Innovation, Diffusion and Trade: Theory and Measurement.*

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Abstract

Growth and imports are correlated across countries. However, the underlying mechanisms remain ill-understood. I develop a general equilibrium model in which imports and growth are connected by technological innovation and international diffusion through trade. Fitting the model to data on innovation, productivity and trade in varieties, I find that between two thirds and three fourths of the correlation is explained by these mechanisms. Moreover, adoption has been particularily important in developing countries, accounting for about 80% of their growth in the last decade. Finally, I carry out a counterfactual analysis to examine the connections between trade and growth. A 50% permanent decrease in the barriers to technology adoption in Asia increases world growth rates by about 1%. In the transition, Asia imports and grows faster than the rest of the world. A 50% permanent increase in the innovation productivity in Asia increases world growth rates by 3%. Either change leads to both higher growth and more trade.

*I am very grateful to Jonathan Eaton for his support and guidance. I am also grateful to Diego Comin, Antonio Fatas, Mark Gertler, Denis Gromb, Boyan Jovanovic, Demian Pouzo, Kim Ruhl, Gianluca Violante, and seminar participants at NYU, Federal Reserve Bank, Wharton UPenn, Boston College, IMF, U Texas Austin, CREI, UAB, U Carlos III, London Business School, U British Columbia, Toulouse School of Economics, and INSEAD

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1 Introduction

In the last decade, some countries in Asia and Europe grew much faster than average. Many of these countries also increased significantly the variety of goods they imported. For instance, China and India had average growth rates of about 8%, and a growth in imported varieties five times higher than the US, Japan or Germany, countries that grew on average at a rate of 2%.[1]

While the positive correlation between imports and growth is well established, the underlying mechanisms remain ill-understood. Theories of the effects of imports on growth go back at least to Romer (1987) and Rivera-Batiz and Romer (1991). However, empirical work has been limited in part due to lack of data. More recently, disaggregated trade data has become available for many countries, yielding new stylized facts. In particular, it appears that much of the increase in trade to GDP ratio comes from the extensive (number of goods traded) rather than from the intensive margin (how much of each good is traded). In a recent paper, Broda, Greenfield, and Weinstein (2008) show that for the average country, the extensive margin explains 80% of this increase.[2] Thus, to understand the relation between GDP growth and imports growth, it seems important to emphasize the extensive margin of trade.

I develop a general equilibrium model in which imports and growth are connected by technological innovation and international diffusion through trade. There are two channels of growth: the 'embodied' and the 'disembodied' channel. Following Greenwood, Hercowitz, and Krusell (1997), the 'embodied' channel is associated to some form of capital accumulation, while 'disembodied' productivity reflects residual, neutral productivity. In my model, 'embodied' productivity is driven by technology accumulation which occurs through two processes.[3] First, in the spirit of the new growth theory, a country accumulates technology

[1]Santacreu (2006) finds that over 60% of Ireland's growth in 1994-2003 was driven by an increase in the variety of goods it imports from very innovative OECD countries.

[2] Broda and Weinstein (2006) find that for developing countries, the extensive margin explains almost 100% of productivity growth. Hummels and Klenow (2002) also perform this decomposition for exports and find that the extensive margin explains two thirds of the increase in trade.

[3]A large literature studies whether differences in growth rates are driven mainly by factor accumulation (capital, in particular) or by TFP differences (e.g. Young (1991)). Easterly and Levine (2001) and Klenow and Rodriguez-Clare (2005) show that it is differences in TFP that drive differences in growth rates across countries. While capital accumulation has been important in several Asian economies, TFP growth affects the marginal return on capital and it could explain why the rental rate of capital was so high in these countries.

as domestic firms innovate by investing in R&D. Technology is embodied in new goods. Second, a country can accumulate technology as firms import goods that embody foreign technologies. The main difference between domestic and foreign sources of technology is that domestic innovations can immediately be sold in the domestic market. Instead, to import a foreign innovation, firms in an adoption sector need to invest resources over time to adapt the good in which it is embodied.[4] For that reason, the international diffusion of innovations is slow and the speed is endogenous. In this setting, a country's equilibrium allocation of resources into innovation and adoption depends on its level of development and other characteristics.

I analyse both the steady state and the transition dynamics of the model. As in models of innovation and international diffusion, all countries grow at the same rate in steady state, while barriers to technology adoption create persistent income differences.[5] More interestingly, countries grow at different rates in the transition. In developing countries, the cost of adoption tends to be lower than that of innovation. As a result, the equilibrium allocation of resources into adoption is higher, and catching-up allows these countries to grow faster. As the economy develops, the cost difference between innovation and adoption decreases, and domestic innovation increases. It is not unreasonable to assume that innovation requires a higher level of technology than adoption. Since rich countries are technologically more advanced, they allocate more resources to innovation. This is consistent with the data: developing countries adopt and grow more, while rich countries innovate more.

