find that the extensive margin explains most of the trade-TFP and trade-output comovement. This result is striking because the extensive margin accounts for only a third of total trade. We then develop a three-country model of technology innovation and international diffusion through trade, in which TFP correlation increases with trade in varieties. A numerical exercise shows that the proposed mechanism increases business cycle synchronization relative to traditional models. Impulse responses to a TFP shock in one country reveal a strong positive effect on the output of its trading partner. Finally, our model implies a trade-output coefficient that is 40% of that observed in the data and 5 times higher than that predicted by standard models.

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1. Introduction

Countries that trade more with each other tend to have more correlated business cycles (Frankel and Rose (1998)). Despite this evidence, traditional international business cycle (IBC) models predict a much weaker link between trade and output comovement.[1] Kose and Yi (2006) can propose several solutions to what they call the "trade comovement puzzle". In particular, they find that (i) total factor productivity (TFP) shocks are more correlated across countries that trade more with each other, and (ii) that calibrations of the standard model that account for this fact are able to fully capture the trade-output comovement observed empirically. However, the underlying mechanisms connecting trade and TFP comovement remain unexplained.

We propose that the international diffusion of technology - through trade in varieties - may be one of the forces driving TFP comovement and thereby output comovement. Indeed, a recent literature shows that trade in varieties can explain differences in TFP growth across countries (Broda, Greenfield, and Weinstein (2006), Goldberg, Khandelwal, Pavcnik, and Topalova (2010), Santacreu (2009)). The main idea is as follows. In autarky, a country's TFP depends only on domestic technology (Romer (1990)). In the case of international trade, however, TFP depends also on foreign technologies embodied in imported goods. Thus trade in varieties involves the international diffusion of technologies through which countries benefit from each others' innovations. Based on this premise, our hypothesis is that business cycles should be more correlated for countries that trade a wider variety (and not necessarily a greater quantity) of goods.[2]

First, we find empirical support for this hypothesis. We update the trade-output and trade-TFP comovement regressions and find results in line with the literature. We then decompose trade intensity into its extensive and intensive margins. We find that the former explains most of the trade-TFP and trade-output comovement while the latter plays only a marginal role.[3] These results hold both at high and medium frequencies.[4] In particular, we find that when the intensive margin is held

[1] In the standard IBC model, which is driven by productivity shocks, two opposing forces determine the trade-output comovement. First, more trade leads to more synchronization by increasing the demand for foreign products (`*demand complementarity*' effect). Second, greater integration induces a stronger reallocation effect toward the most productive country, lessesing synchronization (`*resource-shifting*' effect). When markets are complete, the latter effect dominates. In addition to the standard channels, a third channel - the `*terms of trade*' effect - has an ambiguous sign. An economy experiencing a positive productivity shock benefits from lower prices and so increases its market share relative to other economies, reducing business cycle synchronization. Yet, foreign economies too, benefit from cheaper imports, increasing synchronization. Which effect dominates depends on the elasticity of substitution between domestic or foreign intermediate goods as well as on the share of imported intermediate goods in the foreign economies.

[2] Goldberg, Khandelwal, Pavcnik, and Topalova (2009) and Goldberg, Khandelwal, Pavcnik, and Topalova (2010) study Indias's 1991 trade liberalization and show that imports of varieties generate static and dynamic gains from trade and increase productivity at the plant level.

[3] The extensive margin refers to how much trade is driven by the number of products, and the intensive margin refers to the quantity of each product that is traded.

[4] Comin and Gertler (2006) show that there are strong procyclical movements in embodied technological change, research and development (R&D), and TFP over the medium term. Furthermore, there is strong comovement between output and embodied technological change both at high and medium frequencies. They argue that the strong medium-term procyclicality of TFP may be explained by endogenous productivity. The idea is to introduce mechanisms via which investments in resources lead to higher future productivity.

constant, a doubling of the median extensive margin of trade is associated with an increase in the bilateral TFP correlation of about 0.08 and in the bilateral GDP correlation of about 0.06. In contrast, when the extensive margin is held constant, doubling the median intensive margin of trade is associated with a decrease in the bilateral TFP correlation of about 0.013 and an increase of the bilateral GDP correlation of about 0.01. These estimates are statistically significant only for the extensive margin of trade. Our finding that the extensive margin explains most of the trade-TFP and trade-output comovement is striking because that margin accounts for only a third of the bilateral trade intensity observed in the data. This suggests that an increase in the number of products traded - and not an increase in the volume of each product traded - may lead to a significant increase in TFP comovement and output comovement.

Next, we develop a three-country IBC model with the following features.[5] First, there is trade in differentiated intermediate and capital goods.[6] Second, the dynamics of TFP are mainly driven by domestic innovations and the diffusion of foreign innovations (Santacreu (2009)); this is the mechanism we propose to explain the so-called trade comovement puzzle. Third, variations in trade are induced by iceberg transport costs (which affect mainly the intensive margin of trade) and fixed costs associated with entry-regulations (which affect mainly the extensive margin).

In each country, a firm produces a nontraded final good using domestic and foreign intermediate goods (varieties). Production involves love-for-variety à la Ethier (1982), so production efficiency (TFP) increases with the number of varieties used. Technological innovation occurs when innovators invest the final good to carry out R&D. We allow for spillover effects: R&D productivity increases with the number of technologies available in the country.[7] Each new technology is embodied in a different variety. Domestic varieties (and the domestic innovations they embody) are immediately available to domestic final producers, but foreign varieties become available only after a time-consuming process (which we refer to as adoption) that is slowed-down by entry costs. Country differences in regulations induce differences in the extensive margin of trade.[8]

In the model, two channels strengthen the correlation between trading partners of TFP growth rates. The first such channel is the traditional demand-supply spillover effect. This effect is present in standard IBC models but is empirically too small to explain the trade-output comovement observed in

5 Our choice of a three-country model is based on Kose and Yi (2006)'s argument that, in a two-country model, one of the countries would be the rest of the world and so the model would overstate the impact of one country on the other. A three-country model is needed to accommodate the third-country effect.

6 The structure of international trade in the last decade has shifted toward intermediate and capital goods explaining a higher share (78% of total trade corresponds to capital (14%) and intermediate inputs (64%), and only 22% corresponds to consumption goods). A similar decomposition into consumption, capital, and intermediate goods is obtained when one considers the number of goods traded, rather than trade flows.

7 This is the so-called "variety in, variety out model" of Goldberg, Khandelwal, Pavcnik, and Topalova (2009) and Goldberg, Khandelwal, Pavcnik, and Topalova (2010).

8 This approach to modeling adoption differs from that of Santacreu (2009) and of Comin, Gertler, and Santacreu (2009) in that, in those earlier models, firms must invest resources to adopt the variety through a slow and costly process. In contrast, adoption in our model is exogenous, and it is characterized by a slow process of technology diffusion.

the data. A second (albeit less direct) channel results from the international diffusion of technologies embodied in the traded varieties. Following a positive shock to domestic TFP, domestic final producers do increase their demand for foreign intermediate goods, which in turn increases foreign output. This is the standard demand-supply channel. In addition, however, higher output increases the expected future profits of foreign innovators that sell the varieties to final producers, which spurs the former to invest more in R&D. The resulting higher rates of innovation and technology transfer raise production efficiency by increasing the extensive margin and thereby final output. This international technology diffusion channel reinforces the demand-supply channel, and hence might explain both the trade-TFP and the trade-output comovement.

Finally, we conduct a quantitative analysis to illustrate the main mechanisms of the model. Toward this end, we first analyze how the international diffusion of technologies through trade in varieties amplifies the effect of a TFP shock to one country on the output growth of its trading partner. Second, we consider a 10% decrease in iceberg transport costs between two countries and then analyze its effect on the bilateral correlation of output growth and of TFP growth. This exercise allows us to recover the trade-output coefficient implied by our model, which we compare to the coefficient implied by the data. Our results show that TFP shocks in one country propagate to its trading partners through trade in varieties. The propagation is stronger in our model than in an otherwise similar model of innovation that does not incorporate international diffusion and stronger still than in the IBC model. Then, to compute the trade-output comovement regression coefficient implied by our model, we let the iceberg transport costs vary; this induces variations in bilateral trade intensity, which increase the correlation of output growth across trading partners. The coefficient is higher when entry costs are lower. Adding international technology diffusion to the standard IBC model allows us to explain 40% of the trade-output coefficient found in empirical studies.

Taken together, our results suggest that: (i) much of the trade-TFP and trade-output comovement is explained by the extensive, rather than the intensive, margin of trade; and (ii) the international diffusion of technology through trade in varieties is a plausible explanation for these relationships.

Several strands of literature have tackled the trade comovement puzzle. Kose and Yi (2006) document that TFP shocks are more strongly correlated across countries that trade more with each other. Others emphasize the role of intermediate inputs in increasing plant-level productivity after trade liberalization (e.g., Goldberg, Khandelwal, Pavcnik, Topalova (2009, 2010), Kugler and Verhoogen (2009), Manova and Zhang (2011)). The main innovations in this paper are to disentangle the effects of the extensive and intensive margins of trade on the comovement of TFP growth and output growth and to propose a mechanism explaining the importance of the extensive margin of trade.

Another strand of literature studies the role of vertical linkages, both empirically (Burstein, Kurz, and Tesar (2008), Di Giovanni and Levchenko (2009), Johnson (2011), Ng (2010)) and theoretically (Arkolakis and Ramanarayanan (2009)). Like ours, these papers emphasize the amplifying effect of traded intermediate goods. However, the amplification reported in those papers is driven by the multistage nature of production, whereas in our paper it is driven by the international diffusion of technologies. Comin, Loayza, Pasha, and Serven (2009) also use international technology diffusion to explain how business cycles in the United States propagate to Mexico.

Finally, Drozd and Nosal (2008) posit that a low elasticity of substitution between domestic and foreign intermediate goods at business cycle frequencies can partly explain the trade-output comovement. In their model, frictions in the short run generate a low price elasticity that is compatible with the high long-run elasticity of substitution observed in the data. Although that model captures as much as 50% of the correlation between trade and output comovement found in empirical studies, the mechanism by which that occurs has not been well established empirically.

This paper proceeds as follows. Section 2 updates the trade-output and trade-TFP comovement regressions. Section 3 decomposes bilateral trade intensity into the intensive and extensive margins of trade and shows that much of the comovement is due to the latter. Section 4 presents the model, and Section 5 conducts a quantitative analysis. Section 6 concludes.

2. The Trade-Output Comovement Relationship Revisited

In this section, we study the relationship between bilateral trade intensity and bilateral correlation of real output in terms of gross domestic product (GDP).[9]

We first update the Frankel and Rose (1998) regression for a 30-country sample spanning the period 1980 Q1 to 2009 Q4. This sample of 20 OECD countries and 10 developing countries accounts for nearly 75% of world GDP and 73% of world trade.[10] The country list is given in Appendix B as Table 23.

