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Value Added and Productivity Linkages Across Countries

François de Soyres

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Editorial

On the occasion of the 65th birthday of Governor Klaus Liebscher and in recognition of his commitment to Austria’s participation in European monetary union and to the cause of European integration, the Oesterreichische Nationalbank (OeNB) established a “Klaus Liebscher Award”. It has been offered annually since 2005 for up to two excellent scientific papers on European monetary union and European integration issues. The authors must be less than 35 years old and be citizens from EU member or EU candidate countries. Each “Klaus Liebscher Award” is worth EUR 10,000. The two winning papers of the twelfth Award 2016 were written by Maria Coelho and by François de Soyres. The latter paper is presented in this Working Paper while Maria Coelho’s contribution is contained in Working Paper 210.

November 24, 2016

Value Added and Productivity Linkages Across Countries*

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Abstract

What is the relationship between international trade and business cycle synchronization? Using data from OECD countries, I find that trade in intermediate inputs plays a significant role in synchronizing GDP fluctuations across countries while trade in final goods is found insignificant. Motivated by this new fact, I build a model of international trade in intermediates that is able to replicate more than 70% of the empirical trade-comovement slope, making a significant step toward solving the "Trade Comovement Puzzle". The model relies on two key assumptions: (i) price distortions due to monopolistic competition and (ii) fluctuations in the mass of firms serving each country. The combination of those ingredients creates a link between domestic productivity and foreign shocks through trade linkages. Finally, I provide evidence for the importance of those elements in the link between foreign shocks and domestic GDP and test other predictions of the model.

Keywords: International Trade, International Business Cycle Comovement, Networks, Input-Output Linkages

JEL Classification Numbers: F12, F17, F4, F62, L22

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1 Introduction

The "Trade Comovement Puzzle", uncovered by Kose and Yi (2001 and 2006), refers to the inability of international business cycle models to quantitatively account for the high and robust empirical relationship between international trade and GDP comovement.[1] Using different versions of the workhorse international real business cycle (IRBC) model, several authors have succeeded to qualitatively replicate the positive link between trade and GDP comovement but fall short of the quantitative relationship by an order of magnitude.[2]

In this paper, I refine previous empirical investigations of the association between bilateral trade and GDP comovement and I propose a model that quantitatively accounts for this relationship. First, using data from OECD countries, I show that trade in intermediate inputs plays a significant role in synchronizing GDP fluctuations across countries while trade in final goods is found insignificant, uncovering the strong role of global value chains. Motivated by this new fact, I then propose a general equilibrium dynamic model of trade in inputs with monopolistic pricing and firms entry/exit. In the benchmark calibration, the model is able to replicate more than 70% of the trade-comovement slope, hence proposing a solution for the "Trade Comovement Puzzle". The model features a quantitatively important link between foreign shocks and domestic productivity through trade linkages suggesting that countries with input-output linkages should have correlated TFP, a prediction that I validate in the data. Finally, I provide evidence for the role of the key ingredients generating the quantitative results, namely the importance of price distortions and of the fluctuations of the mass of firms serving every market.

Empirics Since the seminal paper by Frankel and Rose (1998), a large empirical literature has studied cross countries' GDP synchronization, showing that bilateral trade is an important and robust determinant of GDP correlation in the cross section. I update those findings using a panel of 20 OECD countries and uncover a new fact, namely that business cycle synchronization is associated with trade in intermediate inputs while trade in final good is found insignificant.

First, I refine previous analysis by constructing a panel dataset consisting of four 10-years time windows ranging from 1969Q1 to 2008Q4. Controlling for country pair fixed effects that can be correlated with bilateral trade, I show that the relationship between trade and comovement stays high and statistically significant, keeping the "Trade Comovement Puzzle" alive.

[1] For empirical studies on this topic, among many others, see Frankel and Rose (1998), Clark and van Wincoop (2001), Imbs (2004), Baxter and Kouparitsas (2005), Kose and Yi (2006), Calderon, Chong, and Stein (2007), Inklaar, Jong-A-Pin, and Haan (2008), di Giovanni and Levchenko (2010), Ng (2010), Liao and Santacreu (2015) or Duval et al (2016)

[2] For quantitative studies, see Kose and Yi (2001, 2006), Burstein, Kurz and Tesar (2008), Johnson (2014) or Liao and Santacreu (2015)

Furthermore, I make use of disaggregated trade data to disentangle the role of final good from intermediate inputs trade. Regressing GDP comovement on indexes of trade proximity in final and intermediate goods, I show that trade in intermediates captures all of the explanatory power. This new finding suggests that the rise in global value chains plays a particular role in the synchronization of GDP across countries.

Theory As discussed in Kehoe and Ruhl (2008) or Burstein and Cravino (2015), international production linkages alone is not sufficient to generate a strong link between domestic GDP and foreign shocks. The intuition is as follows: GDP is the sum of value added produced within a country and is computed by statistical agencies as the difference between final production and imports, measured using a base price. When imports are used in production, price taking firms choose a quantity of imported input that equalizes their marginal cost and their marginal revenue. Up to a first order approximation, any change in the quantity of imported input yields exactly as much benefit as it brings costs. Hence, foreign shocks have an impact on domestic value added *only* to the extend that they impact the supply of domestic production factors. In other words, foreign shocks have no impact on domestic *productivity*. This "negative result" is at the heart of the Trade-Comovement Puzzle. In this paper, I incorporate two ingredients associating domestic productivity and foreign shock through trade linkages.

First, when firms chose their price, they do not equalize the marginal cost and the marginal revenue product of their inputs. As noted previously by Hall (1988) and discussed in Basu and Fernald (2002), Gopinath and Neiman (2014) or Llosa (2014), this wedge between the marginal cost and the marginal product of inputs implies that any change in input usage is associated with a first order change in value added. Intuitively, the value added produced by a monopolistic firm includes not only the payment to domestic factors of production, but also the firm's profit. This last part is strongly size dependent: any change in the production scale of a firm translates into a change in profit which is also a change in the value added, even for fixed domestic factors of production. At the aggregate level, after a foreign shock, the first order change in GDP for a country populated by price setting firms is not limited to changes in domestic factor supply.[3]

Second, fluctuations along the extensive margin have the potential to create an additional link between domestic productivity and foreign technology. With love for variety, a firm with more suppliers can produce a higher level of output for the same level of inputs. Hence, any change in the

[3]Related to this point, Burstein and Cravino (2015) show that if all firms take prices as given, a change in trade cost can affect aggregate productivity only to the extend that it changes the production possibility frontier at constant prices. This can be interpreted as saying that shocks to the *foreign* trading technology has no impact on aggregate TFP if all firms take prices as given, so that any change in GDP is due to a change in the supply of domestic factors of production.

quantity of imports that is accompanied by a change in the mass of suppliers leads to a first order productivity change. Love for variety is a form of increasing return: a firm with more suppliers is more efficient at transforming inputs into output, which allows value added to react over and beyond changes in domestic factor supply.

Quantitative analysis Motivated by the discussion above, I propose a dynamic general equilibrium a model of international trade in inputs that relies on two key assumptions: (i) monopolistic competition and (ii) fluctuations in the mass of firms serving each country. Production is performed by a continuum of heterogeneous firms combining in a Cobb-Douglas fashion labor, capital and a nested CES aggregate of intermediate inputs bought from other firms from their home country as well as from abroad. Based on their expected profit, firms choose the set of countries they serve (if any). In this context, a firm's marginal cost depends on the number and on the productivity of its suppliers, giving rise to a strong interdependency in pricing and revenues as well as in the export decisions. Moreover, monopolistic competition and fluctuations in the mass of producing firms are key elements in order to break the link between imports and production, thus allowing domestic GDP to be affected by foreign shocks through trade linkages.

I calibrate the model to 14 OECD countries and a composite "rest-of-the-world" and assess its ability to replicate the strong relationship between trade in inputs and GDP synchronization. The model is first calibrated to match GDP, trade flows and the *level* of GDP comovement across all country pairs between 1989 and 2008. Since my goal is to use within country-pair variations in order to perform a fixed-effect estimation of the effect of trade on GDP synchronization, I then recalibrate the model with different targets for trade proximity across countries, decreasing and increasing the target by 10%. In all three configurations, I feed the model with the same sequence of technological shocks, creating a panel dataset in which each country-pair appears three times with three different levels of trade, thus allowing me to estimate the trade comovement *slope*. Fixed effect regressions on this simulated dataset shows that the model is able to replicate more than 70% of the trade-comovement *slope* observed in the data, a significant improvement compared to previous studies.[4]

Decomposing the role of each ingredient, I show quantitatively that trade in intermediates alone is not sufficient to replicate the trade-comovement relationship. The addition of monopolistic pricing and extensive margin adjustments increase the simulated trade-comovement slope by a factor seven and allow the model to better fit the data.

[4] See papers cited in the footnote 2

Further empirical evidence In the last part of the paper, I provide evidence supporting the modeling assumptions. First, using the Price Cost Margin as a proxy for monopoly power and OECD data at the industry level, I find that countries with higher markups experience a higher decrease in their GDP when the price of their import rises.

Second, I construct the extensive and the intensive margins of trade and regress GDP correlation for each country-pair on those indexes. A higher degree of business cycle synchronization is associated with an increase in the range of goods traded and is not associated with an increase in the quantity traded for a given set of goods. This is especially striking since the extensive margin accounts for only a fourth of the variability in total trade.[5]

Finally, I test the prediction that higher trade proximity is associated with higher TFP comovement. I compute and detrend the Solow Residual for 18 OECD countries and compute all pairwise correlations. Regressing TFP correlation on an index of trade proximity shows that, controlling for country-pair fixed effects, a higher trade proximity is associated with a higher degree of TFP comovement, as predicted by the model.

Relationship to the literature If the empirical association between bilateral trade and GDP comovement has long been known, the underlying economic mechanisms leading to this relationship are still unclear. Using the workhorse IRBC with three countries, Kose and Yi (2006) have shown that the model can explain at most 10% of the *slope* between trade and business cycle synchronization, leading to what they called the "Trade Comovement Puzzle". Since then, many papers have refined the puzzle, highlighting different ingredients that could bridge the gap between the data and the predictions of classic models.

Burstein, Kurz and Tesar (2008) show that allowing for production sharing among countries can deliver tighter business cycle synchronization if the elasticity of substitution between home and foreign intermediate inputs is extremely low[6]. Arkolakis & Ramanarayanan (2009) analyse the impact of vertical specialization on the relationship between trade and business cycle synchronization. In their Ricardian model with perfect competition, they do not generate significant dependence of business cycle synchronization on trade intensity, but show that the introduction of price distortions that react to foreign economic conditions allows their model to increase the trade-comovement slope. Incorporating trade in inputs in an otherwise standard IRBC, Johnson (2014) shows that the puzzle cannot be solved by adding the direct propagation due to the international segmentation of supply chains only. Compare to those papers, I add firm entry and exit as well as monopolistic

[5]This result is in line with the analysis in Liao and Santacreu (2015) which emphasizes the role of the extensive margin. Compared to them, I am adding the panel dimension by performing fixed effect regression which allows me to control for country-pair fixed effects that can be correlated with trade intensity.

[6]In their benchmark simulations, the authors take the value of 0.05 for this elasticity.

competition and argue that those are key ingredients for the model to deliver quantitative results in line with the data. Liao and Santacreu (2015) build on Ghironi & Melitz (2005) and Alessandria & Choi (2007) to develop a two-country IRBC model with trade in differentiated intermediates. They show that trade in intermediate varieties leads to an endogenous correlation of measured TFP[7] across trading partners. Compare to this paper, I add multinational production with long supply chains which creates a strong interdependency in firms' pricing end export decisions. Furthermore, I extend the quantitative analysis to many countries and show the international propagation of shocks is affected by the whole network of input-output linkages.[8] Finally, a complementary approach has been developed by Drozd, Kolbin and Nosal (2014) which model the dynamics of trade elasticity. Building on Drozd and Nosal (2012), their model features customers accumulation with matching frictions between producers and retailers. Changes in relative marketing capital across country-specific goods give rise to time variations in the trade elasticity which allow the model to better math the data. Similar to my paper, the setup gives rise to a wedge between the price of imports and their marginal product in final good production, but in their case it is driven by the Nash bargaining over the surplus generated by matches between producers and retailers.

The consequence of input trade on firms efficiency has been studied by Gopinath and Neiman (2014). Focusing on the 2001-2002 Argentinian crisis, they show that trade disruption can cause a significant drop in aggregate productivity. Building a model with monopolistic pricing and exogenous cost of changing the number of suppliers, they replicate the empirical relationship between trade disruption and productivity, showing the importance of within firms' dynamics to understand aggregate productivity. Finally, the role of firms heterogeneity in international business cycles has been pioneered by Ghironi & Melitz (2005) and the business cycle implication of firms' heterogeneity is studied in Fattal-Jaef & Lopez (2014).

The rest of the paper is organized as follows: the second section studies empirically the relationship between trade and GDP synchronization and highlights the important role of trade in intermediate inputs. Section three presents a simple static model of small open economy that provides clear intuitions for the role of markups and entry/exit in generating a link between trade and GDP fluctuations. The fourth section proposes a quantitative model of international trade in intermediate goods with heterogeneous firms and monopolistic competition. In the fifth section, I present the calibration strategy and the quantitative results are presented in section six. Section seven provides further empirical evidence supporting the model, and section eight concludes.

[7] Defined as the Solow residual at the country's level

[8] In their model, no firm is both an importer and an exporter. While this assumption simplifies the resolution, it prevents any network effect.

2 Empirical Evidence

In this section, I use a sample of 20 OECD countries[9] and update the initial Frankel and Rose (1998) analysis on the relationship between bilateral trade and GDP comovement as well as provide empirical support for the specific role of trade in intermediate inputs.