The model is fitted to thirty-seven countries grouped into five regions: Asia, Eastern Europe, Western Europe, Japan, and the US. I use data on innovation, productivity, and trade at the product level to estimate the parameters governing innovation and diffusion with Bayesian techniques. I find that the 'embodied' channel explains between two thirds and three fourths of the correlation between growth in imports and GDP per capita growth in the last decade. Moreover, within this channel, adoption of foreign innovations through trade arises as an important source of productivity growth for developing countries, while domestic innovation has been the main source of growth for developed countries. In fact, more than 80% of embodied growth in Asia can be explained by foreign innovations, especially from the US and Japan. These two regions are also the main sources of foreign technology for

[4] Consistent with recent empirical findings by Comin and Hobijn (2004), diffusion is modelled as a slow process, in which the speed of diffusion depends on the amount of resources invested by the adopters. Eaton and Kortum (1999) find that international diffusion is much slower than domestic diffusion; I make the extreme assumption that diffusion is instantaneous within a country.

[5] See Rodriguez-Clare and Klenow (1997) for a review.

other regions.[6]

Finally, I use counterfactuals to examine the link between trade and growth by changing various exogenous parameters. A 50% permanent decrease in the costs of adoption in Asia increases steady state world growth rates by 1%; in the transition, trade rises, and Asia grows faster than average. A 50% permanent increase in the innovation productivity in Asia increases steady state world growth rates by 3%. The higher productivity in Asia increases the demand of imports from the rest of the world. Both changes induce a positive correlation between imports and growth.

The paper builds on several streams of literature. First, the literature on endogenous growth in which technology is embodied in new goods, as in Romer (1987). To embodied growth, I add an exogenous TFP process that represents disembodied technology, as in Greenwood, Hercowitz, and Krusell (1997).

Second, I follow Eaton and Kortum (1996, 1999) in that innovation and international technology diffusion are the potential channels of embodied technological progress.[7] I differ in the way I model and measure international diffusion. In my framework, diffusion occurs through trade in varieties, which is an endogenous process. That is, firms need to undertake a costly investment to import a good. The incentives for the importer differ across sources of exports and depend on the value of adopting a new technology. I adapt the approach in Comin and Gertler (2006) and Comin, Gertler, and Santacreu (2009) to an open economy setting.[8]

The lack of direct measures of adoption have led to use indirect measures, such as trade in intermediate goods (Rivera-Batiz and Romer (1991), Eaton and Kortum (2001), and Eaton and Kortum (2002)) or international patenting (Eaton and Kortum (1996, 1999)).[9] Because the interest of my paper is to understand the connections between trade and growth, I use trade as the indirect measure of diffusion, in a similar way as Coe, Helpman, and Hoffmaister

[6]Cameron, Proudman, and Redding (2005) analyse a model for a panel of UK manufacturing industries, in which innovation and technology transfer are the main sources of productivity growth for countries lagging behind the technology frontier. They find that technology transfer through international trade is the main driving source of growth for these countries. They obtain a positive and statistically significant effect of distance with respect to the frontier on productivity growth.

[7] A survey of empirical studies in innovation and diffusion can be found in Keller (2004).

[8]Further empirical evidence that shows that innovations are not transferred to other locations at a negligible cost can be found in Griliches (1957) and Teece (1977).

[9] Comin and Hobijn (2004) provide direct measures of adoption for a large sample of countries and a large sample period; they do not distinguish, however, between technologies created in the country and those from abroad.

(1997). They find that for developing countries, TFP is significantly related to the stock of R&D carried out by their trading partners. My model complements this literature by explicitly modelling the mechanisms connecting trade and growth.

The paper also relates to the literature on trade in varieties, as in Feenstra (1994), Broda and Weinstein (2006), Broda, Greenfield, and Weinstein (2008), and Goldberg, Khandelwal, Pavcnik, and Topalova (2009). I follow their methodology to compute the extensive margin of trade, but I model explicitly the incentives of the different agents in the economy to undertake either research or adoption..[10]

Finally, I model technology diffusion as an endogenous process in which firms need to undertake a costly investment to import a good. The incentives for the importer differ across sources of exports and depend on the value of adopting a new technology. I adapt the approach in Comin and Gertler (2006) and Comin, Gertler, and Santacreu (2009) to an open economy setting.[11]

The paper proceeds as follows. Section 2 examines the data. Section 3 presents the model; the steady state and the dynamics are solved in sections 4 and 5. Section 6 explains the estimation procedure and reports the results. Sections 7 and 9 contains the experiments. Section 10 concludes.