The output data are transformed in three ways. First, we apply the Hodrick-Prescott (HP) filter (using the traditional smoothing parameter of 1600) to the real GDP series. Second, we take first differences of natural logarithms of real GDP to calculate the output growth rate. Finally, we apply the band-pass (BP) filter on real GDP to remove the high-frequency variations retaining frequencies between 32 and 116 quarters. The first two measures capture business cycle frequencies; the third captures medium-term business cycles (Comin and Gertler (2006)).

[9] For OECD countries, real GDP data are obtained from the OECD quarterly national account database (series name: VOBARSA, millions of national currency, volume estimates, OECD reference year, annual levels, seasonally adjusted). For the other countries, the quarterly real GDP data are taken from the IMF International Financial Statistics (GDP volume series, 2005=100). For earlier sample periods, quarterly data are not available for some emerging economies. We then interpolate an annual index (also from IFS) while assuming that real GDP is constant in each quarter of any given year. As a robustness check, we perform regressions using shorter sample periods during which quarterly GDP data are available for all economies; the results (available upon request) are consistent with those obtained for the full sample.

We estimate the bilateral correlations of real GDP over six (nonoverlapping) five-year intervals between 1980 and 2009.[11] Toward this end, we use two measures of bilateral trade intensity. The first one is based solely on international trade data:[12]

$$w_{ijt} = (X_{ij,t} + M_{ij,t})/(X_{it} + X_{jt} + M_{it} + M_{jt}),$$

where the $X_{ij,t}$ ($M_{ij,t}$) are bilateral nominal exports (imports) between country i and country j during period t and where the X_{it} (M_{it}) are country i's aggregate nominal exports to (imports from) all countries. The second measure is

$$w_{ijt} = (X_{ij,t} + M_{ij,t})/(GDP_{it} + GDP_{jt}),$$

where GDP_{it} is the nominal GDP of country i at time t.[13] Our results are robust to both measures of trade intensity.[14]

For the three measures of output (growth rates, HP filter, and BP filter), we run the following regression:

$$\text{corr}(\Delta y_{it}, \Delta y_{jt}) = \alpha + \beta \log(w_{ijt}) + \varepsilon_{ijt},$$

where $\text{corr}(\Delta y_{it}, \Delta y_{jt})$ is the correlation of output growth rates between countries i and j over each subsample period t.

Table 1 reports the results for the trade-output comovement regression using distance as an instrumental variable (IV). We find that a doubling of the trade intensity leads to a 0.06 higher correlation of output growth (0.1 HP-filtered output and 0.17 BP-filtered output); the coefficients are

10 We use the total PPP Converted GDP (G-K method, at current prices in millions of International Dollars) collected from the Penn World Table to calculate GDP shares. For trade shares, data are collected from IMF Direction of Trade Statistics database.

11 There are a total of 2,610 observations (435 country pairs, corresponding to 30 countries and six time periods). In order to account for possible measurement error, we also calculate pairwise output correlations for the entire sample period. The results (available upon request) are similar.

12 The bilateral trade data used to calculate trade intensity are obtained from the IMF's Direction of Trade Statistics data set.

13 The nominal GDP data (annual index in national currency) are collected from IMF International Financial Statistics. Because the trade data are in US dollars, we use the official exchange rate (period average; when that rate is not available, the market exchange rate is used instead) to transform the nominal GDP in national currency into USD-denominated data.

14 The international trade data are collected at an annual frequency. We calculate bilateral trade intensity for each year and then take natural logarithms. To match the frequency of bilateral output correlations, we take the average of the trade intensity in each of the six subsamples.

statistically significant for all three measures of output. These results are broadly consistent with the literature and are robust to the inclusion of instrumental variables.[15]

Next, we study the relation between international trade and TFP. Kose and Yi (2006) find that TFP shocks are more correlated across countries that trade more with each other. We calculate TFP as the Solow residual in a standard Cobb-Douglas production function. For each country i:

$$\log(z_{it}) = \log(y_{it}) - \alpha \log(n_{it}) - (1-\alpha)\log(k_{it}), \tag{1}$$

where z_{it} denotes the TFP, y_{it} is the real income, n_{it} measures the total employment, and k_{it} represents the real physical capital stock.[16]

Figure 1 plots the correlation between bilateral correlation of TFP growth and our first measure of trade intensity. The correlation is positive and strong: countries that trade more with each other tend to have TFP growth that is more correlated, as shown in panel (a) of the figure. This relation is strongest for North-South trade, as shown in panel (b); that finding is in line with the empirical evidence of business cycle fluctuations in developed economies tending to have strong effects in developing economies (Comin, Loayza, Pasha, and Serven (2009)).

Finally, we test whether countries that trade more with each other have more correlated TFP. We transform TFP in three ways (quarter-to-quarter growth rates, HP- and BP-filtered TFP) and then compute the bilateral correlations of TFP during each of the six five-year intervals, after which we then run the following regression for the three measures of TFP:

$$\text{corr}(\Delta TFP_{it}, \Delta TFP_{jt}) = \alpha + \beta \log(w_{ijt}) + \varepsilon_{ijt}.$$

Table 2 reports the results. There is a positive and significant relationship between bilateral trade intensity and TFP comovement. These results are consistent with the literature and are robust to the

15 The natural instrument for trade intensity, used in most of the literature, is distance.

16 We take the gross-fixed capital formation data from the IFS and the employment index from the IFS and OECD databases. For OECD countries, the gross-fixed capital formation data are series named VOBARSA (Millions of national currency, volume estimates, OECD reference year, annual levels, seasonally adjusted); the employment data is from the OECD Labour Force Statistics (MEI) Dataset (All persons, Index OECD base year 2005=100, s.a.). For other countries, the data are from the IFS database. The gross-fixed capital formation data are deflated by the GDP deflator (2005=100, also from the IFS database) to obtain the real capital formation data. For countries and periods when quarterly data are not available, we interpolate the annual index assuming constant volume every quarter within a year. As a robustness check, we exclude the periods when quarterly data are not available. This does not affect our results. Physical capital is constructed using the perpetual inventory method with a constant quarterly depreciation of 2.5%, assuming the initial capital stock is zero. Following the literature, the labor share of income in GDP, α, is set to be 0.64 for industrialized countries and 0.5 for emerging markets. As a robustness check, we also calculate TFP for emerging markets using the same labor share as for industrialized countries. This does not affect our results.

inclusion of IVs.[17] This finding indicates that understanding the trade-output comovement relationship requires that we understand the drivers of the trade-TFP comovement relationship.

3. The Trade-Output Comovement Relationship and the Margins of Trade

In this section, we disentangle the effects of the extensive and intensive margins of bilateral trade on both GDP and TFP comovement. This is a departure from the literature, which investigates only the relationship between total bilateral trade and business cycle synchronization. As before, we consider both business cycle frequencies (using growth rates and the HP filter) and medium-term frequencies (using the BP filter).[18]

We use bilateral trade data at the 5-digit level of disaggregation (SITC Rev. 3) from the UN COMTRADE database and calculate the two margins of trade using the Hummels and Klenow (2005) decomposition.[19]

Hummels and Klenow (2005) use the Feenstra and Markusen (1994) methodology to incorporate new varieties into a country's import price index when preferences are CES. The extensive margin is a weighted count of country j's imported varieties from country i relative to its imported varieties from country k. When i's shipments to j are a subset of k's shipments to j, the extensive margin is defined as

$$EM_{ij} = \frac{\sum_{m \in I_{ij}} p_{kjm} x_{kjm}}{\sum_{m \in I} p_{kjm} x_{kjm}};$$

where $I_{ij} \in I$ is the set of observable varieties for which country i has positive exports to j, and I is the set of all varieties. The reference country k (in this case, the rest of the world) has positive exports to j in all I varieties. The terms p_{kjm} and x_{kjm} are (respectively) the price and quantity of variety m exported by the reference country k to country j.

17 Drozd and Nosal (2008) obtain similar results.

18 It has been argued by several authors that the extensive margin of trade does not vary significantly at high frequencies (see, e.g., Kehoe and Ruhl (2003)). For that reason, we follow Comin and Gertler (2006) and remove the high-frequency variations in the data.

19 As a robustness check, we count the number of varieties to obtain the extensive margin of trade (normalized by the number of varieties exported by the rest of the world). The two measures deliver similar results.

The intensive margin compares nominal shipments for country i and country k with respect to a common set of goods:

$$IM_{ij} = \frac{\sum_{m \in I_{ij}} p_{ijm} x_{ijm}}{\sum_{m \in I_{ij}} p_{kjm} x_{kjm}}. \tag{2}$$

The ratio of country i's exports to country j with respect to country k's exports to country j, which we denote by OT_{ij}, equals the product of the two margins; hence, taking logs we have

$$\log(OT_{ij}) = \log(EM_{ij}) + \log(IM_{ij}) \tag{3}$$

Using these expressions, we compute both margins of trade (with respect to overall trade) for the period 1980-2009 and find that, on average, the intensive margin accounts for nearly 75% of overall trade.

Next, we classify the 5-digit goods into three categories (consumption, intermediate, and capital goods) and compute the margins of trade for each category. Then we regress the correlation of our three measures of output correlation against the logarithm of country i's exports to country j relative to country k's exports to country j, including only intermediate and capital goods.[20]

$$\text{corr}(\Delta y_{it}, \Delta y_{jt}) = \beta_{OT}\, log(OT_{ij,t}) + \varepsilon_{jm,t} \tag{4}$$

Because trade is an endogenous variable, we run IV regressions, and use distance as the instrument for overall trade. The results, reported in Table 3, are consistent with those obtained in Section 2.

The next step is to analyze the contribution of each margin of trade to output comovement; we do this via the following regression:

$$\text{corr}(\Delta y_{it}, \Delta y_{jt}) = \beta_{EM} \log(EM_{ij,t}) + \beta_{IM} \log(IM_{ij,t}) + \varepsilon_{ij,t}. \tag{5}$$

We need instruments for both margins of trade. The intensive margin is mainly affected by the iceberg transport cost (a variable cost), whereas the extensive margin is mainly affected by the cost of entering a new market (a fixed cost).[21] Therefore, we use distance as an instrument for the intensive

[20] Technology is embodied in intermediate and capital goods. Eaton and Kortum (2001) show that trade in capital goods helps developing countries grow, because it decreases the price of capital.

[21] See Helpman, Melitz, and Rubinstein (2008) and Chaney (2008).

margin and use Djankov, La Porta, Lopez-de Silanes, and Shleifer (2002)'s country-level data on the regulation costs of firm entry as an instrument for the extensive margin. These entry costs are measured in terms of their effects on the number of days, the number of legal procedures, and the relative cost (as a percentage of GDP per capita) required for an entrepreneur to legally start operating a business. Our indicator of pairwise trade costs is constructed by adding the importing and exporting entry regulation costs. In particular, we use the relative cost as a percentage of GDP per capita so that the measure will be comparable across countries.[22] By construction, these bilateral variables reflect regulation costs, which mostly affect the fixed costs of trade and so should not depend on the actual volume of trade to a particular country.