There are two main findings. First, the empirical association between business cycle synchronization and international trade is robust to country-pair fixed effects. Second, trade in intermediate goods play a significant role in explaining GDP comovement, while the explanatory power of trade in final good is found not significant. I first describe the data, then I explain the econometric strategy and finally I present the results in details.

I use quarterly data on real GDP from the OECD database which is transformed in two ways: (i) HP filter with smoothing parameter 1600 to capture the business cycle frequencies and (ii) Baxter and King band pass filter to keep the fluctuations between 32 and 200 quarters, which represent the medium term business cycles (Comin and Gertler, 2006). Trade data come from the NBER-UN world trade database. It features bilateral trade flows at the 4-digit level of disaggregation (SITC Rev. 4). Such a high level of disaggregation allows me to deepen the analysis by disentangling the effect of trade in final good from the trade in intermediate inputs.

In a first set of regressions, I construct a symmetric measure of bilateral trade intensity between countries i and j using total trade flows as: $\text{Total}_{ij}=\max\left(\frac{Total\ Trade_{ij}}{GDP_i}, \frac{Total\ Trade_{ij}}{GDP_j}\right)$. This measure has the advantage to take a high value whenever one of the two countries depends heavily on the other for its imports or exports.[10]

In order to disentangle the influence of trade flows in inputs from the final goods, I construct the indexes Final_{ij} and Intermediate_{ij} with the same formulation but taking into account only the trade flows in final and intermediate goods respectively. I follow Feenstra and Jensen (2012) to separate the trade flows into final and intermediates and transform the SITC code into End-Use categorization. The End-Use codes are used by the Bureau of Economic Analysis (BEA) to allocate goods to their final use, and are similar to the Broad Economic Categories of the United Nations Statistics Division. This categorization allows me separate products between final and intermediate goods.[11]

[9] The list of countries is: Australia, Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Mexico, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States

[10] The index mostly used in the literature was the sum of total trade flows divided by the sum of GDPs. While the empirical and simulated results hold when I use this index, it has the disadvantage that a country-pair consisting in with a very big country and a very small country cannot have a high index, despite the fact the small country might depend exclusively on the big country's imports and exports.

[11] In appendix, I verify the robustness of my findings using an alternative method of separating intermediate from

The extent to which countries have correlated GDP can be influenced by many factors beyond international trade, including correlated shocks, financial linkages, monetary policies, etc... Because those other factors can themselves be correlated with the index of trade proximity in the cross section, using cross-section identification could yield biased results. In order to separate the effect of trade linkages from other elements, I construct a panel dataset by creating four periods of ten years each. In every time window, I compute GDP correlation for all country pairs as well as trade indexes defined above. The index relative to a given time window is the average of all yearly indexes. Using panel data allows me to control for time invariant country-pair specific factors that are not observables.

I estimate the following equations:

$$(1) \qquad \text{corr}(GDP_{it}^{filtered}, GDP_{jt}^{filtered}) = \alpha_1 + \beta_T \log(\text{Total}_{ijt}) + controls + \epsilon_{1,ijt}$$

$$(2) \qquad \text{corr}(GDP_{it}^{filtered}, GDP_{jt}^{filtered}) = \alpha_2 + \beta_I \log(\text{Intermediate}_{ijt}) + \beta_F \log(\text{Final}_{ijt}) + controls + \epsilon_{2,ijt}$$

In the rest of this section I present two facts that characterize the relationship between GDP synchronization and international trade. Results are gathered in tables 1 and 2

Finding 1: The trade-comovement slope is robust to country-pair fixed effect

The initial Frankel and Rose (1998) finding that bilateral trade correlates with business cycle synchronization does not answer the question of trade's role in transmitting shocks. Using cross-sectional variation shows that country-pairs with higher trade linkages experience more correlated GDP fluctuations but does not rule out omitted variable bias such as, for example, the fact that close by countries have att he same time more correlated shocks and larger trade flows. By constructing a panel dataset and controlling for country-pair fixed effects, this paper relates to recent studies that try to control for unobserved characteristics.[12]

As in previous studies, I find that an increase in the index of trade proximity is associated with an increase in GDP correlation in the cross section, as shown in columns (1) and (2) in table 1. Moreover, controlling for country-pair fixed effects and using only within country-pair variations, the strong relationship between trade in GDP correlation still holds, with the point estimates in column (3) and (5) show that a doubling of the median index is associated with an increase of GDP correlation between 0.065 (in column (5)) and 0.21 (in column (3)). Those numbers imply that

final goods. In the STAN database of the OECD, input-output tables have been used at the country level to disentangle trade flows in intermediate and final goods from 1995 to 2014. All results are robust using this categorization.

[12] Di Giovanni and Levchenko (2010) includes country pair fixed effects in a large cross-section of industry-level data with 55 countries in order to test for the relationship between sectoral trade and *output* (not *value-added*) comovement at the industry level. Duval et al (2016) includes country pair fixed effects in a panel of 63 countries and test the importance of value added trade in GDP comovement.

moving from the 25th to the 75th percentile of trade proximity in my sample is associated with an increase of GDP correlations between 0.20 and 0.67, which is very significant. These findings are also robust when using BK filtered GDP at medium term frequency, as shown in table 2.

Finding 2: Trade in Intermediate inputs plays a strong role in GDP comovement

To investigate further the relationship between trade and GDP comovement at business cycle frequency, columns (2), (4) and (6) of 1 disentangle the effect of trade in intermediate inputs from trade in final goods. The results highlight a specific role for trade in intermediate inputs, both in the cross section and in the panel dimensions.[13] In all specifications the index of trade proximity in intermediate goods is high and significant with a doubling of the intermediate trade index associated with GDP comovement increase between 0.05 (column (6)) and 0.16 (column (4)) depending on the specification. Turning to medium term business cycles, 2 shows that trade in final good is insignificant while trade in intermediate inputs is high and significant in all specifications. These results strongly suggest that international supply chains are an important determinant of the degree of business cycle synchronization across countries.[14]

[13]Di Giovanni and Levchenko (2010) investigate the role of vertical linkages in *output* synchronization (not *value added*) using input-output matrices from the BEA. Their estimates imply that vertical production linkages account for some 30 percent of the total impact of bilateral trade on the business cycle correlation

[14]The results presented here used a fixed effect specification. One might also consider that the variation across country-pairs are assumed to be random and uncorrelated with trade proximity indexes, in which case a random effect treatment would be a better fit. To discriminate between fixed or random effects, I run a Hausman specification test where the null hypothesis is that the preferred model is random effects against the fixed effects. This tests whether the error terms ϵ_{ijt} are correlated with the regressors, with the null hypothesis being they are not. Results display a significant difference ($p < 0.001$), indicating that the two models are different enough to reject the null hypothesis, and hence to reject the random effects in favor of the fixed effect model.

	dependent variable: corr(GDP_i^{HP},GDP_j^{HP})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.090***		0.315***		0.094**	
	(11.15)		(15.04)		(2.56)	
log(Intermediate)		0.125***		0.231***		0.065**
		(6.45)		(9.10)		(2.43)
log(Final)		-0.044*		0.026		0.012
		(-2.08)		(0.67)		(0.48)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
R-squared (within)			0.218	0.230	0.459	0.461
R-squared (overall)	0.140	0.160	0.141	0.156	0.359	0.357
N	———— 760 ————					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 1: Trade and HP-Filtered GDP

	dependent variable: corr(GDP_i^{BK},GDP_j^{BK})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.102***		0.330***		0.100*	
	(10.14)		(12.52)		(1.97)	
log(Intermediate)		0.161***		0.289***		0.135***
		(6.65)		(9.45)		(3.41)
log(Final)		-0.0694**		-0.044		-0.054
		(-2.64)		(-0.95)		(-1.20)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
R-squared (within)			0.168	0.198	0.311	0.317
R-squared (overall)	0.118	0.144	0.120	0.143	0.257	0.260
N	———— 760 ————					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 2: Trade and BK-Filtered GDP

3 A simple model

In this section, I show in a simple framework why the inclusion of input-output linkages across countries is not sufficient for a model to generate a strong relationship between trade and GDP comovement, and how the inclusion of two new elements (monopolistic pricing and extensive margin adjustments) goes a long way toward generating a link between a shock in a trading partner's economy and domestic GDP. Section 4 will then present a quantitative general equilibrium model with many countries that is able to replicate 70% of the trade-comovement relationship observed in the data, hence proposing a solution for the trade comovement puzzle.

For the sake of exposition, I consider here a static small open economy. In such a world, KR showed that a change in the price of imported inputs has no impact, up to a first order approximation, on measured productivity. This means that any change in GDP is due to changes in domestic factors supply. I start by briefly reviewing this important result.

3.1 The Kehoe and Ruhl (2008) negative result

The economy produces a final good y, used for consumption and exports, which is produced by combining imported inputs x and domestic factors of production ℓ (possibly a vector) according to:

$$y = F(\ell, x) \tag{1}$$

where $F(.,.)$ has constant returns to scale and is concave with respect to each of its argument. The final good producer chooses intermediate and imported inputs to maximize its profit taking as given all prices. Optimality requires that factors are paid their marginal product:

$$p_y F_\ell(\ell, x) = w \qquad \text{and} \qquad p_y F_x(\ell, x) = p_x \tag{2}$$

with p_y the final good price, p_x the price of imported inputs x and w the price of domestic factors. Gross Domestic Product is the sum of value added in the country, defined as:

$$GDP = p_y F(\ell, x) - p_x.x \tag{3}$$

Importantly, many statistical agencies (and in particular the OECD database used in the empirical analysis above) use *base period prices* when valuing estimated quantities in the construction of

GDP.[15] Let us now compute the first order change in GDP when the Terms-of-Trade ($\equiv p_x$) change. Keeping prices constant at their base value before the shock, we get:

$$\frac{dGDP}{dp_x} = \underbrace{p_y F_\ell(\ell, x)\frac{\partial \ell}{\partial p_x}}_{\text{Factor Supply Effect}} + \underbrace{\frac{\partial x}{\partial p_x}(p_y F_x(\ell, x) - p_x)}_{\text{Input-Output Effect}} \tag{4}$$

The first term captures the value added change due to variations in factor supply and depends heavily on the degree of substitutability or complementarity between foreign and domestic inputs[16] as well as on the elasticity of factor supply. The second term captures the direct impact of a change imported input usage. With perfect competition, profit maximization insures that $p_y F_x(\ell, x) = p_x$ so that this term disappears. In such a model, any change in GDP is solely driven by changes in domestic factor supply. This is the negative result presented in KR: when firms take prices as given, profit maximization insures that the marginal benefit of using an additional unit of imported input x ($p_y F_x(\ell, x)$) is equal to its marginal cost (p_x). Hence, up to a first order approximation, domestic value added is affected by a foreign technological shock only through a change in factor supply. In other words, the measured productivity is not affected to foreign shocks.[17]

3.2 Markups and Love for variety

Consider now a variant of the economy described above with an additional production step: inputs are imported by a continuum of intermediate producers with a linear production function $m = x$. Critically, I now add two new elements: (1) a *price wedge* for intermediate producers $\mu \neq 1$ so that the price of intermediates m is given by $p_m = \mu \times p_x$, and (2) love for variety in the final good production technology in the form of a Dixit-Stiglitz aggregation of intermediates.[18] The production

[15] In the US, the Bureau of Economic Analysis uses a Fisher chain-weighted price index to construct GDP at time t relative to GDP at time $t-1$ according to:

$$\frac{GDP_t}{GDP_{t-1}} = \left(\frac{\sum_k p_{t-1}^k q_t^k}{\sum_k p_{t-1}^k q_{t-1}^k}\right)^{0.5} \left(\frac{\sum_k p_t^k q_t^k}{\sum_k p_t^k q_{t-1}^k}\right)^{0.5}$$

where k indexes all components of GDP. Intuitively, the Fisher index is a mix between two base period pricing methods where the base price is alternatively the price at $t-1$ and at t.

[16] The role of complementarity is discussed at length in Burstein et al (2008) or in Boehm et al (2015).

[17] Note that an important part of the reasoning rests upon the fact that GDP is constructed using constant base prices. If the prices used to value final goods and imported inputs were to change due to the shock, one would have an additional term in equation (4).

[18] In many models, the elasticity of substitution in the CES aggregation governs at the same time the markup charged by monopolistic competitors and the love degree of love for variety. In order to clearly differentiate the sheer effect of markup from the love for variety, I assume here that the markup μ can take any value, including the case where $\mu = \sigma/(\sigma - 1)$.

function in the final good sector is:

$$y = F(\mathcal{I}, \ell) \qquad \text{with } \mathcal{I} = \left(\int_0^{\mathcal{M}} m_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \tag{5}$$

This production function displays love for variety in the following sense: for a given amount of total imports, the larger the mass of input suppliers $\mathcal{M}$, the higher the amount of final production obtainable.

For each variety m_i, there is a producer with a linear technology using imports only:

$$\forall\ i\ \in [0, \mathcal{M}], \quad m_i = x_i \tag{6}$$

All intermediate producers are completely symmetric and I denote by m their (common) production and by x their (common) import levels. The bundle $\mathcal{I}$ can then be simply expressed as $\mathcal{I} = \mathcal{M}^{\sigma/(\sigma-1)} m$ and the price index dual to the definition of the bundle is $\mathcal{P} = \mathcal{M}^{1/(1-\sigma)} p_m$, which is also equal to $F_{\mathcal{I}}(\mathcal{I}, \ell)$, the marginal productivity of the input bundle in final good production. Finally, taking the derivative of Y with respect to p_x while keeping prices constant, the first order change in GDP when the import price changes is given by

$$\frac{dY}{dp_x} = \left(\mathcal{M} \frac{\partial m}{\partial p_x} + \frac{\partial \mathcal{M}}{\partial p_x} m \right) . (\mu - 1) \, p_x + \frac{1}{\sigma - 1} p_m m \frac{\partial \mathcal{M}}{\partial p_x} \tag{7}$$

First, the existence of a price wedge $\mu \neq 1$ means that the first term does not vanish. With $m'(p_x) < 0$,[19] an decrease in the price of imported inputs leads to a increase in GDP. When firms are price setters and earn a positive profit, the marginal revenue generated by an additional unit of imported input x is larger than its marginal cost p_x. Hence, cheaper inputs means more sales, more profit and more value added.

Moreover, any change in the mass of firms $\mathcal{M}$ also impacts domestic value added. One can model many reasons why the mass of producing firms would change, including a free entry condition with initial sunk cost or any reason that changes the supply of potential entrepreneurs.[20] A change in the number of price setting firms gives a time varying element to the effect described above, triggering a greater reaction of GDP after a foreign shock. Note that this effect is not governed by the love for variety which is captured by the parameter σ. Overall, the key idea governing this first term can be expressed as follows: firms that charge a markup have a disconnect between the marginal cost

[19] This can be easily proved if assuming that $F(.)$ is a Cobb Douglas aggregation of domestic factors and intermediates.

[20] In an additional appendix available upon request, I have modeled the free condition and showed that it indeed leads to a decrease in the mass of firms after an increase of import prices.

and the marginal revenue product of their inputs. The difference between those two is accounted as value added in the form of profits. Any change in input usage leading to a change in profits triggers a change in value added produced.

Second, when $\sigma < +\infty$, another effect arises. When the production function exhibits love for variety, any change in the mass of firms implies an additional reaction for the input bundle $\mathcal{I}$. If the decrease of p_x is accompanied by an increase in the mass of producing firm,[21] the bundle $\mathcal{I}$ increases not only because each intermediate producer will tend to produce more, but also because an increase in the mass of firms mechanically increases $\mathcal{I}$ even for a fixed amount of intermediates.

With love for variety, a producer that has access to more suppliers can produce more output for the same level of input, and a change in the mass of firms impact the marginal cost of producing final goods over and beyond the change in input prices. Another way of saying this is that the set of feasible combinations of output $\mathcal{I}$, and inputs $\int_0^{\mathcal{M}} m_i di = X$ is not independent from the mass of producers $\mathcal{M}$: a change of $\mathcal{M}$ has an effect on the production possibility frontier. Interestingly, this channel is at work independently of the price distortion channel discussed previously. Even in the absence of monopoly pricing, the sheer fluctuation in the mass of producing firms coupled with a love for variety in final good production creates a link between import price and GDP fluctuation even with fixed factor supply.

Finally, note that the introduction of markups and love for variety allows GDP to change over and beyond changes in the domestic factors of productions. Using a "growth accounting" perspective, this means that the introduction of those two elements makes domestic productivity change after a foreign shock, even with a fixed technology. Two countries that have important trade flows in intermediate inputs should then have correlated measured TFP, a prediction I test in the data in section 7.

4 A model of International Trade in Inputs

4.1 Setup

In this section, I build a quantitative model of international trade in inputs with *monopolistic competition* and *firm entry/exit* and assess its ability to replicate the strong relationship between trade and business cycle synchronization.[22] I consider an environment with N countries indexed

[21] If the mass of firms is pinned down by a free entry condition, the increase in profits of each intermediate producer when the price of imported input goes up leads to a increase in the mass of firms.

[22] In section 6, I present a decomposition of the role that each of the novel ingredients have on the quantitative results.

by k. In each country, there is a representative agent with preferences over leisure and the set of available goods Ω_k described by

$$\begin{aligned} U_{k,0} &= \mathbb{E}_0 \left[\sum_{t=0}^{+\infty} \beta^t \left(\log\left(C_{k,t}\right) - \psi_k \frac{L_{k,t}^{1+\nu}}{1+\nu} \right) \right] \\ \text{with} \qquad & C_t = \left(\int\limits_{\Omega_k} q_{i,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

where ψ_k is a scaling parameter, ν is the inverse of the Frisch elasticity of labor supply and σ the elasticity of substitution between different varieties of final goods. The agent chooses consumption, investment and labor in each period subject to the budget constraint:

$$P_{k,t}\left(C_{k,t} + K_{k,t+1} - (1-\delta)K_{k,t}\right) = w_{k,t}L_{k,t} + r_{k,t}K_{k,t}$$

Production is performed by a continuum of heterogeneous firms combining in a Cobb-Douglas fashion labor ℓ_k, capital k_k and intermediate inputs $I_{k,t}$ bought from other firms from their home country as well as from abroad. Firms' productivity is the product of an idiosyncratic part φ and a country specific part $Z_{k,t}$. Firms maximize their static profit taking as given all input prices. Omitting time indexes for now, the intermediate input index in country k, I_k is an Armington aggregation of country specific bundles $M_{k',k}$ for all k', with the Armington elasticity denoted ρ. In order to introduce a rationale for markups and for love for variety, each country specific bundle is itself a CES aggregation of many varieties, with the elasticity of substitution σ (which governs both the markup firms charge and the degree of love for variety). The production function is:

$$\begin{aligned} Q_k(\varphi) &= Z_k.\varphi \ . \ I_k(\varphi)^{1-\eta_k-\chi_k} \ . \ \ell_k(\varphi)^{\chi_k} \ . \ k_k(\varphi)^{\eta_k} \\ \text{with} \qquad & I_k(\varphi) = \left(\sum_{k'} \omega_k(k')^{\frac{1}{\rho}} M_{k',k}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}} \\ \text{and} \qquad & M_{k',k} = \left(\int\limits_{\Omega_{k',k}} m_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

where $\omega_k(k')$ is the share of country k' in the production process of country k with $\sum\limits_{k'} \omega_k(k') = 1$ and $\Omega_{k',k}$ is the endogenous set of firms based in k' and exporting to k. For later use, I define notations for the ideal price indexes dual to the two layers of the nested CES aggregation. $\mathcal{P}_{k,k'}$ denotes the price of the country-pair specific bundle $M_{k',k}$ and IP_k the unit price of the intermediate input bundle I_k. The unit cost of the Cobb Douglas bundle aggregating I_k, k_k and ℓ_k (called the "input bundle") is PB_k and represents the price of the basic production factor in country k. The exact expressions of those objects are standard and can be found in the appendix.

The only stochastic elements of this model are the country specific technological shocks (Z_k) which follow an AR(1) process. In all countries, the distribution of productivity φ is Pareto with shape parameter γ and density $g(\varphi) = \gamma\varphi^{-\gamma-1}$. For simplicity and in line with the empirical results in section 2, I restrict trade to be only between firms which means that I consider only trade in intermediate inputs.

In order to be allowed to sell its variety to a country j, a firm from country i must pay a fixed cost f_{ij} (labeled in unit of the "input bundle") as well as a variable (iceberg) cost τ_{ij}. Firms choose which countries they enter (if any), affecting both the level of competition and the marginal cost of all firms in the country. As will be clear below, profits are strictly increasing with productivity φ so that equilibrium export decisions are defined by country-pair specific thresholds $\varphi_{k,k'}$ above which firms from k find it profitable to pay the fixed cost $f_{kk'}$ and serve country k'. Finally there is an overhead entry cost $f_{E,k}$, sunk at the production stage, to be paid before firms know their actual productivity. Based on their expected profit in all markets, firms enter the economy until the expected value of doing so equals the overhead entry cost. This process determines the mass of firms M_k actually drawing a productivity, some of which optimally decide to exit the market before production due to the presence of fixed costs.

4.2 Equilibrium

In this section, I present the key conditions that characterize the equilibrium of the model. Introducing X_k the aggregate consumers' revenue in k and S_k the total firms' spendings (including fixed costs payments) in country k respectively, total demand faced by firm φ is given by

$$q(\varphi) = \left(\frac{p_{k,k}(\varphi)}{\mathcal{P}_k}\right)^{-\sigma} \frac{X_k}{\mathcal{P}_k} + \sum_{k'} \left(\frac{p_{k,k'}(\varphi)}{\mathcal{P}_{k,k'}}\right)^{-\sigma} \left(\frac{\mathcal{P}_{k,k'}}{IP_{k'}}\right)^{-\rho} \frac{\omega_{k'}(k)(1-\eta_{k'}-\chi_{k'})S_{k'}}{IP_{k'}} \tag{8}$$

where $p_{k,k'}(\varphi)$ is the price charged by a firm from country k, with productivity φ, when selling in country k' and the summation is done over all markets that are served by a firm with productivity φ. Firms are monopolists within their variety and choose their price at a constant markup over marginal cost and the markup depends on the price elasticity of demand. In this case, the only elasticity that is relevant to firms' pricing is σ, capturing the fact that firms compete primarily with other firms coming from their home country since their individual pricing decision has no impact on the country-specific price index in every market.[23] The marginal cost of a firm with productivity φ in country k is $PB_k/(Z_k\varphi)$ and its optimal price is given by:

$$p_{k,k'} = \tau_{k,k'} \frac{\sigma}{\sigma-1} \frac{PB_k}{Z_k\varphi} \tag{9}$$

Unlike in the canonical Krugman (1980) or Melitz (2003) models, one cannot solve for prices for each firm independently. Through PB_k, the price charged by firm φ in country k depends on the prices charged by all firms supplying country k (both domestic and foreign) which in turn depend on the prices charged by their suppliers and so on and so forth. The input-output linkages across firms create a link between the pricing strategies of all firms and one needs to solve for all those prices at once. Doing so requires solving for all country-pair specific price indexes $\mathcal{P}_{k,k'}$.

The definitions of price indexes give rise to a simple relationship between the price of the country k specific bundle at home, $\mathcal{P}_{k,k}$, and its counterpart in country k', $\mathcal{P}_{k',k}$:

$$\mathcal{P}_{k,k'} = \tau_{kk'} \left(\frac{\varphi_{k,k'}}{\varphi_{k,k}}\right)^{\frac{\sigma-\gamma-1}{1-\sigma}} \times \mathcal{P}_k \tag{10}$$

Intuitively, the ratio between the price of a country specific bundle in two different markets depends on the relative iceberg costs as well as the relative entry thresholds. Using this relation in the definition of price indexes in every country yields a system of N equations which jointly defines all price indexes:

$$\mathcal{P}_k^{1-\rho} = \mu_k \left(\sum_{k'} \omega_k(k') \left(\tau_{k'k} \left(\frac{\varphi_{k',k}}{\varphi_{k',k'}}\right)^{\frac{\sigma-\gamma-1}{1-\sigma}} \mathcal{P}_{k'}\right)^{1-\rho}\right)^{1-\eta_k-\chi_k} \quad, \; k = 1, ..., N \tag{11}$$

with μ_k depending on entry thresholds, the mass of firms and parameters.[24] For given thresholds and mass of firms, this system admits a unique non negative solution.[25]

Turning now to the determination of export strategies, the productivity thresholds above which firms from country k optimally decide to pay the fixed cost and serve market k' are simply given

[23] With a finite number of firms, both elasticities σ and ρ would appear in the pricing strategy. In such a case, every firm would take into account the fact that its own price has an impact on the unit cost of the corresponding country-specific bundle. Therefore, when decreasing its price a firm would attract more demand compare to firms from its own country but also increase the share of total demand that goes to every other firms from the its country.

[24] $\mu_k^{\frac{1-\sigma}{1-\rho}} = \frac{\gamma\varphi_{k,k}^{\sigma-\gamma-1}}{\gamma-(\sigma-1)} M_k \left(\frac{\sigma}{\sigma-1} \frac{w_k^{\chi_k} \times r_k^{\eta_k}}{\chi_k^{\chi_k} \times \eta_k^{\eta_k} \times (1-\eta_k-\chi_k)^{1-\eta_k-\chi_k}} \frac{1}{Z_k}\right)^{1-\sigma}$

[25] Following Kennan (2001) and denoting $G_k = \mathcal{P}_k^{1-\rho}$ and G the associated $N \times 1$ vector, it suffices to show that the system is of the form $G = f(G)$ with $f : \mathbb{R}^N \to \mathbb{R}^N$ a vector function which is strictly concave with respect to each argument, which is obvious as long as $0 < \eta_k + \chi_k < 1$. This argument stresses the importance of decreasing return to scale with respect to intermediate inputs in order to ensure unicity of the equilibrium.

by:

$$\pi_{k,k'}(\varphi_{k,k'}) = \frac{PB_k}{Z_k}.f_{k,k'} \quad \text{for all } k \text{ and } k' \tag{12}$$

where $\pi_{k,k'}(\varphi)$ is the variable profit earned by a firm with productivity φ in market k'. I assume that the fixed cost $f_{k,k'}$ is paid in unit of the basic production factor in country k deflated by the aggregate level of productivity, as is the case in Ghironi and Melitz (2005) for example.

The mass of firms deciding to enter the market in each period is finally determined by the free entry condition. With the assumption that $f_{E,k}$ is labeled in units of labor,[26] the condition writes:

$$\Pi_k = M_k \frac{w_k}{Z_k}.f_{E,k} \quad \text{for all } k \tag{13}$$

where Π_k denotes aggregate profits of all firms in country k. An expression of Π_k can be found using a property first noted by Eaton and Kortum (2005) according to which total profit in country k are proportional to total revenues. Defining R_k the total sales of firms from country k made on all markets, we have the following result:

Lemma 1 : Total profit in country k are proportional to total revenues:

$$\Pi_k = \frac{\sigma - 1}{\gamma\sigma} R_k \tag{14}$$

Proof: see Appendix.