We then run IV regressions of the GDP comovement on the extensive and intensive margins of trade for all measures of output.[23] We find that the extensive margin has a positive and significant effect on GDP comovement whereas the intensive margin's effect is statistically nonsignificant (see Table 4). The results are stronger for the BP filter. Indeed, the coefficients are double those of either the HP filter or GDP growth, which indicates that the relationship between business cycle synchronization and international trade is stronger at medium-term frequencies.

We then examine the relationship between the correlation of TFP growth between country i and j and overall trade. The results are reported in Table 5 and are consistent with those obtained in Section 2.

Similarly, we investigate the contribution of the different margins of trade on TFP comovement by running the following regression:

$$\operatorname{corr}(\Delta TFP_{it}, \Delta TFP_{jt}) = \beta_{EM}\log(EM_{ij,t}) + \beta_{IM}\log(IM_{ij,t}) + \varepsilon_{ij,t} \tag{6}$$

We find that the extensive margin has a positive and statistically significant effect on the comovement of TFP, while the intensive margin has a small negative effect see Table 6).[24]

Taken together, the empirical results reported in this section suggest that we cannot understand the connections between international trade and business cycle synchronization without first understanding the role played by the extensive margin of trade.

22 Helpman, Melitz, and Rubinstein (2008) use, as an alternative measure of entry costs, the number of days and procedures; however, they find that the jointly defined indicator variable has substantially more explanatory power. Entry regulation costs might also be correlated with the variable trade cost affected by distance, but Helpman, Melitz, and Rubinstein (2008) add country fixed effects to the first-stage regression and show that this is not the case.

23 To evaluate the validity of the instruments, we conduct the Stock-Yogo weak identification test. For all the instruments we use, the null hypothesis that the estimator is weakly identified is rejected. Results of these tests are reported in Table 10 (see Appendix B).

24 Similar results on the effect of trade cost changes on the two margins of trade are obtained by Dutt, Mihov, and Van Zandt (2011) in the context of the WTO. They show that the effect is almost exclusively on the extensive margin of trade and has a negligible (or negative) impact on the intensive margin.

4. The Model

We develop a multicountry growth model in which technological progress in each country is driven by domestic innovation and the diffusion of foreign technologies embedded in imported varieties.[25] Iceberg transport costs (variable trade costs) and entry regulation costs (fixed costs) generate variation in the intensive and extensive margins of trade. In each country there is a set of available technologies embedded in intermediate goods that are either produced domestically or imported. The only factors of production are labor and capital, which are used to produce traded intermediate goods. Intermediate goods are combined to produce a nontraded final good, which is used for consumption and domestic innovation.

Time is discrete and is indexed by $t = 0,1,\ldots$. There are M countries in the world, indexed by $n = 1,2,\ldots,M$. Each period is divided into two stages. In the first stage (described in Section 4.1), production and consumption occur, taking each country's available technologies as given. In the second stage (described in Section 4.2), innovation and diffusion of technologies occur, determining the technologies available in the next period.

4.1 Production and Consumption

In each country, a firm produces a nontraded final good using domestic and foreign intermediate goods (varieties). Production involves love-for-variety, à la Ethier (1982), so production efficiency (i.e., TFP) increases with the number of varieties used. In this sense, TFP is endogenous; it depends on the number of intermediate goods (and the technologies embedded in them) that are available for final production. In addition, an exogenous TFP shock provides the only source of uncertainty in the model. Each intermediate good is produced by a monopolistically competitive firm using labor and capital as inputs. The nontraded final good is sold to households that consume, supply labor and capital, and save.

4.1.1 Intermediate Production

In each country $n = 1,\ldots,M$, the total labor and capital supplies (L_{nt} and K_{nt}, respectively) are employed by a continuum of monopolistically competitive firms (henceforth, intermediate producers) to produce intermediate goods indexed by $j \in [0, Z_{nt}]$, where Z_{nt} represents the mass (or, alternatively, the number) of available products. We assume intermediate goods to be differentiated by export source; that is, countries exogenously specialize in different sets of goods (Armington assumption). As is standard in the literature, we define variety nj as the intermediate good j

[25] The model is a variation of the one descibed in Santacreu (2009).

produced in country n.[26] Each firm produces a different good according to a Cobb-Douglas production function:

$$y_{njt} = (k_{njt})^{\alpha}(l_{njt})^{1-\alpha}, \tag{7}$$

where y_{njt} is the quantity of variety nj produced, k_{njt} is the amount of capital rented from households, l_{njt} is the labor employed, and $\alpha \in (0,1)$ is the capital share. Note that all intermediate producers in a country have the same productivity regardless of what particular good they produce.

The producer of variety nj chooses the amount of labor l_{njt} and capital k_{njt} to minimize the cost C_{njt}, subject to the technological constraint (7); thus

$$C_{njt} = \omega_{nt} l_{njt} + R_{nt} k_{njt}, \tag{8}$$

where ω_{nt} is the wage and R_{nt} is the rental price of capital.

The producer of variety nj takes as given the demand by the final producer in each country $i = 1,2,...,M$ and then sets a price that reflects a constant markup over the marginal cost. Prices can differ across countries because markets are segmented owing to iceberg transport costs: for products shipped from country n to country i, the transport cost is $d_n^i > d_n^n = 1$ for $i \neq n$. The marginal cost is given by mc_{njt}

$$mc_{njt} = \left(\frac{\omega_{nt}}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_{nt}}{\alpha}\right)^{\alpha}. \tag{9}$$

Hence the price of variety nj in country i is

$$p_{njt}^i = \frac{\sigma}{\sigma-1} mc_{njt} d_n^i, \tag{10}$$

[26] The Armington assumption allows us to define a variety nj as a good j from a particular country n (in this sense, good j from a country n is a different variety than the same good j from country k).

where $\frac{\sigma}{\sigma-1}$ is the constant markup (with σ to be defined shortly). The producer of variety nj then makes the profit

$$\pi_{njt} = \sum_{i=1}^{I} p_{njt}^{i} x_{njt}^{i} - \omega_{nt} l_{njt} - R_{nt} k_{njt}. \tag{11}$$

4.1.2 Final Production

In each country $i = 1, \ldots, M$, a perfectly competitive firm (henceforth, final producer) uses traded intermediate goods - both domestic and foreign - to produce a nontraded final good. Intermediate products (or varieties) are combined according to the CES production function

$$Y_{it} = e^{a_{it}} \left(\sum_{n=1}^{M} \int_{j=0}^{A_{nt}^{i}} b_{njt}^{i} (x_{njt}^{i})^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}. \tag{12}$$

Here Y_{it} is the quantity of the final good produced in country i at time t; A_{nt}^{i} is the mass of intermediate goods that country i imports from country n; the b_{njt}^{i} are the Armington weights, which represent the share of country i's spending on variety nj; $\sigma > 1$ is the elasticity of substitution across varieties, which become perfect substitutes as $\sigma \to \infty$; and a_{it} is an exogenous TFP shock following the AR(1) process

$$a_{it} = \bar{g}t + \rho_i a_{i,t-1} + u_{it}, \tag{13}$$

where $\bar{g} \in (0,1)$ is the economy's steady-state growth rate, $\rho_i \in (0,1)$, and $u_{it} \sim N(0, \sigma_u^2)$.

The engine of economic growth is growth in productivity, which itself is driven by technological progress. Technology is embodied in intermediate goods traded across countries and may be used by final producers in all countries. This is captured by the CES production function, which introduces the love-for-variety effect: when expenditures are held constant, using a wider range of varieties corresponds to increased productivity (Ethier 1982). The shock process captured by equation (13) introduces an additional channel of technological progress by reflecting the unexplained component of productivity growth given the steady-state growth rate $\bar{g}$.

The final producer chooses x_{njt}^{i} to maximize the profit

$$\Pi_{it} = P_{it}Y_{it} - \sum_{n=1}^{I}\int_{j=0}^{A_{nt}^{i}} p_{njt}^{i} x_{njt}^{i}\, dj; \tag{14}$$

here P_{it} is the price index for the final good and takes the CES form

$$P_{it} = \left(\sum_{n=i}^{M}\int_{j=0}^{A_{nt}^{i}} (b_{njt}^{i})^{\sigma} \left(p_{njt}^{i}\right)^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}}. \tag{15}$$

This expression implies the following demand for variety nj ;

$$x_{njt}^{i} = a_{it}(b_{njt}^{i})^{\sigma} \left(\frac{p_{njt}^{i}}{P_{it}} \right)^{-\sigma} Y_{it}. \tag{16}$$

Total spending by country i on variety nj is then

$$p_{njt}^{i} x_{njt}^{i} = (b_{njt}^{i})^{\sigma} \left(\frac{p_{njt}^{i}}{P_{it}} \right)^{1-\sigma} P_{it}Y_{it} \tag{17}$$

Observe that the price index faced by the final producer is decreasing in the number of varieties.

4.1.3 Households

In each country $n = 1,\ldots,M$, a representative household consumes the final good, supplies labor, rents capital to intermediate producers, and saves. The household maximizes its lifetime expected utility function,

$$U_t = E_t \sum_{s=t}^{\infty} \beta^{s} \left(\log(C_{ns}) - \frac{L_{ns}^{\psi+1}}{\psi+1} \right), \tag{18}$$

subject to the budget constraint

$$P_{nt}C_{nt} + I_{nt} = \omega_{nt}L_{nt} + \Pi_{nt}^{T} + R_{nt}^{k}K_{nt} + R_{nt}B_{nt} - B_{n,t+1}. \tag{19}$$

Here C_{nt} is consumption; $\beta \in (0,1)$ is the discount factor; ψ is the labor supply elasticity; P_{nt} is the price index; I_{nt} is nominal investment; ω_{nt} is the wage; Π_{nt}^{T} are the total profits of all firms in country

n; B_{nt} is total loans extended by the household at time $t-1$ that are payable at time t; R_{nt} is the risk-free rate; R^k_{nt} is the rental price of capital; and K_{nt} is the supply of capital, which is accumulated through the standard law of motion

$$K_{nt} = (1-\delta)K_{n,t-1} + I_{nt}/P_{nt} \tag{20}$$

for $\delta \in (0,1)$ the depreciation rate. The household's decision problem is to choose consumption, labor supply, and capital to maximize (18) subject to (19) and (20).

4.2 Innovation and International Technology Diffusion

We now turn to period t's second stage, in which innovation and the diffusion of technologies through trade in varieties determine the set of technologies available in the different countries in period $t+1$. Technological innovation occurs as innovators invest the final good in R&D activities. We allow for spillover effects: R&D productivity increases with the number of technologies available in the country, and each new technology is embodied in a different variety. Although domestic varieties (and the domestic innovations they embody) are immediately available to domestic final producers, foreign varieties do not become available until after a time-consuming adoption process that is slowed-down by entry regulation costs. Differences in the entry regulations faced by trading partners induce differences in the extensive margin of trade.