Closing the model involves market clearing conditions for capital, labor and goods. Labor can be used either for production (L_k^p) or for the entry cost (L_k^e) so that $L_k = L_k^p + L_k^e$. Classic properties of Cobb-Douglas production functions imply that total labor and capital payments for production are equal to a fraction $\eta_k + \chi_k$ of firms' variable spendings. Since total profit are used in the entry fixed cost payment, total consumer's spending is defined as $X_k = w_k L_k + r_k K_k = (\eta_k + \chi_k)S_k + \Pi_k$. Moreover, the investment Euler Equation (capital supply) is given by

$$\frac{1}{C_{k,t}} = \beta \mathbb{E}_t \left[\frac{1}{C_{k,t+1}} \times \left(\frac{r_{k,t+1}}{P_{k,t+1}} + (1-\delta) \right) \right] \tag{15}$$

while labor supply is:

$$\psi_k L_{k,t}^{\nu} = \frac{w_{k,t}}{P_{k,t}} \frac{1}{C_{k,t}} \tag{16}$$

[26] An alternative specification could be that the sunk cost is paid in unit of the production bundle combining labor, capital and intermediate. The issue with using such a specification is that the model could feature multiple equilibria, where either many firms enter which decreases price indexes and hence the cost of entering, or few firms enter which is associated with a high cost of the production bundle.

Finally, trade being allowed in intermediate goods only, revenues in foreign countries come from other firms' spending while domestic revenues also include consumers' spendings. Total revenues of all firms from country k are:

$$R_k = X_k + \left[\sum_{k'} \left(\frac{\mathcal{P}_{k,k'}}{IP_{k'}} \right)^{1-\rho} \omega_{k'}(k)(1 - \eta_{k'} - \chi_{k'}) S_{k'} \right] \tag{17}$$

This formula has a simple interpretation: firms in country k receive revenues from their final good sales to their home consumers (for a total amount of X_k) as well as from sales as intermediate goods on all markets. In every country k', firms allocate a constant fraction $1 - \eta_k - \chi_k$ of their total spendings to intermediate inputs, which is then scaled by the weight $\omega_{k'}(k)$ representing the importance of country k in the production process of country k'. Finally, since country k specific bundle in k' is in competition with other country specific bundles in the input market, total revenues of k-firms when selling in k' also depend on the ratio of $\mathcal{P}_{k,k'}$ to $IP_{k'}$ to a power reflecting the relevant the price elasticity, in this case the macro (Armington) one ρ. For later use, it is useful to define total trade between k and k' as

$$T_{k \to k'} = \left(\frac{\mathcal{P}_{k,k'}}{IP_{k'}} \right)^{1-\rho} \omega_{k'}(k)(1 - \eta_k - \chi_k) S_{k'}$$

Using $X_k = (\eta_k + \chi_k) S_k + \Pi_k$, the good market clearing condition can be written in compact form as

$$\left\{ \underbrace{\left(\mathcal{I}_N - \left(W^T \circ P\right)\right)}_{=M} \begin{pmatrix} (1 - \eta_1 - \chi_1).S_1 \\ \vdots \\ (1 - \eta_N - \chi_N).S_N \end{pmatrix} = 0_{\mathbb{R}^N} \right. \tag{18}$$

where W the weighting matrix defined as $W_{ij} = \omega_i(j)$, P a matrix defined by $P_{ij} = \left(\frac{\mathcal{P}_{i,j}}{IP_i}\right)^{1-\rho}$ and $\circ$ is the element-wise (Hadamard) product. To gain intuitions, one can note that the matrix P scales the weights $\omega_{k'}(k)$ in order to account for the competition across country-specific bundles. If the Armington elasticity ρ is above unity (country specific bundles are substitutes) then a country i which is able to charge low prices in some market j (a low $\mathcal{P}_{i,j}$) will attract a higher share of total expenditures from all firms in this country. Classically, this effect completely disappears in the case of a Cobb-Douglas aggregation of country specific bundles, because in such a case the spending shares are fixed.

The solutions of this system form a one dimensional vector space.[27] Setting $w_1 = 1$, implying $S_1 = L_1^p / \chi_k$, provides a unique solution for all variables by solving together the price system (11),

[27] One can easily show that the matrix M is non invertible: summing all rows results in a column of zero.

the threshold system (12), the Spending system (18), the Free Entry system (13) as well as the labor and capital market equilibrium conditions.

GDP definition An important feature of GDP construction in OECD data is the use of base prices and quantity estimates.[28] In order to be as close as possible to the method used in the construction of the data used in the empirical analysis, I define GDP using steady state prices as base prices. The GDP definition that is model-consistent is obtained by using welfare-based price indexes to deflate nominal spending, such that:

$$GDP_{k,t} = \underbrace{\mathcal{P}_k^{ss} \frac{X_{k,t}}{\mathcal{P}_{k,t}}}_{\text{Consumption + Investment}} + \underbrace{\sum_{k'} \mathcal{P}_{k,k'}^{ss} \frac{T_{k\to k',t}}{\mathcal{P}_{k,k',t}}}_{\text{Exports}} - \underbrace{\sum_{k'} \mathcal{P}_{k',k}^{ss} \frac{T_{k'\to k,t}}{\mathcal{P}_{k',k,t}}}_{\text{Imports}} \tag{19}$$

Note that the first term is also equal to the Gross National Income (GNI_k) since there is no trade in assets across countries.

However, since both consumers' utility and production functions have a CES component, it is well known that the associated price indexes can be decomposed into components reflecting average prices (captured by statistical agencies) and product variety (which is not taken into account in national statistics).[29] In order to be consistent with the way actual data are collected, I define GDP using modified price indexes such that $\widehat{\mathcal{P}_{k,k'}} = \left(M_k.\varphi_{k,k'}^{-\gamma}\right)^{1/(\sigma-1)} \mathcal{P}_{k,k'}$. Using those statistical-consistent price indexes in the GDP definition yields $\widehat{GDP_k}$, a GDP construct that can be compared to the actual data:

$$\widehat{GDP_k} = \underbrace{\widehat{\mathcal{P}_k^{ss}} \frac{X_k}{\widehat{\mathcal{P}_k}}}_{\text{Consumption + Investment}} + \underbrace{\sum_{k'} \widehat{\mathcal{P}_{k,k'}^{ss}} \frac{T_{k\to k',t}}{\widehat{\mathcal{P}_{k,k',t}}}}_{\text{Exports}} - \underbrace{\sum_{k'} \widehat{\mathcal{P}_{k',k}^{ss}} \frac{T_{k'\to k,t}}{\widehat{\mathcal{P}_{k',k,t}}}}_{\text{Imports}} \tag{20}$$

4.3 GNI elasticity in a simplified case

In order to investigate the mechanics driving the propagation of shocks across countries in the model, let us study a special case with $\rho = 1$ and fixed labor, capital and mass of potential entrants.[30] The goal of this section is to compute the elasticity of GNI in any country i with respect to a technology shock in country 1:

$$\eta_{GNI_i,Z_1} = \frac{\partial \log(GNI_i)}{\partial \log(Z_1)}$$

[28]The GDP series used in the empirical analysis is VPVOBARSA and is constructed as "*US dollars, volume estimates, fixed PPPs, OECD reference year*".

[29]See Feenstra (1994) or Ghironi and Melitz (2005) for a discussion of this

[30]Without capital supply, the model is completely static. A fixed mass of potential entrants does not mean a fixed mass of actual producers because entry thresholds $\varphi_{k,k}$ are not fixed.

Moreover, in order to understand the differences between using model-based and statistic-based price indexes, I also compute the elasticity of Gross National Income as computed in national statistics ($\widehat{GNI_k} = (w_k L_k + r_k K_k)/\widehat{\mathcal{P}_k}$):

$$\eta_{\widehat{GNI_i},Z_1} = \frac{\partial \log(\widehat{GNI_i})}{\partial \log(Z_1)}$$

Computing the elasticity of all endogenous variable with respect to technological shocks leads to the closed-form formula in lemma 2.

Lemma 2 : In the Cobb-Douglas ($\rho = 1$) case and fixing both labor and capital supply, the elasticity of model-based GNI and statistical GNI in all countries with respect to a technology shock in country 1 are given by:

$$\begin{pmatrix} \eta_{GNI_1,Z_1} \\ \vdots \\ \eta_{GNI_N,Z_1} \end{pmatrix} = (\mathcal{I}_N - \widehat{W} - T)^{-1} \begin{pmatrix} 1 \\ 0 \\ \vdots \end{pmatrix} \tag{21}$$

and

$$\begin{pmatrix} \eta_{\widehat{GNI_1},Z_1} \\ \vdots \\ \eta_{\widehat{GNI_N},Z_1} \end{pmatrix} = \left(\frac{\gamma - (\sigma - 1)}{\sigma\gamma - (\sigma - 1)}\right) \cdot \begin{pmatrix} \eta_{GNI_1,Z_1} \\ \vdots \\ \eta_{GNI_N,Z_1} \end{pmatrix} \tag{22}$$

with $\widetilde{W}_{i,j} = (1 - \eta_i - \chi_i)\omega_{i,j}$ the matrix of scaled weights $\omega_{i,j}$ representing the intensive margin adjustments and T a "Transmission" matrix[31], function of γ and σ, accounting for extensive margin movements.

Proof: see Appendix.

These expressions are reminiscent of what can be found in static Cobb-Douglas network models such as Acemoglu et al (2012) for example, with an additional effect coming from firm heterogeneity and the extensive margin adjustments captured by the matrix T. In this context, the international propagation pattern of country specific shocks runs through two channels. First, for fixed spending share, the matrix $\widetilde{W}$ records the input-output linkages if the export decision of firms are kept constant. Second, the change in prices and revenues in all markets triggers a change in the productivity thresholds $\varphi_{k,k'}$. This channel is characterized by the matrix T which is a function of σ and γ which govern the adjustments along the extensive margin. Note that the elasticities of model- and statis-

[31] $T = \Lambda \mathcal{I}_N$, with $\Lambda = \frac{1}{\sigma + \frac{(\sigma-1)^2}{\gamma-(\sigma-1)}}$

tical agency-based GNIs are exactly proportional, with $\eta_{\widehat{GNI_k},Z_1} < \eta_{GNI_k,Z_1}$ for all k. Not taking into account the love for variety effect in the computation of price indexes leads to a downward bias in the response of price indexes to technological shocks.

The computations leading to the expressions of the GNI elasticities in this lemma are greatly simplified by the assumption that factors of production (labor and capital) are fixed. In the general model, however, this constitute an important amplification channel through two effects. First, as in many macro models, a positive productivity shock in any country contributes to the decrease of prices all over the world and hence an increase in real wage. This triggers an increase in labor supply that amplifies the benefits of the shock in terms of output.[32] In addition, there is a second channel going through the change in the mass of active firms in every country. With the assumption that the mass of potential entrepreneurs is proportional to the labor size, an increase in labor supply results in a proportional increase in the mass of potential entrants. Whether the mass of actual producing firms goes up or down in any country k will also be determined by the changes in the thresholds φ_{ik} for all i which in turns crucially depends on the value of the Armington elasticity ρ. In the Cobb-Douglas case where the expenditure shares are fixed, a positive technological shock will result in a decrease of all entry thresholds in every market. Putting pieces together, a positive shock triggers at the same time more potential entrepreneurs and a decrease of the entry threshold in every market. As a result, the new structure of input-output linkages amplifies the benefits of the shock.

5 Calibration

The goal of this section is to quantitatively assess the model's ability to match the strong empirical relationship between trade proximity in intermediate input and GDP synchronization. The model is calibrated to 14 countries and a composite rest-of-the-world for the time period 1989 to 2008. In what follows, I explain in detail the calibration strategy while the simulation results are gathered in the next section.

For a calibration with N countries, there are $3\times N^2 + N + 6$ parameters to determine, on top of which one needs to set parameters relative to the technological shocks. For each country-pair (i, j), one needs values for the weights $\omega_i(j)$, the iceberg trade costs τ_{ij} and the fixed costs $f_{i,j}$, then for every country i one needs values for "value added" share in production $(\eta_k + \chi_k)$ and scaling

[32] This increase in labor supply is tempered by the wealth effect.

parameter ψ_i. The set of common parameters is given by $\chi_k/(/chi_k + \eta_k)$ the labor share in value added, ν for the (inverse) elasticity of labor supply, γ for the distribution of productivity draws, σ for the within country (micro) elasticity of substitution across varieties and ρ for the (macro) elasticity of substitution of country-specific bundles. Finally, we will also need to set the volatility, covariance and auto-correlation of the TFP shocks in all countries, as discussed in detail below.

My calibration is a mixture of estimations from micro data (taken from the literature as well as re-estimated) and a matching of macro moments. The goal is to match exactly the relative GDP across all country pairs, the volatility, persistence and level of GDP co-movement as well as the trade proximity in intermediate goods in order to give a reasonable account of the ability of the model to generate a strong link between bilateral trade and GDP synchronization despite the fact that typical trade flows between two given countries are very low compare to their GDPs.

From micro data

The discount factor β is 0.99. The (inverse) elasticity of labor supply ν is 2/3 leading to a Frisch elasticity of 1.5. The sunk entry cost $f_{E,k}$ in each country is set in order to get a ratio of total number of *potential* (not actual) firms divided by the population of 10%, in line with US estimates taking into account that not all potential entrepreneurs enter the economy in equilibrium. The variable (iceberg) trade costs are taken from the ESCAP World Bank: "International Trade Costs Database"[33]. This database features symmetric bilateral trade costs in its wider sense, including not only international transport costs and tariffs but also other trade cost components discussed in Anderson and van Wincoop (2004).

As in di Giovanni and Levchenko (2013), fixed access costs are computed from the "Doing Business Indicators".[34] In particular, I measure the relative entry fixed costs in domestic markets by using the information on the amount of time required to set up a business in the country relative to the US.[35] If according to the Doing Business Indicators database, in country i it takes 10 times longer to register a business than in the U.S., then $f_{i,i} = 10 \times f_{US,US}$. I normalize the lowest entry fixed cost so that no entry threshold lies below the lower bound o the productivity distribution, which is taken to be one in every country. To measure the fixed costs associated with entry in a foreign market, I use the Trading Across Borders module of the Doing Business Indicators. I choose

[33] See at http://artnet.unescap.org/

[34] The World Bank's Doing Business Initiative collected data on regulations regarding obtaining licenses, registering property, hiring workers, getting credit, and more. See http://francais.doingbusiness.org/data/exploretopics/trading-across-borders and http://francais.doingbusiness.org/data/exploretopics/starting-a-business

[35] As argued in di Giovanni and Levchenko (2013), using the time taken to open a business is a good indicator because it measures entry costs either in dollars or in units of per capita income, because in the model $f_{i,i}$ is a quantity of inputs rather than value.

the number of days it takes to import to a specific country, using the same normalization as for the domestic entry cost.[36]

In the benchmark simulations, I choose the macro (Armington) elasticity ρ to be equal to unity while the micro elasticity σ is equal to 5. There are many papers estimating those elasticities for intermediate or final goods. Saito (2004) provides estimations from 0.24 to 3.5 for the Armington elasticity[37] and Anderson and van Wincoop (2004) report available estimates for the micro elasticity in the range of 3 to 10. Following Bernard, Eaton, Jensen, and Kortum (2003), Ghironi and Melitz (2005) choose a micro elasticity of 3.8. Recently, papers such as Barrot and Sauvagnat (2015) or Boehm, Flaaen and Pandalai-Nayar (2015) argue that firms' ability to substitute between their suppliers can be very low. The choice of a value of $\sigma = 5$ leads to markups of 25%. The aggregate profit rate, however, is only of 17.4% since firms have to pay fixed cost in order to access any market. There is also a theoretical convenience to use $\rho = 1$, as it allows the model to take the same form as other network models such as Acemoglu (2012), Bigio and La'O (2015) and many others. Finally, the capital and labor shares in value added are fixed at 2/3 and 1/3 respectively and I set $\gamma = \sigma - 0.4$ as described in Fattal-Jaef and Lopez (2010).

Parameter	**Value**	**Counterpart**
β	0.99	Discount factor – Annual discount rate of 4%
ρ	1	Macro (Armington) Elasticity of substitution (from Literature)
σ	5	Micro Elasticity of substitution – 25% markup, average profit of 17.4%
ν	2/3	Labor Curvature – Frisch elasticity of 1.5
$f_{E,i}$	[1 - 10]	$M/L = 0.1$ – Mass of plants over working population
τ_{ij}	[1 - 3]	Iceberg trade cost – From ESCAP - World Bank
f_{ij}	[1 - 10]	Fixed trade cost – "Doing Business Indicators"
γ	4.6	Pareto shape – (Fattal-Jaef & Lopez (2014))
$\chi_k/(\chi_k + \eta_k)$	0.7	Labor share – 70% of value added.

Table 3: Parameters fixed using micro data

Matching of macro moments

For the remaining parameters, I use data on 14 countries from 1989 to 2008 and chose parameter values in order to match specific targets. More precisely, I jointly set the country size parameters

[36] This approach means that the fixed cost associated with trade from France to the US is the same as the one from Germany to the US. One must keep in mind, however, that the iceberg variable cost will differ.

[37] Feenstra et al (2014) studies the macro and micro elasticities for final goods and reports estimates between -0.29 and 4.08 for the Armington elasticity. They find that for half of goods the macro elasticity is significantly lower than the micro elasticity, even when they are estimated at the same level of disaggregation.

$(\psi_i)_{i=1,\ldots,N}$, the value added share $\chi_k + \eta_k$ as well as the spending weights $\omega_i(j)$ (the matrix W) in order to match all countries relative GDP and all relative trade flows in real terms. I normalize the real GDP of the composite rest-of-the-world to 100 and set all other real GDPs so that the ratio of their real GDP to the one of the rest-of-the-world in the simulated economy matches exactly its counterpart in the data for the time window 1989 to 2008. My targets are then N real GDP targets as well as N^2 directed trade flows (over GDP), to which one must add the constraint that spending shares $\omega_i(j)$ sum to one for each country, which leads to $(N^2 + 2N)$ equations for an equal number of parameters to match. Since complete financial autarky is inconsistent with the trade balances observed in the data, I calibrate the model to match steady-state trade imbalances, and then hold those nominal imbalances constant. Note that in order to be as close as possible to the OECD database used in the empirical analysis, I construct the quantity estimates by deflating the nominal spendings by the price index that do not take into account love for variety, as described in section 4.2.

Finally, I need to calibrate the persistence and the variance-covariance matrix for the country-level TFP shocks $(Z_i)_{i=1,\ldots,N}$. In order not to overestimate the impact of idiosyncratic shocks, I chose to set their volatility (the diagonal elements of the variance-covariance matrix) so that the model can replicate GDP volatility (de-trended using HP filtering) in every country. This allows me to generate fluctuations in the simulated economy that are similar to those observed in the data. Similarly, I set the off diagonal elements (the covariance terms) so that the average correlation of GDP in the model match the one observed in the data, which is 0.475 for the 1989-2008 time window. Recall that the goal of this exercise is not to explain the *level* of comovement across countries, but its *slope* when there is a change in trade. Hence, I set the *level* at the observed value and will vary parameters governing trade in order to evaluate the *slope*. Finally, I set a common value for auto-correlation of shocks so that the GDP series generated by the model is exactly 0.84 which is the value of GDP autocorrelation observed in the data.

6 Quantitative results

Trade Comovement Slope

The goal of this section is to assess the ability of the model to replicate the strong empirical relationship between trade proximity in intermediate inputs and GDP synchronization. The calibration procedure presented in the previous section yields values for all parameters so that the model economy matches the data for the period 1989 to 2008. With those values, I simulate a sequence of 5,000 shocks and record the correlation of HP-filtered GDP as well as the average index of trade proximity. Since my goal is to use within country-pair variations in order to perform a fixed-effect estimation of the effect of trade on GDP comovement, I then recalibrate the model with different targets for trade proximity across countries, decreasing and increasing the target by 10%. For each configuration, I feed the economy with the *exact same* sequence of 5,000 shocks and record the correlation of HP-filtered GDP as well as the average index of trade proximity. This gives rise to a panel dataset in which I have $14 \times 13/2 = 91$ observations for each of the 3 configurations, hence a total of 273 observations. I then perform fixed effect regressions on the simulated dataset and find that the model is able to explain more than 70% of the trade-comovement slope.

	dependent variable: corr(GDP_i^{HP},GDP_j^{HP})	
	Data	Model
log(Intermediate)	0.065***	0.047***

Decomposition - Role of the ingredients

In order to assess the role of each ingredient in the quantitative results, I then turn off one by one the key elements of the model. Results yield interesting insights. First, the sole addition of price distortions to an otherwise classic IRBC model with input-output linkages increases the trade comovement slope from 0.007 to 0.032. Finally, the amplification coming through the fluctuation in the mass of firms serving all markets increases the slope from 0.032 to 0.047, showing that adjustments along the extensive margin is a powerful way to generate quantitative results in line with the empirical link between trade in inputs and GDP comovement.

	Trade-Comovement Slope
I/O linkages + Markups + Extensive Margin	0.047***
I/O linkages + Markups	0.031***
I/O linkages	0.007***

Table 4: Decomposition of the result

Quantifying the Entry/Exit Margin

An important part of the quantitative results presented above come from the variation in the mass of firms serving every market. It is then necessary to understand if the entry/exit pattern predicted by the model is in line with what is observed in the data. Using French data from 1993 to 2008, I compute the number of products exported to many country.[38] After taking the logarithm to remove any level effect, I then apply the HP filter with smoothing parameter 6.25 to isolate the business cycle frequency fluctuations and compute the standard deviation across all years. Taking the average across all countries yields a value of 0.0086, meaning that on average the standard deviation of exported product represents 0.86 percent of the number of total number of product.

Computing the counterpart of this moment in the simulated dataset, I find a value of 0.0111 meaning that the model is roughly in line with the data on this respect, although it is slightly over-predicting the variance of the entry-exit pattern on foreign markets. Computing now the volatility of the number firms serving the domestic market (and not only export markets), using the universe of all French firms with at least one employee, the associated standard deviation is equal to 0.087, ten times larger than the value when considering only export markets. In the model, however, the value is 0.0114, meaning that the model *under*-predicts the entry/exit pattern in the domestic market.

Impulse Response functions

In order to give a better sense of the mechanics behind the model, I consider a simplified version with two countries (Home and Foreign) that are symmetric in the steady state. Keeping the value of all technological parameter as described above[39], I generate impulse response functions of Home GDP after a technological shock in Foreign. In order to have a sense of the trade comovement *slope*, I consider two calibrations of the W matrix: one that induces a low level of trade and the other with a high level of trade. By comparing the GDP responses in those two cases, one can understand the effect of increasing trade on GDP synchronization. Figure 1 presents the result of this exercise for three versions of the model. In the benchmark case with no markups (perfect competition within each variety) and no extensive margin (no fixed cost to enter any market and a fixed mass of firms), the GDP hardly moves. When introducing monopolistic pricing for all varieties, increasing trade between the two countries leads to a significant increase in the Home GDP reaction after a foreign techonlogical shock. Finally, letting the mass of firms and entry decisions be as described in the quantitative models further amplify the trade comovement slope, with an increase in trade inducing a very high increase in GDP reaction.

[38]Due to data availability, destination countries considered are Australia, Austria, Canada, Denmark, Germany, Ireland, Italy, Mexico, The Netherlands, Spain, United Kingdom and United States

[39]Except for the W matrix which is now symmetric and 2x2.

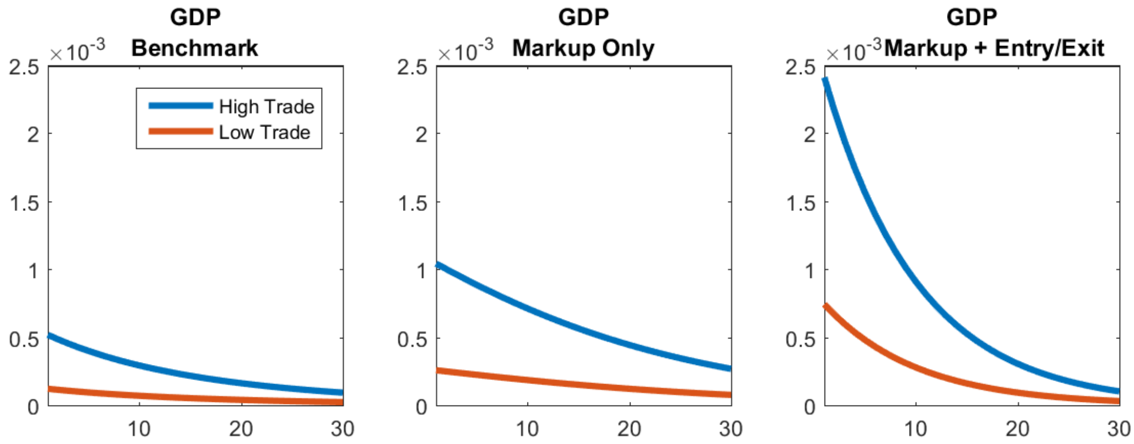

Figure 1: IRF of domestic GDP after a foreign shock

Before describing the role of each of those ingredients in the context of a simplified model in section 3, I further decompose the GDP reactions described above by performing a "growth accounting" exercise in which I decompose GDP fluctuations into labor and capital movements as well as the Solow residual that is usually referred to as the aggregate TFP.[40] In the benchmark case with no markups and no extensive margin, one can see that GDP fluctuation is due almost only to fluctuations in factor supply with TFP playing a insignificant role. This result is consistent with Kehoe and Ruhl (2008) or Cravino and Burstein (2015) which argue that foreign technological shocks have no effect on domestic productivity up to a first order approximation.

Interestingly, this result does not hold anymore when markups are introduced and measured TFP is affected by a foreign shock. As described more precisely in section 3, the reason stems from fact that in the presence of markups, the change in import due to the positive technological shock in the foreign country is smaller than the increase in final good production. As noted in Hall (1988) or Basu and Fernald (2002), when firms are price setters, the opportunity cost of using inputs is lower than their marginal revenue product. Note also that the TFP change induces a larger reaction of domestic factors (labor and capital) which increases the GDP reaction after the foreign shock.

Finally, introducing fluctuations in the mass of firms serving all countries increases further the TFP reaction. This effect is due to the love for variety encompassed in the Dixit-Stiglitz aggregation of inputs. With love for variety, one can think of the mass of firms as being an input for production since an economy with a higher number of firms has the ability to produce more final output with the same amount of inputs. As suggested by the decomposition in table 4, the most important part of this mechanism is not due to the fixed cost associated to the access of any market but rather to

[40] Consistently with the theory, I used $\eta_k/(\eta_k + \chi_k)$ for the labor share and $\chi_k/(\eta_k + \chi_k)$ for the capital share to compute the solow residual

the fluctuation in the mass of potential entrants, that is assumed to be proportional to the labor force. Indeed, any fluctuations along the labor supply margin is associated with a change in the mass of potential entrants. With love for varieties, the production technology frontier is affected by such a change in the number of producer, so that the final output reacts more than imported inputs. Moreover, since the Solow residual is computed using only Labor and Capital as domestic inputs and not controlling for the change in the mass of domestic firms, this increase in the production technology frontier is reflected in the TFP.