4.2.1 Innovation

In each country $n = 1,\dots,M$, a continuum of start-ups invest final good to undertake R&D. Start-ups are ranked according to their efficiency: a start-up with productivity k invents a new technology at the stochastic rate

$$\alpha^r_{nt}\gamma_r T_{nt} Y_{nt}^{-\gamma_r} k^{\gamma_r - 1},$$

where $\alpha^r_{nt}T_{nt}$ is R&D productivity and $\gamma_r \in (0,1)$ is a parameter that captures the diminishing returns to R&D. The fraction of total output invested in R&D, $\frac{y^r_{nt}}{Y_{nt}}$, measures the research intensity in country n. If y^r_{nt} units of final output are invested in R&D, then the mass of newly invented technologies is

$$E_t Z_{n,t+1} - Z_{nt} = \int_{k=0}^{y^r_{nt}} \alpha^r_{nt}\gamma_r T_{nt} Y_{nt}^{\gamma_r} k^{\gamma_r - 1} dk = \alpha^r_n T_{nt}\left(\frac{y^r_{nt}}{Y_{nt}}\right)^{\gamma_r}. \tag{21}$$

There are two components of R&D productivity. The first one is

$$\alpha_{nt}^{r} = \alpha_{n}^{r}\varepsilon_{nt}^{z};$$

here α_n^r is a country-specific parameter reflecting policies and institutions that affect the country's innovative environment (patent protection, education, etc.) and ε_{nt}^z is a shock that follows the AR(1) process

$$\varepsilon_{nt}^{z} = \rho_{n}^{z}\varepsilon_{n,t-1}^{z} + u_{nt}^{z} + \overline{a},$$

where $\overline{a}$ is the steady-state growth rate of new technologies, $\rho \in (0,1)$, and u_{nt}^z is white noise. The second component is a spillover effect determined by the total number of technologies available, $T_{nt} = Z_{nt} + \sum_{i\neq n} A_{it}^{n}$, where Z_{nt} is the stock of technologies introduced domestically through innovation in country i prior to period t. That is, innovators "learn" from the available range of technologies, both domestic Z_{nt} (learning by doing) and foreign $\{A_{it}^n\}$ (learning by using imports). This assumption has two implications: (i) countries in which more varieties are available have lower R&D costs; and (ii) countries that expand the variety of their imports (increasing $\{A_{nt}^i\}$) will thereby reduce their R&D costs.

Each start-up chooses how much final output to invest in R&D to maximize expected profits. Free entry determines the level of that investment, which is given by the break-even condition

$$\alpha_{nt}^{r}\gamma_{r}(\gamma_{r}-1)T_{nt}Y_{nt}^{\gamma_{r}}k^{\gamma_{r}-2}V_{nt} = P_{nt}; \qquad (22)$$

here V_{nt} is the market price for an innovation (to be determined). The start-ups invest final output until marginal revenue is equal to marginal cost. Successful start-ups use the new technology to produce an intermediate good; that is, they join the pool of intermediate good producers in period $t+1$.

4.2.2 International Diffusion of Technology

Each new variety (and the new technology it embodies) must be adopted before it is available to a foreign final producer. Out of Z_{nt} goods available in country n, there remain $Z_{nt+1} - A_{nt}^{i}$ goods to be adopted by the final producer in country i. The law of motion of varieties from country n that are newly adopted by country i is

$$\Delta A_{nt}^{i} = \bar{\varepsilon}_{n}^{i} \frac{A_{nt}^{i}}{Z_{nt}} (Z_{nt} - A_{nt}^{i}). \tag{23}$$

Here $\bar{\varepsilon}_n^i \in [0,1]$ is a parameter that is specific to the pair of countries i and n, captures the rate of adoption, and has a positive effect on the strength of extensive margin linkages between those two countries. If $\bar{\varepsilon}_n^i = 0$ then there is no adoption; if $\bar{\varepsilon}_n^i = 1$ then adoption is instantaneous and, in every period, country i adopts all the varieties produced in country n during that period. For $\bar{\varepsilon}_n^i \in (0,1)$, adoption is delayed. Because the speed of adoption, $\bar{\varepsilon}_n^i$, is specific to country pairs, it induces variation in the extensive margin of trade between pairs of countries. Because technologies are embodied in varieties, variety adoption also corresponds to technology diffusion: once a variety is adopted, the technology embodied in that variety is diffused to the importer.

The process of adoption in equation (23) has three main features. First, the parameter $\bar{\varepsilon}_n^i$ moves at low frequencies (because it involves institutions) and amplifies shocks that hit the economy. Second, the rate of adoption is increasing in the fraction of foreign varieties already adopted (A_{nt}^i / Z_{nt}). Third, the more distant is the adopter from the technological frontier of the innovator (the lower A_{nt}^i / Z_{nt}), the faster is the growth rate of newly adopted technologies (thus, there is a convergence effect).

Finally, the process of adoption is irreversible in that, once a good has been imported, it remains in the stock of available goods even it ceases to be imported.

4.2.3 Value Functions

Innovators decide how much final output to invest in R&D based on the value of an innovation, which is determined by the present discounted value of the future profits from selling the product in each potential destination. We express the value of technologies from country n expressed by country i at time t as

$$W_{nt}^{i} = \pi_{nt}^{i} + \beta E_t W_{n,t+1}^{i}, \tag{24}$$

where π_{nt}^i is the profit and $W_{n,t+1}^i$ is the continuation value. The value of technologies from country n that, at time t, that have not been adopted by country i may be written as

$$J_{nt}^{i} = \beta E_t (\varepsilon_{nt}^{i} W_{n,t+1}^{i} + \beta (1 - \varepsilon_{nt}^{i}) J_{nt}^{i}). \tag{25}$$

At $t+1$, adoption is successful with probability ε^i_{nt} and the firm obtains the value of an adopted technology, $W^i_{n,t+1}$. However, with probability $(1-\varepsilon^i_{nt})$, adoption is not successful and the firm obtains the continuation value $J^i_{n,t+1}$.

The market price for an innovation in country n is given by the expected value of selling the good in each of the potential destinations:

$$V^r_{nt} = \sum_{i=1}^{I} J^i_{nt}, \tag{26}$$

where $J^n_{nt} = W^n_{nt}$.

4.3 Trade Balance

We assume financial autarky. From this it follows that trade is balanced in every period, and that the total value of exports in each country n equals the total value of its imports:

$$\sum_{i=1}^{I}\int_{j=0}^{A^i_{nt}} p^i_{njt} x^i_{njt}\, dj = \sum_{i=1}^{I}\int_{j=0}^{A^n_{it}} p^n_{ijt} x^n_{ijt}\, dj. \tag{27}$$

4.4 Equilibrium

This section describes the equilibrium in which all firms within a country behave symmetrically. The countries themselves are asymmetric, however, and are characterized by $\{\bar{\varepsilon}^i_n, L_i, d^i_n, \rho_i, \rho^z_i\}$.

For all i and n, a general symmetric equilibrium in this economy is defined as an exogenous stochastic sequence $\{a_{it}, \varepsilon^z_{it}\}$, an initial vector $\{A^i_{n0}, Z_{i0}, K_{i0}\}$, a set of parameters $\{\sigma, \alpha, \beta\}$ that are common across countries, a set of parameters $\{\bar{\varepsilon}^i_n, L_i, d^i_n, \rho_i, \rho^z_i\}$ that differ across countries, an aggregate sequence of prices and wages $\{P_{it}, R_{it}, \omega_{it}\}^{\infty}_{t=0}$, a set of intermediate goods' prices $\{p^i_{nt}\}^{\infty}_{t=0}$, a sequence of aggregate quantities $\{Y_{it}, y_{nt}, I_{nt}\}$, quantities of intermediate goods $\{x^i_{nt}\}^{\infty}_{t=0}$, a sequences of profits and value $\{\pi^i_{nt}, W^i_{nt}, J^i_{nt}, V^r_{nt}\}^{\infty}_{t=0}$, and laws of motion $\{A^i_{n,t+1}, Z_{i,t+1}, K_{it}\}^{\infty}_{t=0}$ such that such that the following conditions hold:

- the state variables $\{K_{it+1}, A^i_{n,t+1}, Z_{i,t+1}\}^{\infty}_{t=0}$ satisfy the laws of motion given equations (34), (41), and (42);

• the endogenous variables solve the producer and household problems given by equations (28)-(38);

• feasibility is satisfied in equations (39) and (40);

• prices are such that markets clear.

The cited equations that establish this symmetric equilibrium are given in Appendix A.

4.5 Steady State

The economy has a balanced growth path in which all countries grow at the same rate but differ in their relative income per capita. The common growth rate is guaranteed by international diffusion whereas differences in relative income are driven by the country-specific parameters $\{\bar{\varepsilon}_n^i, L_i, d_n^i, \rho_i, \rho_i^z\}$, which can be identified from the system's initial conditions.

Along the balanced growth path, the number of adopted and invented technologies (A_{nt}^i and Z_{nt}, respectively) grows at a common rate (by equations (41) and (42)). Therefore, the total amount of output invested in innovation grows at the rate of final output.

Solving for the steady state of the model requires an algorithm to compute relative prices. Taking advantage of the model's recursive structure, we proceed as follows. First, from the law of motion for newly adopted technologies, equation (42), we can obtain the steady-state value of $A_{nt}^i/Z_{nt} = \varepsilon_n^i/(g_a + \varepsilon_n^i)$. We then use this equality to obtain the ratio A_n^i/A_k^i as well as an expression for Z_n/Z_k. We can approximate the ratio Z_n/Z_k using the ratio of the number of varieties exported. Finally, we use the trade balance equation (35) to obtain relative prices.

4.6 The Mechanism

We log-linearize the model around the stochastic steady state and use Dynare to solve it with numerical methods. The starting point for understanding how our mechanism influences the trading partner's output growth is equation (12). This equation indicates that a country's output depends not only on the quantity x_{nt}^i of intermediate goods used for final production but also on the range A_{nt}^i of these intermediate goods or varieties. The second component characterizes the extensive margin and is positively associated with the efficiency of production and hence with TFP. Final producers benefit from the technology embodied in the domestic and foreign goods they use. Domestic technology increases by investing final output in R&D, per equation (41), and by adopting foreign innovations through trade, per equation (42). At the same time, an increase in the range of foreign technologies translates into higher innovation via the spillover effect in equation (41). Technological accumulation translates into higher output by increasing the efficiency of production from equation (12). Higher output increases demand, profits, and the value V_{nt}^{r} of an innovation by equation (41); these factors translate into more investment in research. This process defines the mechanism of international technology diffusion that we add to the standard IBC model. The higher is the rate of adoption, the stronger is this mechanism.