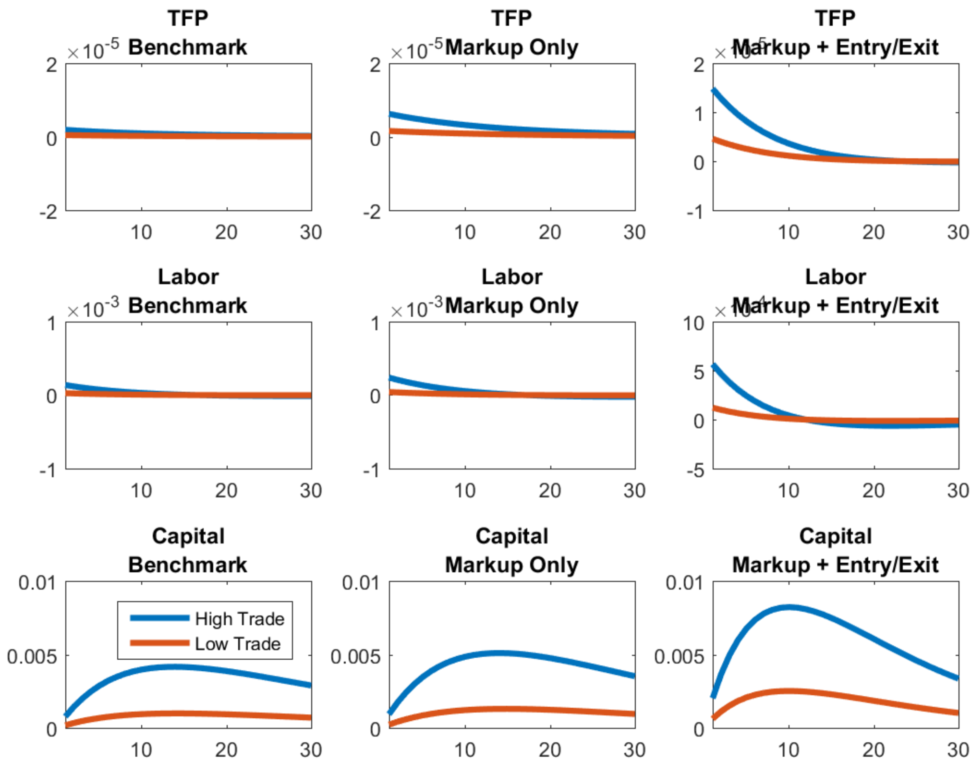

Figure 2: Growth Accounting Decomposition

7 Further Empirical Evidence

7.1 The Role of Extensive Margin of Trade

Following Hummels & Klenow (2005) as well as Feenstra & Markusen (1994), I construct the Extensive and Intensive margins of trade between countries j and m using the Rest-of-the-World as a reference country k. The extensive margin (EM) is defined as a weighted count of varieties exported from j to m relative to those exported from k to m. If all categories are of equal importance and the reference country k exports all categories to m, then the extensive margin is simply the fraction of categories in which j exports to m. More generally, categories are weighted by their importance in k's exports to m. The corresponding intensive margin (IM) is defined as the ratio of nominal shipments from j to m and from k to m in a common set of goods. With this construction, the product of both margins of trade between j and m is equal to the ratio of total trade flows between j and m to total trade flows from the reference country k to m, which is usually denoted as OT. Formally, the margins are defined as:

$$\text{Extensive Margin} \quad EM_{jm} = \frac{\sum\limits_{i \in I_{jm}} p_{kmi} q_{kmi}}{\sum\limits_{i \in I} p_{kmi} q_{kmi}}$$

$$\text{Intensive Margin} \quad IM_{jm} = \frac{\sum\limits_{i \in I_{jm}} p_{jmi} q_{jmi}}{\sum\limits_{i \in I_{jm}} p_{kmi} q_{kmi}}$$

$$\text{Trade Ratio} \quad OT_{jm} = \frac{X_{j \to m}}{X_{k \to m}} = EM_{jm} \times IM_{jm}$$

Where I_{jm} is the set of observable categories in which j has a positive shipment to m, I is the set of all categories exported by the reference country which is supposed to be the universe of all categories and $X_{j \to m}$ is total trade flows from country j to country m. Since those measures are not symmetric within every country-pair, I define for a given country pair (i, j) as the sum of the margins from i to j and from j to i, which are then averaged over the time window.

Constructing four 10-years time window ranging from 1969Q1 to 2008Q4, I estimate the following equation

$$\text{corr}(Y_{it}^{HP}, Y_{jt}^{HP}) = \alpha + \beta_{EM} \log(\text{EM}_{ijt}) + \beta_{IM} \log(\text{IM}_{ijt}) + controls + \epsilon_{ijt} \tag{23}$$

Results are gathered in 5 and show that the extensive margin of trade is an important determinant of GDP comovement. This result is particularly striking given that most of the variation in trade is explained by variations along the intensive margin. Indeed, performing a Shapley value decomposition of OT on the intensive and extensive margins, one finds that only one fourth of the total variance in OT is explained by the variation of the extensive margin. Put simply: even though EM does not vary too much (compare to IM), its variations are strongly correlated with the variations of GDP comovement.[41]

	dependent variable: corr(GDP_i^{HP},GDP_j^{HP})		
	(1)	(2)	(3)
log(EM)	0.249***	0.246***	0.104
	(8.91)	(6.27)	(1.91)
log(IM)	0.0111	0.120	0.023
	(1.08)	(0.45)	(1.08)
Country-Pair FE	no	yes	yes
Time FE	no	no	yes
N	760	760	760

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 5: Strong Influence of the Extensive Margin of trade

7.2 Terms of Trade and GDP: the role of Markups

Using data from 22 countries from 1971 to 2010,[42] I assess the role of markups in generating a link between terms of trade and GDP fluctuations.

I test the following hypothesis: countries where markups are high experience a larger decrease in GDP when experiencing an increase in their terms-of-trade. In order to test this hypothesis, I compute the correlation of filtered GDP with the terms of trade and regress this correlation on markups estimates. Results show that markups have a significant impact on GDP-Terms of Trade correlation, with higher markups associated with lower correlation between GDP and the terms of trade.

Data on real GDP and terms of trade at the annual frequency are both taken from the OECD database and filtered according to two different procedure. I first apply the Hodrick and Prescott filter with a smoothing parameter of 6.25 which captures the business cycle frequencies. I also apply the Baxter and King band pass filter and keep fluctuations between 8 and 25 years in order to capture medium-term business cycles (Comin and Gertler (2006)). Using the detrended series, I compute the correlation between filtered GDP and filtered terms-of-trade for two 20-years time windows from 1971 to 2010, hence creating a panel dataset where each country appears two times.

[41] Those results are in line with the similar analysis in Liao and Santacreu (2015).

[42] The list of countries is: Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Iceland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Portugal, Spain, Sweden, the United-Kingdom and the United-States

I use Price Cost Margin (PCM) as an estimate of markups within each industry. Introduced by Collins and Preston (1969) and widely used in the literature, PCM is the difference between revenue and variable cost, i.e. the sum of labor and material expenditures, over revenue:

$$PCM = \frac{\text{Sales} - \text{Labor expenditure} - \text{Material expenditure}}{\text{Sales}} \tag{24}$$

Data at the industry level come from the OECD STAN database, an unbalanced panel covering 107 sectors for 34 countries between 1970 and 2010. Due to missing data for many countries in the earliest years, I restrict the analysis for 22 countries.[43] I compute PCM for each industry-country-year and then construct an average of PCM within each country-year by taking the sales-weighted average of PCM over each industry. Finally, the average PCM for a given time window is simply the mean of country-year PCM over all time periods. Results are presented in table 6.

	dependent variable: corr($GDP_i^{filtered}$,$ToT_i^{filtered}$)			
	HP-filter	BK-filter	HP-filter	BK-filter
Average PCM	-1.507***	-2.049***	-2.650***	-3.705***
	(-2.70)	(-3.11)	(-2.87)	(-4.10)
Country FE	no	no	yes	yes
Time FE	no	no	yes	yes
N	43			

Note: The dependent variable is the correlation of filtered GDP with ToT. t stat. in parentheses, *** means $p < 0.01$

Table 6: Markups and GDP-ToT correlation

The first two columns of table 6 show the results of pooled cross-section analysis where I do not use the panel dimension of the dataset. In the last two columns, I perform fixed effect regression and add time dummies to control for time specific factors that might affect the correlation of GDP and terms-of-trade. In each of those cases, regressions are performed using the two filtering methods and are found to be statistically significant, implying that countries with higher markups also experience a larger decrease in their GDP when the relative price of their import rises.

[43]For Germany, data are available only from 1991 onward (after the reunification), which is why the total number of observation in the regressions is 43.

7.3 Trade and TFP comovement

The model predicts that in the presence of markups and extensive margin adjustment, a country's TFP is impacted by foreign shocks even when technology is fixed. As a result, trade proximity across countries should be positively related to TFP correlation. I test this prediction using 18 OECD countries. Computing the correlation of all pairwise filtered TFP wihtin four 10-years time window ranging from 1969Q1 to 2008Q4, I estimate the following equations:

$$
\begin{aligned}
(1) \qquad \text{corr}(TFP_{it}^{filtered}, TFP_{jt}^{filtered}) &= \alpha_1 + \beta_T \log(\text{Total}_{ijt}) + controls + \epsilon_{1,ijt} \\
(2) \qquad \text{corr}(TFP_{it}^{filtered}, TFP_{jt}^{filtered}) &= \alpha_2 + \beta_I \log(\text{Intermediate}_{ijt}) + \beta_F \log(\text{Final}_{ijt}) + controls + \epsilon_{2,ijt}
\end{aligned}
$$

Results are presented in table 7 for the HP-filtered TFP, capturing the business cycle fluctuations and in table 8 for the BK-filtered TFP capturing medium run cycles. When using HP filter, total trade is positively associated with TFP correlation, with trade in intermediate input capturing all the statistical significance in columns (2) and (4) while neither trade in intermediate nor final good is found significant in column (6). The picture is clearer when studying the medium term fluctuation, as can be seen in table 8: trade in intermediate input captures all the statistical significance in columns (2), (4) and (6), leaving final good trade with no explanatory power. Overall, this analysis is more nuanced that when studying the relationship between trade and GDP comovement. Nevertheless, it suggests that international trade is linked to TFP synchronization across countries as predicted by the theory.

	dependent variable: corr(TFP_i^{HP},TFP_j^{HP})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.092***		0.272***		0.099**	
	(9.12)		(11.05)		(2.78)	
log(Intermediate)		0.99***		0.205***		0.049
		(4.47)		(7.53)		(1.45)
log(Final)		-0.14		0.018		0.044
		(-0.56)		(0.44)		(1.11)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
R-squared (within)			0.185	0.194	0.245	0.244
R-squared (overall)	0.118	0.128	0.120	0.130	0.213	0.217
N	612					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 7: Relationship between Trade and HP filtered TFP correlation

	dependent variable: corr(TFP_i^{BK},TFP_j^{BK})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.091***		0.296***		0.079	
	(6.97)		(9.58)		(1.63)	
log(Intermediate)		0.133***		0.290***		0.126**
		(4.68)		(8.55)		(2.56)
log(Final)		-0.53*		-0.081		-0.054
		(-1.66)		(-1.48)		(-1.00)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
R-squared (within)			0.140	0.172	0.201	0.207
R-squared (overall)	0.072	0.089	0.074	0.091	0.161	0.155
N	612					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 8: Relationship between Trade and BK filtered TFP correlation

8 Conclusion

This paper analyzes the relationship between international trade and business cycle synchronization across countries. I start by refining previous empirical studies and show that higher trade in intermediate input is associated with an increase in GDP comovement, while trade in final good is found insignificant.

Motivated by this new fact, I propose a model of trade in intermediates with two key ingredients: (1) monopolistic pricing and (2) firm entry/exit. Both elements are necessary in order for foreign shocks to have a first order impact on domestic productivity through trade linkages. The propagation of technological shocks across countries depends on the worldwide network of input-output linkages, which emphasize the importance of going beyond two-country models to understand international GDP comovement.

I calibrate this model to 14 OECD countries and assess its ability to replicate the empirical findings. Overall, the quantitative exercise suggests that the model is able to replicate more than 70% of the trade comovement slope, making an important step toward solving the "Trade Comovement Puzzle". Decomposing the role of each ingredient, I show that trade in intermediates alone is not sufficient to replicate the trade-comovement relationship. The addition of monopolistic pricing and extensive margin adjustments increase the simulated trade-comovement slope by a factor seven.

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A Empirical Appendix

A.1 Data description

I focus the empirical analysis on a subset of all OECD countries. For the evolution of GDP correlation, I use 24 countries for which I could gather quarterly data on real GDP, which gives me $N(N-1)/2 = 276$ country pairs. Those are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New-Zealand, Norway, Portugal, South-Africa, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. For the study of the trade-comovement, I took out four countries from the sample. I get rid of Belgium and Luxembourg because they were pooled together in the trade data until the year 2000, preventing me from using 4 time windows and perform the fixed effect regression properly. I also took out New Zealand and South Africa because their trade data contained many zeros for some time periods,[44] resulting in some country-pairs being presents only for some time windows and hence reducing the effectiveness of the fixed effect regression. This leaves me in the end with 20 countries, so 190 country pairs for each of the four time window.

I use data from the OECD database "VPVOBARSA" which features quarterly GDP. In this database, GDP is constructed with volume estimates and with constant 2005 prices. As for the trade flows, I use two datasets. From 1968 to 1999, I use the NBER-UN world trade data updated on the 30th of January, 2009.[45] From 2000 onward, I use the revision of those data. In both datasets, trade flows are categorized using SITC4, which represents the first 4 digits of the SITC Rev 2 categorization. I follow Feenstra and Jensen (2012) to separate final from intermediate goods. First, I translate the SITC4 codes into END USE codes using the concordance table available on the CID website.[46] The end-use codes are used by the Bureau of Economic Analysis to allocate goods to their final use, within the National Income and Product Accounts. I then label as "intermediate goods" the products which end-use codes correspond to the list put together by Feenstra and Jensen (2012).

[44] To fix ideas, in 1969, while Spain was importing from 134 countries and exporting to 140 countries, South Africa was importing from only 65 and exporting to 77 countries. As for New Zealand, the numbers were 105 (imports) and 127 (exports).

[45] This data is constructed from United Nations trade data by Robert Feenstra and Robert Lipsey. It can be downloaded, as well as the associated documentation, from the Center for International Data (CID)'s website at http://cid.econ.ucdavis.edu/nberus.html

[46] See at http://cid.econ.ucdavis.edu/usix.html, under the directory "1972-2006 U.S. import data - SAS and STATA".

A.2 Robustness Checks and other results

A.2.1 Changing the Dataset

As a robustness check, I also use the STAN Bilateral Trade Database by Industry and End-Use data (BTDIxE).[47] BTDIxE consists of values of imports and exports of goods, broken down by end-use categories. Estimates are expressed in nominal terms, in current US dollars for all OECD member countries. The trade flows are divided into capital goods, intermediate inputs and consumption. For the sake of comparison with the results in the main text, I first group the capital and intermediate goods together and create the index of trade proximity as explained in the main text. Due to data availability, I use the data from 1995 to 2014 which allows me to create four time windows of 5 years each (tables 9 and 10). With 20 countries, the dataset contains 190 pairs, for a total of 760 observations with four time windows. The tables below present the robustness results using both the HP filter (for business cycle frequencies) and then the Baxter and King filter (for medium term frequencies).

	dependent variable: corr(GDP_i^{HP},GDP_j^{HP})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.064***		-0.009		0.103	
	(5.94)		(-0.14)		(1.53)	
log(Intermediate)		0.044*		0.146*		0.209***
		(1.88)		(1.77)		(2.59)
log(Final)		0.021		-0.152*		-0.107
		(1.06)		(-2.04)		(-1.39)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
N	760					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 9: Trade and HP-Filtered GDP - STAN database (1995 to 2014)

[47] See at http://www.oecd.org/trade/bilateraltradeingoodsbyindustryandend-usecategory.htm.

	dependent variable: corr(GDP_i^{BK},GDP_j^{BK})					
	(1)	(2)	(3)	(4)	(5)	(6)
log(Total)	0.075***		0.433***		0.397***	
	(5.23)		(3.86)		(3.16)	
log(Intermediate)		0.115***		0.562***		0.538***
		(3.71)		(3.71)		(3.60)
log(Final)		-0.036		-0.106		-0.122
		(-1.32)		(-0.76)		(-0.83)
Country-Pair FE	no	no	yes	yes	yes	yes
Time Trend	no	no	no	no	yes	yes
N	760					

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 10: Trade and BK-Filtered GDP - STAN database (1995 to 2014)

A.2.2 Separating Intermediate goods from Capital goods

In the OECD STAN database, one can separate intermediate goods from capital goods. I use this categorization and perform the same empirical exercise as above.

	dependent variable: corr(GDP_i^{HP},GDP_j^{HP})		
	(1)	(2)	(3)
log(Intermediate)	0.044	0.073	0.143*
	(1.47)	(0.89)	(1.74)
log(Capital)	0.004	0.114*	0.094
	(0.15)	(1.70)	(1.47)
log(Final)	0.018	-0.18**	-0.129
	(0.84)	(-2.36)	(-1.62)
Country-Pair FE	no	yes	yes
Time Trend	no	no	yes
R-squared (within)		0.011	0.304
R-squared (overall)	0.044	0.000	0.391
N	———————— 760 ———————-		

t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 11: Trade and HP-Filtered GDP - STAN database (1995 to 2014)

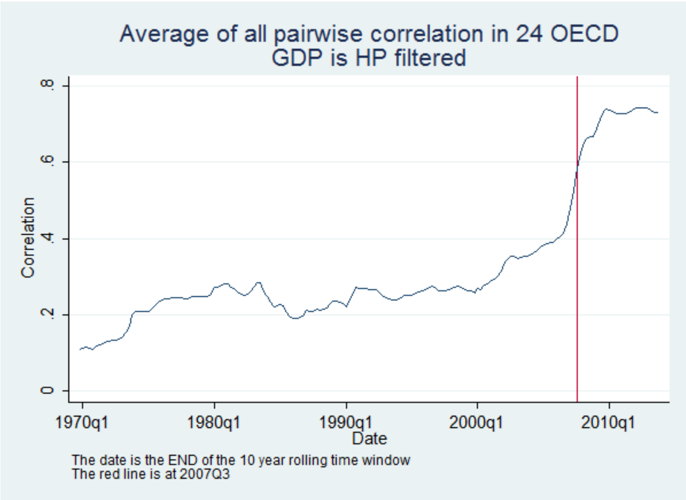
	dependent variable: corr(GDP_i^{BK},GDP_j^{BK})		
	(1)	(2)	(3)
log(Intermediate)	0.024	0.449***	0.420***
	(0.62)	(3.05)	(2.95)
log(Capital)	0.112***	0.150	0.158
	(2.95)	(1.37)	(1.42)
log(Final)	-0.053*	-0.132	-0.153
	(-1.88)	(-0.96)	(-1.04)
Country-Pair FE	no	yes	yes
Time Trend	no	no	yes
R-squared (within)		0.057	0.059
R-squared (overall)	0.045	0.042	0.044
N	————— 760 —————-		

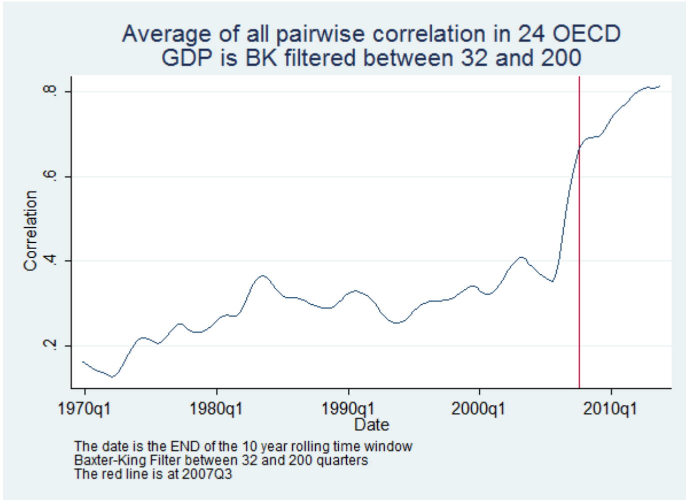
t stat. in parentheses, *** means $p < 0.01$, ** means $p < 0.05$ and * means $p < 0.10$

Table 12: Trade and BK-Filtered GDP - STAN database (1995 to 2014)

A.3 Evolution of GDP correlation

In the graph below, I use a sample of 24 OECD countries from 1960 to 2012 and compute the GDP correlation for all pair of countries using a 10 years rolling window. Each point of this graph represents the average correlation of GDP across all country-pair in the 10 years *preceding* the point. The vertical red line is set at 2007Q3 and is a rough materialization of the last financial crisis. The point which is exactly at the red line is then the average GDP correlation from 1997Q3 to 2007Q3 and hence is not affected by the collapse of subprime markets and the events that followed. The graph on the left is the correlation HP filtered in order to keep the business cycle frequency, while on the right I used the Baxter and King filter to extract fluctuations from 32 to 200 quarters as suggested by Comin and Gertler (2006).





B Theoretical Appendix

B.1 Equilibrium Conditions in the general CES case

Price Indexes and Pricing System

$$\mathcal{P}_{k,k'} = \left(\int_{\Omega_{k,k'}} p_{k,k'}(\varphi)^{1-\sigma} g(\varphi) d\varphi \right)^{\frac{1}{1-\sigma}} \quad \text{and} \quad IP_k = \left(\sum_{k'=1,\dots,N} \omega_k(k') \mathcal{P}_{k',k}^{1-\rho} \right)^{\frac{1}{1-\rho}}$$

$$PB_k = \chi_k^{-\chi_k} \times \eta_k^{-\eta_k} \times (1-\eta_k-\chi_k)^{(\eta_k+\chi_k-1)} \times IP_k^{1-\eta_k-\chi_k} \times w_k^{\chi_k} \times r_k^{\eta_k}$$

Using the optimal pricing strategy $p_{k,k'} = \tau_{k,k'} \frac{\sigma}{\sigma-1} \frac{PB_k}{Z_k \varphi}$ with the definition of the price index relative to each country specific bundle, we have the pricing system:

$$\mathcal{P}_k^{1-\rho} = \mu_k \left(\sum_{k'} \omega_k(k') \left(\tau_{k'k} \left(\frac{\varphi_{k',k}}{\varphi_{k',k'}} \right)^{\frac{\sigma-\gamma-1}{1-\sigma}} \mathcal{P}_{k'} \right)^{1-\rho} \right)^{1-\eta_k-\chi_k} \quad , \; k = 1, \dots, N$$

with $\mu_k^{\frac{1-\sigma}{1-\rho}} = \frac{\gamma \varphi_{k,k}^{\sigma-\gamma-1}}{\gamma-(\sigma-1)} M_k \left(\frac{\sigma}{\sigma-1} \frac{w_k^{\chi_k} \times r_k^{\eta_k}}{\chi_k^{\chi_k} \times \eta_k^{\eta_k} \times (1-\eta_k-\chi_k)^{1-\eta_k-\chi_k}} \frac{1}{Z_k} \right)^{1-\sigma}$.

Entry Thresholds

In very market, entry occurs until the profit of the least productive firms is equal to the fixed cost of accessing the market. Denoting by X_k total final good spending by consumers ($X_k = P_k(C_k + I_k) = w_k L_k + r_k K_k + \Pi_k$), we get

- At Home

$$\pi_{k,k}(\varphi_{k,k}) = f_{k,k}\frac{PB_k}{Z_k}$$

$$\Leftrightarrow \quad \varphi_{k,k} = \left(\frac{\sigma}{\sigma-1}\frac{PB_k}{Z_k}\frac{1}{\mathcal{P}_k}\right) \times \left(\frac{\sigma f_{k,k}\frac{PB_k}{Z_k}}{X_k + \left(\frac{\mathcal{P}_k}{IP_k}\right)^{1-\rho}\omega_k(k)(1-\eta_k-\chi_k)S_k}\right)^{\frac{1}{\sigma-1}}$$

- Abroad

$$\pi_{k,k'}(\varphi_{k,k'}) = f_{k,k'}\frac{PB_k}{Z_k}$$

$$\Leftrightarrow \quad \varphi_{k,k'} = \left(\tau_{kk'}\frac{\sigma}{\sigma-1}\frac{PB_k}{Z_k}\frac{1}{\mathcal{P}_{k,k'}}\right) \times \left(\frac{\sigma f_{k,k}\frac{PB_k}{Z_k}}{\left(\frac{\mathcal{P}_{k,k'}}{IP_{k'}}\right)^{1-\rho}\omega_{k'}(k)(1-\eta_k-\chi_k)S_{k'}}\right)^{\frac{1}{\sigma-1}}$$

Replacing $\mathcal{P}_{k,k'}$ by its expression using $\mathcal{P}_k$, we also get

$$\varphi_{k,k'}^{1+\frac{(\gamma-(\sigma-1)).(\sigma-\rho)}{(\sigma-1)^2}} = \left(\tau_{kk'}^{\frac{\rho-1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{PB_k}{Z_k}IP_{k'}^{\frac{1-\rho}{\sigma-1}}\left(\varphi_{k,k}^{\frac{\sigma-\gamma-1}{\sigma-1}}.\mathcal{P}_k\right)^{\frac{\rho-\sigma}{\sigma-1}}\right) \times \left(\frac{\sigma f_{k,k'}\frac{PB_k}{Z_k}}{\omega_{k'}(k)(1-\eta_k-\chi_k)S_{k'}}\right)^{\frac{1}{\sigma-1}}$$

Spending System

Total revenue of all firms from country k can be written as

$$R_k = X_k + \left[\sum_{k'}\left(\frac{\mathcal{P}_{k,k'}}{IP_{k'}}\right)^{1-\rho}\omega_{k'}(k)(1-\eta_k-\chi_k)S_{k'}\right]$$

Free entry insures that variable profits are exactly equal, on aggregate, to fixed costs and entry costs payment, implying that $R_k = S_k$. Capital and labor demand impose $r_kK_k+w_kL_k = (\eta_k+\chi_k)S_k+\Pi_k$. Finally, the spending system can be simply written as

$$\left\{ \underbrace{\left(\mathcal{I}_N - \left(W^T \circ P\right)\right)}_{=M}\begin{pmatrix} S_1 \\ \vdots \\ S_N \end{pmatrix} = 0_{\mathbb{R}^N} \right.$$

where W the weighting matrix defined as $W_{ij} = \omega_i(j)$, P a matrix defined by $P_{ij} = \left(\frac{\mathcal{P}_{i,j}}{IP_i}\right)^{1-\rho}$ and $\circ$ is the element-wise (Hadamard) product. One can easily show that the matrix M is non invertible[48] and is of rank exactly $N-1$, meaning that the solutions of the system is a one dimensional space.

[48]One can easily see that summing all rows results in a column of zero.