5. Simulation and Quantitative Analysis

In this section we conduct a quantitative analysis to illustrate the main model's mechanisms. First, we analyze how the international diffusion of technologies through trade in varieties amplifies the effect of a TFP shock to country 1 on the output growth of its trading partner (country 2). Second, we consider a 10% decrease in iceberg transport costs between country 1 and country 2 and then analyze its effect on the correlation of output growth and on that of TFP growth between the two countries. This exercise allows us to recover the trade-TFP and trade-output coefficients implied by our model, which we compare to the coefficients derived from the data, and from the standard IBC model.

5.1 Simulation

We simulate a symmetric three-country version of our model at an annual frequency.[27] The simulation we present is designed as a reasonable benchmark, and the model's behavior is robust to small variations around this benchmark. To the extent possible, we use steady-state restrictions to pin down parameter values; otherwise, we borrow estimates from the literature (see Table 7). There are nine parameters in total, of which six appear in other studies and three relate to the processes of innovation and adoption. The discount factor β is calibrated to 0.99, which implies an annual steady-state real interest rate of 4%. The depreciation rate δ is set to 0.025 per quarter, which implies an annual depreciation rate of 10%. We set $\alpha = 0.3$, which implies a steady state share of labor income in total output amounting to 70%. For the inverse elasticity of labor supply we use $\psi = 2$, which is between the relatively low elasticities typically estimated in the micro-labor literature and the larger ones typical of DSGE models. The elasticity of substitution between domestic and foreign goods, σ, is set to 3. Estimates of this parameter in the trade and industrial organization literature usually range from 3 to 10, and the value differs across goods - as shown by Broda, Greenfield, and Weinstein (2006), who report lower elasticities for goods that are more differentiated. Macroeconomic studies typically find a value of 2 for this parameter, and our use of a single value ($\sigma = 3$) is a simplifying assumption. Finally, we allow the iceberg transport cost to vary from $d = 1.0$ (free trade) to $d = 1.1$ (reflecting iceberg transport costs of 10%).

27 The simulation is not a full-fledged calibration but rather a quantitative exercise meant to illustrate the main mechanisms of the model. We do calibrate the parameters that are common across countries. That being said, we perform simulations for different values of the country-specific parameters (the iceberg transport cost, the rate of adoption, and the parameters governing the TFP process) because we are not fitting the model to any particular pair of countries. The proper calibration of a more comprehensive model is left for future research.

The steady-state growth rate $\bar{g}$ of domestic technologies, is assumed to be common across countries. Following Eaton and Kortum (1996), we use the Frobenious theorem and obtain a value $\bar{g} = 0.01$. (See Santacreu (2009)). The parameter of diminishing returns to research, $\beta_r = 0.25$, lies between the 0.02 estimate in Eaton and Kortum (1996) and the 0.80 estimate in Comin and Gertler (2006). Our value is closer to the one that Eaton and Kortum (1996) find in a model with exogenous adoption and endogenous innovation. The diffusion rate $\bar{\varepsilon}_n^i$ ranges between 0 (standard IBC model) and 1; positive values of $\bar{\varepsilon}_n^i$ correspond to a model with technological diffusion.

5.2 Quantitative Analysis

Our numerical experiments mostly involve varying two parameters: the iceberg transport cost d, which affects mainly the intensive margin of trade, and the entry costs $\bar{\varepsilon}_n^i$, which affects mainly the extensive margin of trade.

5.2.1 A TFP Shock in Country 1

In this section, we consider a positive TFP shock in country 1 and then analyze its effect on country 2's output growth for different values of the rate of diffusion $\bar{\varepsilon}_n^i$. The impulse responses to a one percent standard deviation TFP shock are shown in Figure 2 (the x-axis units in figures 2-4 are years). In the extreme case of no innovation or adoption ($\bar{\varepsilon}_n^i = 0$), which corresponds to the standard IBC model, a positive TFP shock in country 1 has a positive but small effect on the real GDP of country 2 (dotted line in Figure 2). With diffusion ($\bar{\varepsilon}_n^i > 0$), however, the TFP shock in country 1 increases output in country 2 via the international technology diffusion channel. This effect is stronger for higher values of the rate of adoption (solid and dashed lines in Figure 2 correspond to $\bar{\varepsilon}_n^i = 0.6$ and $\bar{\varepsilon}_n^i = 0.2$, respectively).

The details are as follows. A positive TFP shock in country 1 increases its final output and hence the demand for intermediate goods (both domestic and foreign), thereby increasing final output in country 2. This is the traditional demand-supply spillover channel, which is present also in the model without adoption. As the dashed line in Figure 2 reveals, this channel alone is not sufficient to boost the output of country 2 significantly. When adoption is introduced, a new channel reinforces the spillover effect: higher final output in country 1 increases its innovation because the value of a new technology is now greater. New technologies are then introduced into country 1, increasing its final producers' efficiency of production via the love-for-variety effect and thus boosting final output in country 1 even further. Similarly, higher output in country 2 increases innovation in that country and hence the efficiency of its own final producers, increasing country 2's output. Here, the international diffusion channel is at play: goods that are developed in a country are eventually adopted by its trading partners. Therefore, expected profits of the intermediate producers that sell the good abroad increase and so the market price of an innovation - which is the present discounted value of the expected profits from selling the good domestically and abroad - also increases, triggering higher innovation and higher efficiency in final production. This effect is increasing in the rate of adoption. In the medium term, when adoption occurs, then the production efficiency of country 2 increases even further because it benefits from the technology embedded in the intermediate goods adopted from country 1. Although the effect of adopted foreign technologies in country 2 occurs at medium frequencies, the adoption process reinforces the traditional demand-supply spillover channel at high frequencies through its effect on the market price of an innovation (see Figure 4).

Thus TFP shocks originating in one country propagate internationally, and the effect is amplified by the international technology diffusion channel. A positive (respectively negative) shock increases (respectively decreases) the growth rate of the number of newly adopted varieties, but the number of varieties is always increasing because the process of adoption is irreversible.

In Figure 3, we compare the results for different values of the elasticity of substitution σ. The lower is σ, the stronger is the love-for-variety effect in the final production function, and the stronger is the trade-output comovement. This finding is consistent with those of Kose and Yi (2006) and Drozd and Nosal (2008) that, when domestic and foreign goods are less substitutable, the trade-output comovement relationship is stronger. In our model, this dynamic reflects that the effect of the extensive margin on a country's output growth becomes stronger when foreign and domestic goods are less substitutable. In Figure 3, the solid line plots the effect of a TFP shock in country 1 for a high value of the elasticity of substitution ($\sigma = 10$); the dashed line plots the results for a lower elasticity of substitution ($\sigma = 3$). The effect of a TFP shock in country 1 on the final output of country 2 becomes stronger as the value of σ decreases.

5.2.2 The Trade-Output and Trade-TFP Coefficients

We now consider a decrease in the iceberg transport costs between country 1 and 2 - from costly trade ($d = 1.1$) to free trade ($d = 1.0$) - and compute the trade-output and trade-TFP coefficients implied by our model of adoption. We then compare these results to what the standard IBC model predicts.

We simulate the model for the two values of the iceberg transport cost, computing the implied change in the bilateral trade intensity and the bilateral correlation of output growth (and TFP growth). The ratio of the change in the correlation of output (resp., TFP) growth to the change in the bilateral trade intensity is the simulated trade-output (resp., trade-TFP) coefficient.

Figure 5 displays the results.[28] The x-axis represents the rate of adoption between country 1 and country 2, and the y-axis represents the coefficient of the trade-output comovement (top panel) and the trade-TFP comovement (bottom panel). In the standard IBC model ($\varepsilon_n^i = 0$ and no innovation), the trade-TFP and trade-output coefficients are negligible (the same is true for the IBC model with innovation). These coefficients increase as the rate of adoption rises above zero.

The standard IBC model does not explicitly address the extensive margin of trade. Yet because this margin (as demonstrated in Section 3) captures most of the trade-output comovement in the data, the standard model fails to capture the quantitative effect of international trade on the synchronization of business cycles. In contrast, by modeling explicitly the extensive margin of trade, we are able to capture a significant part of the relevant coefficient. According to the data, the adoption rate is approximately 0.3 for the average country (as estimated in Santacreu (2009)). For an adoption rate of this magnitude, our model predicts an annual trade-output coefficient of 0.1 (0.025 at a quarterly frequency), which is more than 5 times higher than the coefficient implied by the standard IBC model and about 40% of the coefficient observed in the data (0.06 at a quarterly frequency).[29]

Finally, Table 8 summarizes the response of the comovement of output growth (TFP growth) trade intensity and the two margins of trade to a 10% increase in iceberg transport costs for different values of the rate of adoption. As the rate of adoption increases, the correlation of output growth and TFP growth increases along with trade intensity. The effect of an increase in trade intensity on the comovement of output growth and TFP growth is stronger when the rate of adoption is higher. It is clear that the extensive margin of trade does not vary significantly with changes in the iceberg transport costs. However, a positive rate of adoption does amplify the trade-output comovement via the extensive margin of trade, as confirmed by the empirical results in Section 3.

6. Conclusion

We show that the international diffusion of technology through trade in varieties can help explain the so-called trade comovement puzzle. Countries that trade more at the extensive margin have more correlated TFP growth and, in turn, more correlated output growth. Standard models, which do not account for the extensive margin of trade, miss an important channel through which international trade may drive business cycle synchronization. Based on the empirical findings, we develop a three-country model of innovation and international technology diffusion with TFP shocks and then show, for reasonable parameter values, that our proposed mechanism captures 40% of the trade-output coefficient found in empirical studies. This is a significant improvement over the standard IBC model, which predicts a practically negligible effect of trade on output comovement.

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28 These results correspond to the last two columns of Table 8.

29 Adoption rates lower than 0.1, which correspond to the model with innovation and no international technology diffusion, deliver very small coefficients.

The analysis has abstracted from a number of interesting issues. These include the calibration of a full-blown model (for a sample of OECD and emerging countries) to data on R&D, productivity, and trade in varieties. Such a calibration would enable us to disentangle the effect of three different mechanisms proposed in the literature: vertical linkages, elasticity of substitution between domestic and foreign goods, and technological adoption. We leave these issues for future research.

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Table 1. Output Correlation and Trade Intensity

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr($y_i^{\mathrm{HP}}, y_j^{\mathrm{HP}}$)	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr($y_i^{\mathrm{BP}}, y_j^{\mathrm{BP}}$)	Coeff.
log(w_{ij})	0.139***	log(w_{ij})	0.081***	log(w_{ij})	0.240***
	(0.009)		(0.006)		(0.015)
Constant	1.095***	Constant	0.634***	Constant	1.506***
	(0.052)		(0.033)		(0.085)

Note: Instrumental variables (2SLS) regression with log distance as the IV. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

Table 2. TFP Correlation and Trade Intensity

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr($tfp_i^{\mathrm{HP}}, tfp_j^{\mathrm{HP}}$)	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr($tfp_i^{\mathrm{BP}}, tfp_j^{\mathrm{BP}}$)	Coeff.
log(w_{ij})	0.064***	log(w_{ij})	0.043***	log(w_{ij})	0.131***
	(0.008)		(0.005)		(0.012)
Constant	0.563***	Constant	0.386***	Constant	1.274***
	(0.046)		(0.030)		(0.067)

Note: Instrumental variables (2SLS) regression with log distance as the IV. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

Table 3. Output Correlation on OT_{ij}

Only use capital and intermediate goods to calculate OT_{ij}					
Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr($y_i^{\mathrm{HP}}, y_j^{\mathrm{HP}}$)	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr($y_i^{\mathrm{BP}}, y_j^{\mathrm{BP}}$)	Coeff.
$\log(OT_{ij})$	0.115***	$\log(OT_{ij})$	0.067***	$\log(OT_{ij})$	0.197***
	(0.006)		(0.004)		(0.010)
Constant	0.851***	Constant	0.492***	Constant	1.084***
	(0.028)		(0.017)		(0.045)

Note: Instrumental variables (2SLS) regression using log distance as the IV. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

Table 4. Output Correlation on EM and IM

Using Hummels and Klenow's decomposition method

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{HP}, y_j^{HP})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{BP} , y_j^{BP})	Coeff.
$\log(EM_{ij})$	0.309***	$\log(EM_{ij})$	0.196***	$\log(EM_{ij})$	0.593***
	(0.042)		(0.027)		(0.036)
$\log(IM_{ij})$	0.031	$\log(IM_{ij})$	0.011	$\log(IM_{ij})$	0.028
	(0.021)		(0.013)		(0.036)
Constant	0.644***	Constant	0.354***	Constant	0.662***
	(0.059)		(0.037)		(0.101)

Note: Instrumental variables (2SLS) regression using log distance and log of entry costs as the IVs. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

Table 5. TFP Correlation on OT_{ij}

Only use capital and intermediate goods to calculate OT_{ij}

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{HP}, tfp_j^{HP})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{BP} , tfp_j^{BP})	Coeff.
$\log(OT_{ij})$	0.053***	$\log(OT_{ij})$	0.036***	$\log(OT_{ij})$	0.109***
	(0.005)		(0.003)		(0.007)
Constant	0.452***	Constant	0.309***	Constant	1.047***
	(0.023)		(0.015)		(0.034)

Note: Instrumental variables (2SLS) regression using log distance as the IV. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

Table 6. TFP Correlation on EM and IM

Using Klenow and Hummels' decomposition method

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{HP}, tfp_j^{HP})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{BP} , tfp_j^{BP})	Coeff.
$\log(EM_{ij})$	0.275***	$\log(EM_{ij})$	0.181***	$\log(EM_{ij})$	0.557***
	(0.037)		(0.024)		(0.062)
$\log(IM_{ij})$	-0.042*	$\log(IM_{ij})$	-0.027*	$\log(IM_{ij})$	-0.084**
	(0.018)		(0.012)		(0.030)
Constant	0.215***	Constant	0.154***	Constant	0.568***
	(0.051)		(0.034)		0.568***

Note: Instrumental variables (2SLS) regression using log distance and log of entry costs as the IVs. Standard errors are given in parentheses. *** (**) denotes significance at the 1% (5%) level.

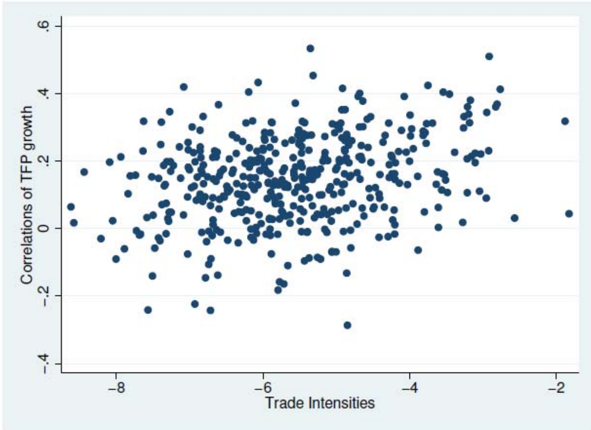
Table 7. Calibrated Parameters

Parameter	Value
β_r	0.25
ψ	2.00
δ	0.10
α	0.30
σ	3.00
β	0.99
$\bar{g}$	0.01
d	[1, 1.1]
ε_n^i	[0, 1]

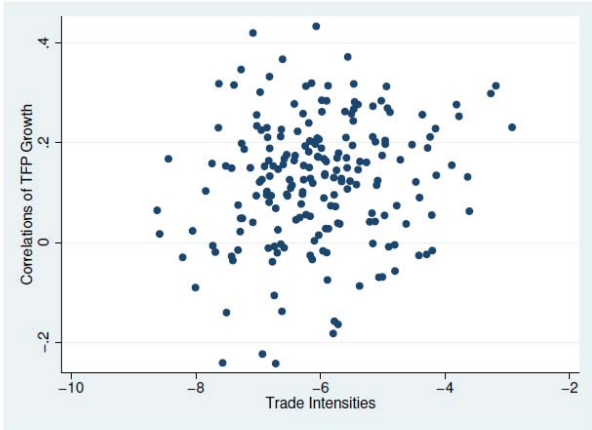
Table 8. Comovement Response to a 10% Increase in International Trade Costs

e_{ij}	Δ corr($\Delta y_i, \Delta y_j$)	Δw_{ij}	ΔEM_{ij}	ΔIM_{ij}	Δ corr($\Delta tfp_i, \Delta tfp_j$)	GDP-trade slope	TFP-trade slope
0	0.0017	0.0002	NA	NA	−0.0041	0.0004	−0.0009
0.2	0.0079	0.0033	0.0003	0.003	0.0134	0.024	0.0025
0.3	0.0182	0.0032	0.0003	0.0029	0.0078	0.057	0.0041
0.4	0.0184	0.0028	0.0003	0.0025	0.0047	0.066	0.0059
0.5	0.0185	0.0023	0.0001	0.0022	0.0031	0.080	0.0074
0.6	0.0185	0.0021	0.0001	0.002	0.0023	0.089	0.0091
0.7	0.0186	0.0019	0	0.0017	0.0017	0.098	0.0117
0.8	0.0186	0.0016	0	0.0016	0.0013	0.116	0.0123
0.9	0.0186	0.0016	0	0.4399	0.0009	0.116	0.0177

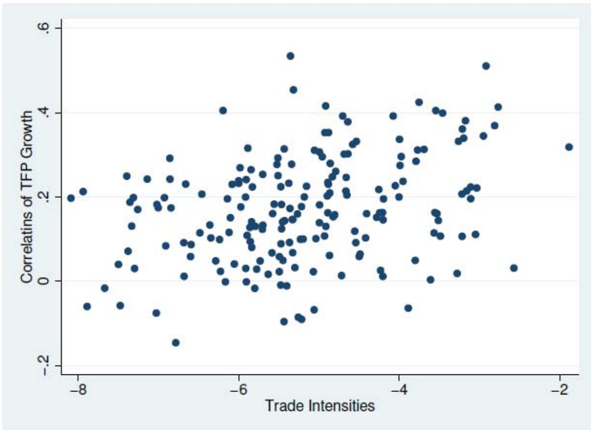
Figure 1. TFP Correlation Versus Trade Intensity



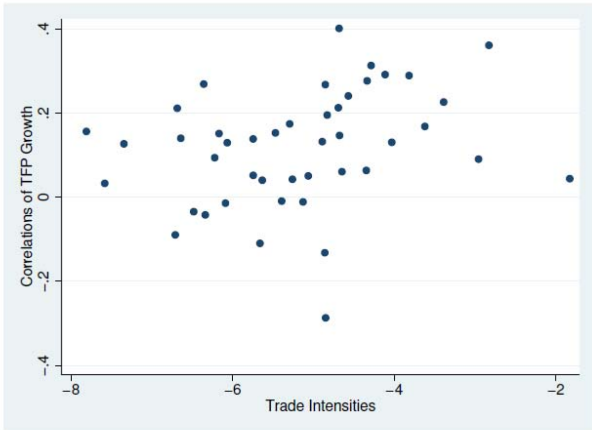
(a) Total sample



(b) North–South



(c) North–North



(d) South–South

Figure 2. Impulse Responses to a TFP Shock in Country 1 for Different Rates of Adoption