This is reassuring because it means we can normalize one price to one. I then normalize $w_1 = 1$ and with the labor demand equation this results is

$$S_1 = \frac{L_1}{\chi_1}$$

Labor and Capital Market Equilibrium

Using the labor supply equation, L_k is simply

$$L_k^{\nu} = \frac{1}{\psi_k} \frac{w_k}{\mathcal{P}_k}$$

Equipped with S_k the total spending of all firms in k, wages w_k and rental rate r_k are defined simply by

$$w_k = \chi_k \frac{S_k}{L_k} \qquad \text{and} \qquad r_k = \eta_k \frac{S_k}{K_k}$$

Free Entry

At each date, firms enter the model until total profits are equal to total sunk cost payment:

$$\Pi_k = M_k \frac{PB_k}{Z_k}.f_{E,k} \qquad \text{for all } k$$

B.2 Proof of Lemma 1

Reminder of Lemma 1 : Total profit in country k are proportional to total revenues:

$$\Pi_k = \frac{\sigma - 1}{\gamma \sigma} R_k$$

Proof

First, since firms charge a constant markup $\sigma/(\sigma - 1)$ over marginal cost, we know that variable profits are a fraction $1/\sigma$ of total revenues. Hence, total profits net of fixed costs for all firms in k are simply

$$\Pi_k = \frac{R_k}{\sigma} - \sum_{k'} FC_{k \to k'}$$

where $FC_{k\to k'}$ is the sum of fixed cost payment from all firms from country k serving market k'. Then, note that total fixed cost payment for all firms in country k is

$$FC_{k\to k'} = M_k \int_{\varphi_{k,k'}}^{+\infty} f_{kk'} \times \frac{PB_k}{Z_k} \times \gamma\varphi^{-\gamma-1} \times d\varphi$$
$$= M_k f_{kk'} \frac{PB_k}{Z_k} \times \varphi_{k,k'}^{-\gamma}$$

- If $k \neq k'$, we can also express total revenues (sales) from k to k' as

$$R_{k,k'} = M_k \int_{\varphi_{k,k'}}^{+\infty} \left(\tau_{kk'} \frac{\sigma}{\sigma-1} \frac{PB_k}{Z_k} \frac{1}{\mathcal{P}_{k,k'}}\right)^{1-\sigma} \times \omega_{k'}(k) S_{k'} \varphi^{\sigma-1} g(\varphi) d\varphi$$
$$= \frac{\gamma M_k}{\gamma-(\sigma-1)} \times \left(\tau_{kk'} \frac{\sigma}{\sigma-1} \frac{PB_k}{Z_k} \frac{1}{\mathcal{P}_{k,k'}}\right)^{1-\sigma} \times \omega_{k'}(k) S_{k'} \varphi_{k,k'}^{\sigma-\gamma-1}$$

  Next, using the expression for the threshold $\varphi_{k,k'}^{\sigma-1}$ derived above (as a function of $\mathcal{P}_{k,k'}$), we get

$$R_{k,k'} = \frac{\gamma M_k}{\gamma-(\sigma-1)} \times \sigma f_{k,k'} \frac{PB_k}{Z_k} \varphi_{k,k'}^{-\gamma}$$

  And we recognize finally that

$$R_{k,k'} = \frac{\gamma}{\gamma-(\sigma-1)} \times \sigma FC_{k\to k'}$$

- For domestic revenues, we can show using the same steps that

$$X_k + R_{k,k} = \frac{\gamma}{\gamma-(\sigma-1)} \times \sigma FC_{k\to k}$$

Combining those expressions, we get

$$\sum_{k'} FC_{k\to k'} = \frac{\gamma-(\sigma-1)}{\gamma\sigma} \times \left(X_k + \sum_{k'} R_{k,k'}\right)$$
$$= \frac{\gamma-(\sigma-1)}{\gamma\sigma} \times R_k$$

Using this expression of $\sum_{k'} FC_{k\to k'}$ in the definition of profits completes the proof.

B.3 Proof of Lemma 2

Reminder of Lemma 2 : In the Cobb-Douglas ($\rho = 1$) and fixed labor supply case, the elasticity of every GNI with respect to a technology shock in country 1 is given by:

$$\begin{pmatrix} \eta_{GNI_1,Z_1} \\ \vdots \\ \eta_{GNI_N,Z_1} \end{pmatrix} = (\mathcal{I}_N - (1 - \eta_k - \chi_k)W - T)^{-1} \begin{pmatrix} 1 \\ 0 \\ \vdots \end{pmatrix}$$

with W the weighting matrix defined above and T a "Transmission" matrix function of γ and σ.

Proof:

In this simplified case ($\rho = 1$ and fixed labor and capital supply), the labor and capital demand schedules $w_k L_k = \chi_k S_k$ and $r_k K_k = \eta_k S_k$ provide a one to one mapping between total spendings S_k and the wages w_k and the interest rate r_k. Moreover, inspecting the spending system (18) when $\rho = 1$ reveals that once a choice of numeraire is done (that is, taking $w_1 = 1$ and hence fixing $S_1 = L_1/\chi_1$), the vector of spendings $(S_i)_{i=1,\dots,N}$ is independent of the technology level. Using lemma 1 and the fact that labor and capital supply are fixed, we can then show that total consumers' spending X_i also independent of technology level. Thus, since $GNI_k = X_k/\mathcal{P}_k$ the GNI elasticity is simply the opposite of the elasticity of the country's consumers price index. Moreover, with fixed labor supply and the assumption that the mass of potential entrepreneurs is proportional to labor size, the mass of firms M_i is fixed for every country i. In the next sections, I compute elasticities of all endogenous variables step by step until I can solve for the price index elasticities.

B.3.1 Model-based Price Indexes

Home Price Index at home $\mathcal{P}_k$

Using the definitions of price indexes, we can easily show that

$$\frac{\partial \log(\mathcal{P}_k)}{\partial \log(Z_k)} = -1 + \frac{\partial \log(PB_k)}{\partial \log(Z_k)} + \left(\frac{\gamma - (\sigma - 1)}{\sigma - 1}\right) \frac{\partial \log(\varphi_{k,k})}{\partial \log(Z_k)}$$

We can see in this formula the direct effect of lowering all prices in country k plus two other indirect effects : the propagation going through the input-output linkages in the PB_k term as well as the extensive margin of entry of new firms through the $\varphi_{k,k}$ term.

Foreign Price Index "at their home" $\mathcal{P}_{k'}$

$$\frac{\partial \log(\mathcal{P}_{k'})}{\partial \log(Z_k)} = \frac{\partial \log(PB_{k'})}{\partial \log(Z_k)} + \left(\frac{\gamma - (\sigma-1)}{\sigma - 1}\right)\frac{\partial \log(\varphi_{k',k'})}{\partial \log(Z_k)}$$

The foreign price index "at their home" is not affected directly but only through the effects going through the input output linkages as well as the entry of new firms.

Export Price indexes $\mathcal{P}_{i,j}$

The price index relative to varieties from i sold on j's market is affected by the shock according to:

$$\frac{\partial \log(\mathcal{P}_{i,j})}{\partial \log(Z_k)} = \frac{\partial \log(\mathcal{P}_{i})}{\partial \log(Z_k)} + \left(\frac{\gamma - (\sigma-1)}{\sigma - 1}\right)\left(\frac{\partial \log(\varphi_{i,j})}{\partial \log(Z_k)} - \frac{\partial \log(\varphi_{i,i})}{\partial \log(Z_k)}\right)$$

We can see that the effect of a technology shock on exporting price indexes depends on the widening in the range of exported goods, as measured by the second term, in the brackets.

Input Bundle Price $PB_{k'}$ Abroad

Using the fact that wages are not affected by technology shocks, I can compute the elasticity of the input bundle price with respect to a technology shock at home as follow:

$$\frac{\partial \log(PB_{k'})}{\partial \log(Z_k)} = (1 - \eta_k - \chi_k)\sum_j \omega_{k'}(j)\left[\frac{\partial \log(\mathcal{P}_j)}{\partial \log(Z_k)} + \left(\frac{\gamma - (\sigma-1)}{\sigma - 1}\right)\left(\frac{\partial \log(\varphi_{j,k'})}{\partial \log(Z_k)} - \frac{\partial \log(\varphi_{j,j})}{\partial \log(Z_k)}\right)\right]$$

B.3.2 Thresholds

Home Entry Threshold $\varphi_{k,k}$ at Home

Using the definition of the thresholds from above and replacing $\frac{\partial \log(PB_k)}{\partial \log(Z_k)} - 1$ by its expression in the expression of the elasticity of the Home price index at home, we get

$$\frac{\partial \log(\varphi_{k,k})}{\partial \log(Z_k)} = \frac{1}{\sigma - 1 + \kappa\sigma} \times \frac{\partial \log(\mathcal{P}_k)}{\partial \log(Z_k)}$$

The scaling factor $(\frac{1}{\sigma-1+\kappa\sigma})$ is positive while the second term is negative, meaning that a positive technology shock trigers the entry of more firms in the country, which amplifies the effect of the shock.

Export Entry Threshold $\varphi_{k,k'}$ for Home firms exporting to k'

Using the second definition of the export thresholds from above, we get

$$(\frac{\gamma}{\sigma-1})\frac{\partial \log(\varphi_{k,k'})}{\partial \log(Z_k)} = (1 + \frac{1}{\sigma-1}) \times \left(\frac{\partial \log(PB_k)}{\partial \log(Z_k)} - 1\right) + \kappa\frac{\partial \log(\varphi_{k,k})}{\partial \log(Z_k)} - \frac{\partial \log(\mathcal{P}_k)}{\partial \log(Z_k)}$$

Moreover, replacing $\frac{\partial \log(PB_k)}{\partial \log(Z_k)} - 1$ by its expression we get and using the fact that $1 + \kappa = \frac{\gamma}{\sigma - 1}$, we get

$$\frac{\partial \log(\varphi_{k,k'})}{\partial \log(Z_k)} = \frac{1}{\sigma - 1 + \kappa\sigma} \times \frac{\partial \log(\mathcal{P}_k)}{\partial \log(Z_k)}$$

Home Entry Threshold $\varphi_{k',k'}$ Abroad

Using the definition of the thresholds from above and replacing $\frac{\partial \log(PB_{k'})}{\partial \log(Z_k)}$ by its expression, we get

$$\frac{\partial \log(\varphi_{k',k'})}{\partial \log(Z_k)} = \frac{1}{\sigma - 1 + \kappa\sigma} \times \frac{\partial \log(\mathcal{P}_{k'})}{\partial \log(Z_k)}$$

Export Entry Threshold $\varphi_{k',j}$ for Foreign firms exporting to j

With the "second" definition of the threshold and using the expression of $\eta_{\varphi_{k',k'},Z_k}$, one can show that the elasticity of the exporting threshold is proportional to the elasticity of the domestic entry threshold and that the scaling factor do not depend on the export market considered:

$$\frac{\partial \log(\varphi_{k',j})}{\partial \log(Z_k)} = \frac{1+\kappa}{\frac{\gamma}{\sigma-1}} \times \frac{\partial \log(\varphi_{k',k'})}{\partial \log(Z_k)}$$

Finally, using the expression for $1 + \kappa$, we get

$$\frac{\partial \log(\varphi_{k',j})}{\partial \log(Z_k)} = \frac{\partial \log(\varphi_{k',k'})}{\partial \log(Z_k)} = \frac{1}{\sigma - 1 + \kappa\sigma} \times \frac{\partial \log(\mathcal{P}_{k'})}{\partial \log(Z_k)}$$

Price indexes as constructed by statistical agencies

Using results above together with the definition of $\widehat{\mathcal{P}_k}$, we get:

$$\frac{\partial \log(\widehat{\mathcal{P}_{k'}})}{\partial \log(Z_k)} = \frac{\gamma - (\sigma - 1)}{\sigma\gamma - (\sigma - 1)} \frac{\partial \log(\mathcal{P}_{k'})}{\partial \log(Z_k)}$$

B.3.3 Final Expression

Now that I have an expression for the elasticity of all thresholds as functions of the elasticities of price indexes, I can gather the results. Introducing $\Lambda = \frac{1}{\sigma + \frac{(\sigma-1)^2}{\gamma - (\sigma - 1)}}$, I define a matrix T (for Transmission) as $T = \text{diag}(\Lambda, ..., \Lambda)$. This matrix characterizes the additional propagation mechanism due to the change in the mass of firms in all markets. Then, the price index elasticities are defined by

$$\begin{pmatrix} \eta_{\mathcal{P}_1, Z_1} \\ \vdots \\ \eta_{\mathcal{P}_N, Z_1} \end{pmatrix} = (\mathcal{I}_N - (1 - \eta - \chi)W - T)^{-1} \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$$

Finally, noting that for all i, $\eta_{\mathcal{P}_i,Z_1} = -\eta_{GNI_i,Z_1}$ concludes the demonstration.

In order to gain intuition on this formula, a few comments are in order. First, note that in the case of complete autarky of all countries we have $W = \mathcal{I}_N$ to that the elasticity for country 1 is simply $\eta_{GNI_1,Z_1} = 1/(\eta_1 + \chi_1 - \Lambda)$ whereas all other elasticities are zero. This result is reminiscent of what is found in Jones (2011) with the additional propagation mechanism due to the adjustment along the extensive margin captured by Λ. Interestingly, this special case highlights the fact that we need $(1-\eta-\chi)+\Lambda < 1$ in order to get a positive own-country elasticity. This condition is necessary for the validity of (21), since it corresponds to imposing that the reason of the geometric sequence is below one.[49] Secondly, noting that $\Lambda = \frac{1}{\sigma+\frac{(\sigma-1)^2}{\gamma-(\sigma-1)}}$, one can see that for a fixed σ, $\Lambda(\gamma)$ is a strictly increasing function. When $\gamma \to \sigma-1$, $\Lambda \to 0$ and when $\gamma \to +\infty$, $\Lambda \to 1/\sigma$. For a labor and capital share so that $\eta+\chi = 0.7$ we can see that any value $\sigma > 1.5$ is sufficient to insure the validity of the condition $(1-\eta-\chi)+\Lambda < 1$ for any value of γ within the range of admissible values ($\gamma > \sigma - 1$).

[49] The formula (21) is the matrix analogue of summing an infinite geometric sequence. $(1-\eta-\chi)W+T$ corresponds to the first order effect of the shock, $((1-\eta-\chi)W+T)^2$ is the second order effect, etc... The total effect can then be described by the matrix $(\mathcal{I}_N-(1-\eta-\chi)W-T)^{-1}$ if and only if the eigenvalues of the matrix $(1-\eta-\chi)W+T$ all lie within the unit circle. In the autarcy case, this condition is insured by $(1-\eta-\chi)+\Lambda < 1$.

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