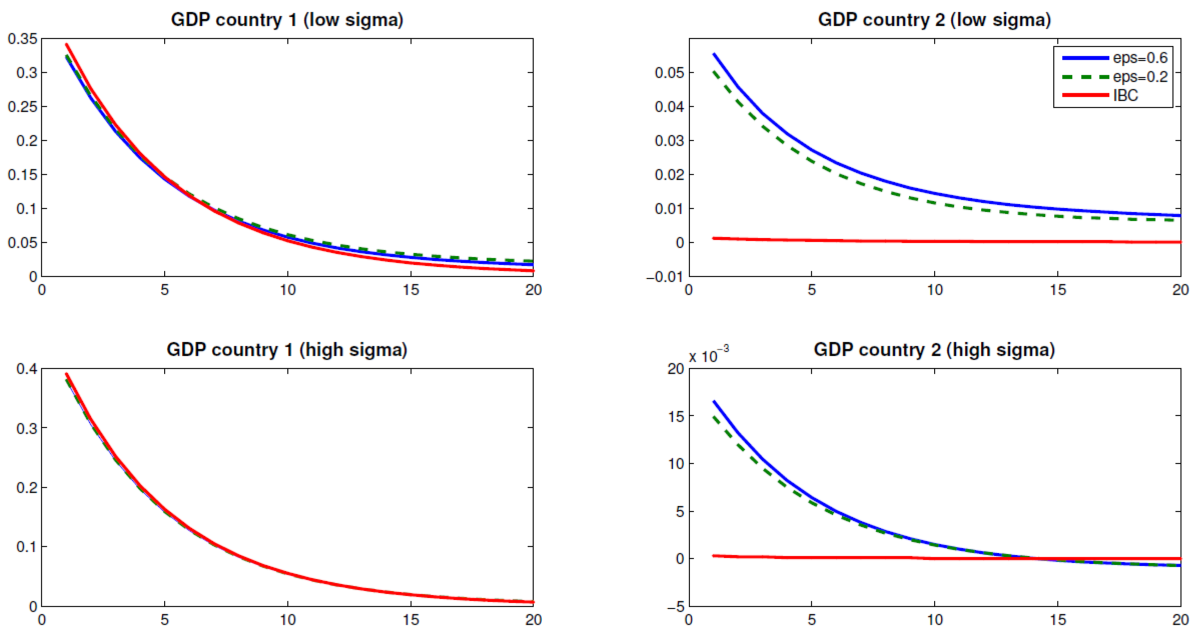


Figure 3. Impulse Responses to a TFP Shock in Country 1 for Different σ

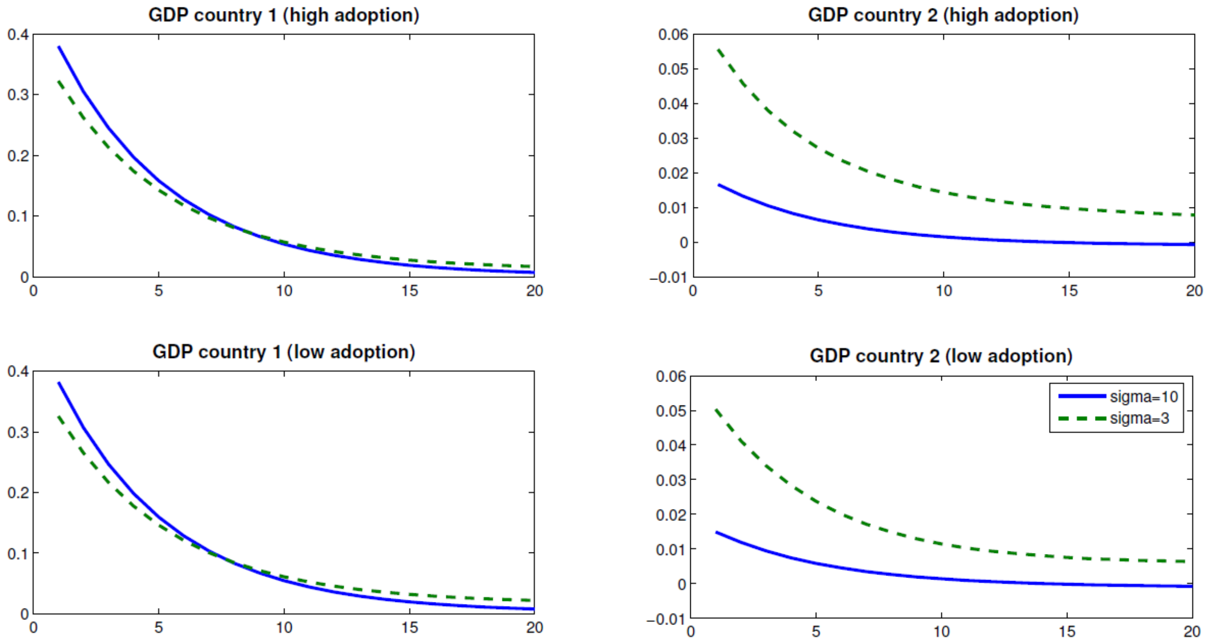


Figure 4. Impulse Responses to a TFP Shock in Country 1

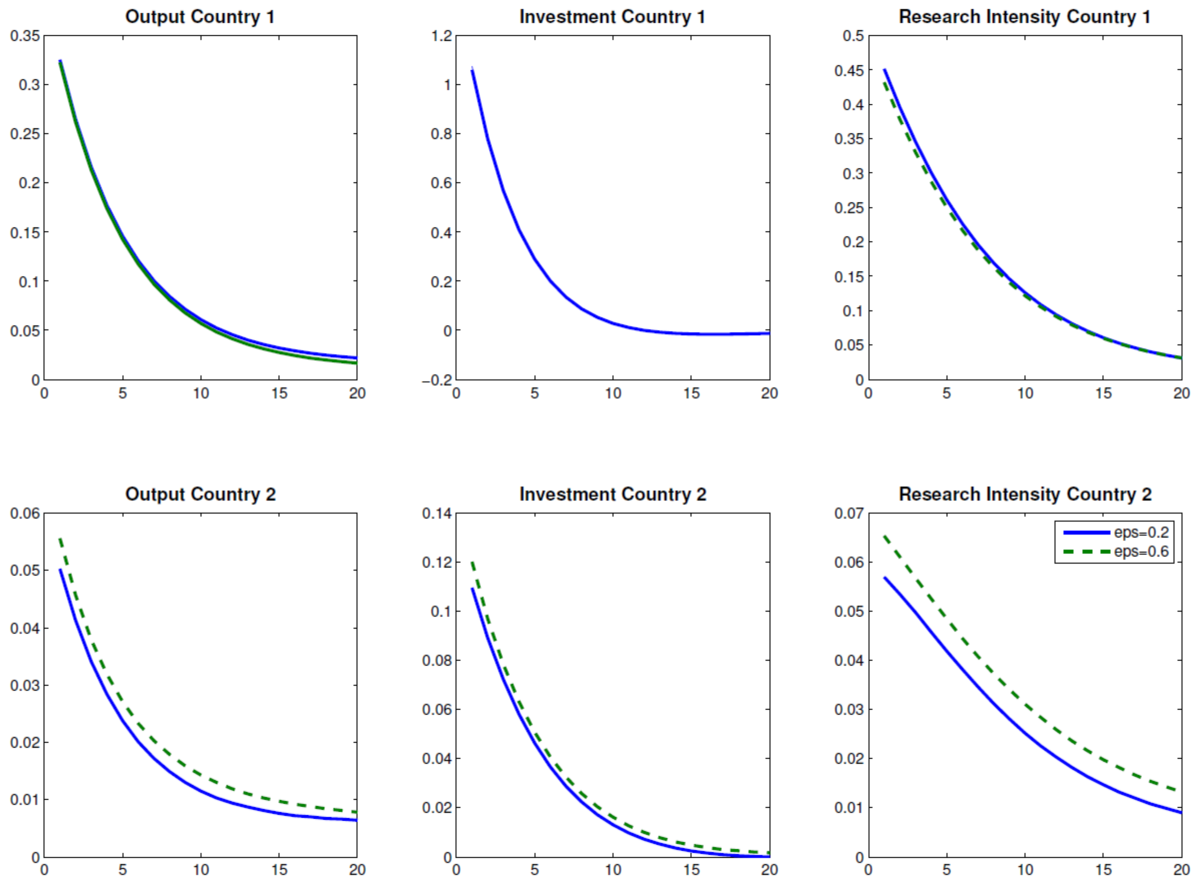
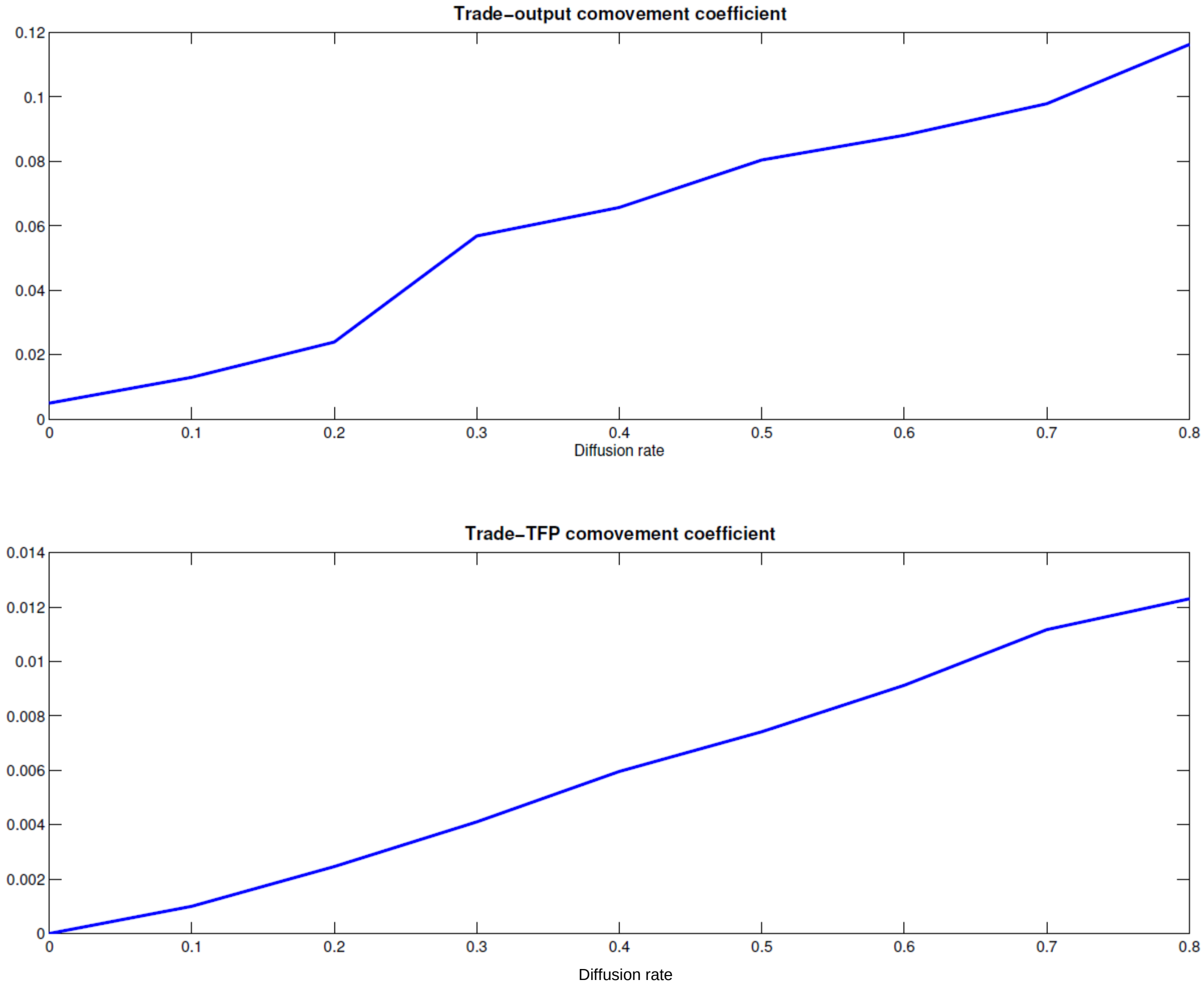


Figure 5. Trade-Output and Trade-TFP Comovement Coefficients



Appendix A. Equilibrium Equations

Here we list the equations that define the symmetric equilibrium described in Section 4.4.

Total spending of country i in country n:

$$x_{nt}^{i} = a_{it} A_{nt}^{i} (\frac{p_{nt}^{i}}{P_{it}})^{1-\sigma} P_{it} Y_{it}. \tag{28}$$

Demand for factors of production:

$$w_{nt} L_{nt} = (1-\alpha) \frac{\sigma - 1}{\sigma} x_{nt}. \tag{29}$$

$$R_{nt} K_{nt} = \alpha \frac{\sigma - 1}{\sigma} x_{nt}. \tag{30}$$

Optimal pricing by intermediate producers:

$$mc_{nt} = \left(\frac{w_{nt}}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_{nt}}{\alpha} \right)^{\alpha}; \tag{31}$$

$$p_{nt}^{i} = \frac{\sigma}{\sigma - 1} mc_{nt} d_{n}^{i}. \tag{32}$$

Optimal investment in innovation:

$$\beta_r \alpha_{nt}^{R} T_{nt} \left(\frac{Y_{nt}^{R}}{Y_{nt}} \right)^{\beta_r - 1} V_{nt}^{R} = P_{nt} Y_{nt}. \tag{33}$$

Law of motion for capital:

$$\frac{1}{P_{nt}} I_{nt} = K_{n,t+1} - (1-\delta) K_{nt}. \tag{34}$$

Trade balance equation:

$$\sum_{i \neq n}^{M} A_{nt}^{i} x_{nt}^{i} = \sum_{i \neq n}^{M} A_{it}^{n} x_{it}^{n}. \tag{35}$$

Price index:

$$P_{nt} = (\sum_{i=1}^{M} A_{it}^{n} (p_{it}^{n})^{1-\sigma})^{\frac{1}{1-\sigma}}. \tag{36}$$

First-order conditions for consumers:

$$L_{nt}^{\psi} = \frac{w_{nt}}{C_{nt}}. \tag{37}$$

$$\frac{C_{n,t+1}}{C_{nt}} = \beta \frac{R_{n,t+1} + (1-\delta) q_{n,t+1}}{q_{nt}}. \tag{38}$$

Total sales of intermediate goods in country n:

$$x_{nt} = \sum_{i=1}^{M} A_{nt}^{i} x_{nt}^{i}. \tag{39}$$

Resource constraint:

$$Y_{nt} = C_{nt} + I_{nt}. \tag{40}$$

Innovation:

$$Z_{nt+1} - Z_{nt} = \alpha_{nt}^{R} T_{nt} \left(\frac{Y_{nt}^{R}}{Y_{nt}} \right)^{\beta_r}. \tag{41}$$

Adoption:

$$\Delta A_{nt}^{i} = \bar{\varepsilon}_{n}^{i} \frac{A_{nt}^{i}}{Z_{nt}} (Z_{nt} - A_{nt}^{i}). \tag{42}$$

Shock process:

$$\varepsilon_{nt}^{z} = \rho_{n}^{z} \varepsilon_{nt-1}^{z} + u_{nt}^{z} + \bar{a}. \tag{43}$$

$$a_{it} = \rho_{i} a_{i,t-1} + u_{it}. \tag{44}$$

Appendix B. Tables 9-23

Table 9a. Empirical Link between Trade and Business Cycle Comovement

Descriptive Statistics	Bilateral trade intensity	HP-filtered GDP correlation	Log first-differenced GDP correlation	BP-filtered GDP correlation
Median	0.0035	0.40	0.16	0.39
Minimum	0	−0.89	−0.71	−1
Maximum	0.1976	0.99	0.96	1
Standard deviation	0.0157	0.47	0.30	0.77

Table 9b. Empirical Link between Trade and Business Cycle Comovement (OECD countries prior to 2000)

Descriptive Statistics	Bilateral trade intensity	HP-filtered GDP correlation	Log first-differenced GDP correlation	BP-filtered GDP correlation
Median	0.0053	0.36	0.15	0.86
Minimum	0.0003	−0.85	−0.53	−1
Maximum	0.1607	0.98	0.87	1
Standard deviation	0.0179	0.42	0.25	0.72

Table 10. Weak Identification Test

Endogenous regressor	Instrument	Cragg-Donald Wald F-statistic	Stock-Yogo weak ID test	critical values
$\log(w_{ij})$	log distance	4397.597	10% maximal IV size	16.38
			15% maximal IV size	8.96
$\log(OV_{ij})$	log distance	1613.203	20% maximal IV size	6.66
			25% maximal IV size	5.53
$\log(EM_{ij})$, $\log(IM_{ij})$	log distance and log of entry cost	85.519	10% maximal IV size	7.03
			15% maximal IV size	4.58
Using country data: $\log(EM_{ij})$, $\log(IM_{ij})$	log distance and log of entry cost	27.455	20% maximal IV size	3.95
			25% maximal IV size	3.63

Table 11. Output Correlation on EM and IM

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coef.	corr($\Delta y_i, \Delta y_j$)	Coef.	corr(y_i^{bp}, y_j^{bp})	Coef.
$\log(EM_{ij})$	0.348***	$\log(EM_{ij})$	0.229***	$\log(EM_{ij})$	0.701***
	(0.063)		(0.041)		(0.108)
$\log(IM_{ij})$	-0.067	$\log(IM_{ij})$	-0.063	$\log(IM_{ij})$	-0.201*
	(0.056)		(0.036)		(0.095)
Constant	1.528***	Constant	0.954***	Constant	2.502***
	(0.166)		(0.108)		(0.284)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 12. TFP Correlation on EM and IM Using Count Data

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
$\log(EM_{ij})$	0.362***	$\log(EM_{ij})$	0.241***	$\log(EM_{ij})$	0.744***
	(0.061)		(0.041)		(0.100)
$\log(IM_{ij})$	-0.197***	$\log(IM_{ij})$	-0.133***	$\log(IM_{ij})$	-0.415***
	(0.054)		(0.036)		(0.088)
Constant	1.303***	Constant	0.867***	Constant	2.759***
	(0.162)		(0.107)		(0.262)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 13. Output Correlation on EM and IM Using Hummels-Klenow Decomposition

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{bp}, y_j^{bp})	Coeff.
$\log(EM_{ij}) + \log(EM_{ji})$	0.155***		0.098***		0.296***
	(0.029)		(0.018)		(0.049)
$\log(IM_{ij}) + \log(IM_{ji})$	0.016		0.006		0.014
	(0.014)		(0.009)		(0.024)
Constant	0.644***	Constant	0.354***	Constant	0.662***
	(0.080)		(0.051)		(0.136)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 14. TFP Correlation on EM and IM Using Hummels'-Klenow Decomposition

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
$\log(EM_{ij}) + \log(EM_{ji})$	0.138***		0.091***		0.279***
	(0.025)		(0.017)		(0.042)
$\log(IM_{ij}) + \log(IM_{ji})$	-0.021		-0.013		-0.042*
	(0.012)		(0.008)		(0.021)
Constant	0.215**		0.154**		0.568***
	(0.071)		(0.047)		(0.118)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 15. Output Correlation on EM and IM Using Count Data

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{bp}, y_j^{bp})	Coeff.
$\log(EM_{ij}) + \log(EM_{ji})$	0.355***		0.237**		0.736***
	(0.106)		(0.073)		(0.194)
$\log(IM_{ij}) + \log(IM_{ji})$	-0.216*		-0.157*		-0.495*
	(0.108)		(0.074)		(0.197)
Constant	2.097***	Constant	1.340***	Constant	3.731***
	(0.440)		(0.301)		(0.805)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 16. TFP Correlation on EM and IM Using Count Data

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
$\log(EM_{ij}) + \log(EM_{ji})$	0.365**		0.249**		0.793***
	(0.118)		(0.080)		(0.221)
$\log(IM_{ij}) + \log(IM_{ji})$	-0.298*		-0.205*		-0.660**
	(0.120)		(0.081)		(0.224)
Constant	1.870***		1.269***		4.095***
	(0.488)		(0.331)		(0.914)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs.

Table 17. Output Correlation Versus Trade Intensity as Normalized by GDP

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{bp}, y_j^{bp})	Coeff.
log(w_{ij})	0.123***	log(w_{ij})	0.071***	log(w_{ij})	0.213***
	(0.006)		(0.004)		(0.010)
Constant	0.977***	Constant	0.565***	Constant	1.304***
	(0.030)		(0.019)		(0.055)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance as IV. Trade intensities are measured by $w_{ijt}^2 = (X_{ij,t} + M_{ij,t})/(GDP_{it} + GDP_{jt})$.

Table 18. Output Correlation and Trade Intensity as Normalized by GDP

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
log(w_{ij})	0.057***	log(w_{ij})	0.038***	log(w_{ij})	0.117***
	(0.005)		(0.003)		(0.008)
Constant	0.510***	Constant	0.349***	Constant	1.164***
	(0.027)		(0.018)		(0.044)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance as IV. Trade intensities are measured by $w_{ijt}^2 = (X_{ij,t} + M_{ij,t})/(GDP_{it} + GDP_{jt})$.

Table 19. Output Correlation and Trade Intensity

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{bp}, y_j^{bp})	Coeff.
log(w_{ij})	0.186***		0.121***		0.220***
	(0.011)		(0.007)		(0.020)
Constant	1.331***		0.845***		1.363***
	(0.060)		(0.037)		(0.111)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance as IV. Trade intensity is normalized by total bilateral trade, and averaged over1985-2009. Bilateral correlations are calculated using sample from 1985 to 2009.

Table 20. TFP Correlation and Trade Intensity

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
log(w_{ij})	0.091***		0.064***		0.108***
	(0.011)		(0.008)		(0.014)
Constant	1.306***		1.196***		1.431***
	(0.063)		(0.045)		(0.079)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance as IV. Trade intensity is normalized by total bilateral trade, and averaged over 1985-2009. Bilateral correlations are calculated using sample from 1985 to 2009.

Table 21. Output Correlation on EM and IM Using Hummels-Klenow Decomposition

Panel 1: HP-filtered output		Panel 2: Output growth		Panel 3: BP-filtered output	
corr(y_i^{hp}, y_j^{hp})	Coeff.	corr($\Delta y_i, \Delta y_j$)	Coeff.	corr(y_i^{bp}, y_j^{bp})	Coeff.
$\log(EM_{ij})$	0.232***		0.167***		0.205**
	(0.035)		(0.023)		(0.063)
$\log(IM_{ij})$	0.009		$-$0.001		0.040
	(0.017)		(0.011)		(0.031)
Constant	0.662***	Constant	0.375***	Constant	0.721***
	(0.099)		(0.065)		(0.176)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs. Trade intensity is normalized by total bilateral trade, and averaged over 1985-2009. Bilateral correlations are calculated using sample from 1985 to 2009.

Table 22. TFP Correlation on EM and IM Using Hummels-Klenow Decomposition

Panel 1: HP-filtered TFP		Panel 2: TFP growth		Panel 3: BP-filtered TFP	
corr(tfp_i^{hp}, tfp_j^{hp})	Coeff.	corr($\Delta tfp_i, \Delta tfp_j$)	Coeff.	corr(tfp_i^{bp}, tfp_j^{bp})	Coeff.
$\log(EM_{ij})$	0.266***		0.211***		0.244***
	(0.035)		(0.026)		(0.041)
$\log(IM_{ij})$	$-$0.062***		$-$0.053***		$-$0.042*
	(0.017)		(0.013)		(0.020)
Constant	0.651***		0.686***		0.808***
	(0.098)		(0.074)		(0.114)

Note: Standard errors in parentheses. Significance at the 1% (5%) level is indicated by *** (**). Instrumental variables (2SLS) regression, using log distance and log of entry cost as IVs. Trade intensity is normalized by total bilateral trade, and averaged over 1985-2009. Bilateral correlations are calculated using sample from 1985 to 2009.

Table 23. Country List

Developed countries	Developing countries
Australia	Argentina
Austria	Brazil
Canada	China
Denmark	Hong Kong, SAR
Germany	India
Finland	Indonesia
France	Korea
Greece	Malaysia
Ireland	Philippines
Italy	Singapore
Japan	
Netherlands	
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	
United Kingdom	
United States	

Source: UN classification.