2 A first look at the Data

To motivate the model that I develop next, this section presents data on innovation, trade, and productivity for a sample of 37 countries, which I divide into three groups: innovative economies in Europe, Japan, and the US, which grow and import at lower than average rates, less innovative countries in Europe and Asia, which grow and expand imports more than average, and less developed countries in Africa and Latin America, which innovate and import at low rates. The data is summarized in Appendix A.

The positive relation between trade and growth is a well established stylized fact. In the last decade, some countries in Asia and Europe have experienced a significant increase in their variety of imports and have been growing faster than average.[12] Figure 1 shows, for a

[10]A variety is defined as a 6-digit category product from a particular source-country. This is the Armington assumption, by which countries specialize exogenously in producing a different good.

[11]Further empirical evidence that shows that innovations are not transferred to other locations at a negligible cost can be found in Griliches (1957) and Teece (1977).

[12]One could argue that looking at exports is just as important as looking at imports to explain the development experienced by Asia and Eastern Europe. When I look at the growth in exported varieties and

sample of thirty-seven countries, a positive correlation between the average growth rate of income per capita and the expansion in import variety.[13] The US, Japan or Germany are in one extreme, with lower import and productivity growth, while China, Vietnam or India are in the other extreme. Even though the link between the two variables is clear from the graph, we cannot infer any causality effect, and the question of what are the mechanisms that connect trade and growth remains open.

Another feature of fast growing countries is a relatively low level of income per capita, signalling a catching-up effect. Figure 2 plots the average growth rate of income per capita, for the period 1994-2003, against the initial level in 1994. Once we eliminate Africa and Latin America, there is a clear positive correlation between the two variables. Thus, catching-up is a feature of only those economies expanding the variety of goods that they import.[14]

Developing countries have a lower extensive margin of trade. In fact, there is a positive correlation between levels of income per capita and the level of imports across countries (see figure 4). Under the assumption that technology diffuses through international trade, this evidence suggests that rich countries have a higher level of foreign embodied technology, while less developed countries are expanding it faster. A model consistent with the data, needs to allow for rich countries being technologically more advanced.

One of the features of international diffusion through trade is that it is a slow process. Using bilateral trade data from UN COMTRADE, I compute the hazard of adoption over the period 1994-2003 for a sample of 37 countries that are grouped into five regions: Asia, Eastern Europe, Western Europe, Japan and the US.[15] The results are displayed in table 1.

I compute the correlation with productivity growth, I obtain a correlation of 0.4. The correlation between productivity growth and growth in imports is almost 0.8.

[13]The average is taken over the period 1994-2003, for a sample of thirty seven countries. The circles in red represent less developed countries in Asia, Europe, Africa, and Latin America. The circles in blue represent rich countries in Europe, Japan, and the US. I use bilateral trade data at the 6 digit level of disaggregation, from UN COMTRADE. A variety is defined as a 6-digit product from a specific source of exports. Growth in imported varieties is computed as in Broda, Greenfield, and Weinstein (2008), who adjust for quality and symmetry bias. Output growth is growth in real GDP per capita, from the Penn World Table, adjusted by the extensive margin of intermediate imports, as in Feenstra (1994) and Broda, Greenfield, and Weinstein (2008).

[14] Even though Africa and Latin America start with relatively low levels of GDP per capita, their expansion of imports and economic growth is low.

[15]Keller (2004) already considered the importance of analysing the interaction between these regions when he said: *'Many economist believe that the increased economic integration [. . .] has tended to increase the long-run rate of economic growth. If they were asked to make a prediction, they would suggest that prospects for growth would be permanently diminished if a barrier were erected that impeded the flow of all goods, ideas*

The inverse of the hazard rate represents the average time that it takes, for each importer, to adopt goods from each exporter. It takes, on average, between three and ten years to start importing a new good.[16]

Note that if diffusion were instantaneous, all countries would have access to the same technology and the levels of income per capita would be the same. If, instead, there were not international diffusion, the growth rate of a country would depend exclusively on technology accumulation through domestic innovation. Since rich countries invest more in doing research, we would expect these countries to grow at higher rates. Empirically, however, when developing countries are added to the analysis, there is not a positive correlation between innovation and growth. Figure 4 plots the research intensity of the country against the expansion in imported varieties. The correlation is negative, suggesting that less innovative countries are expanding imports faster and, from figure 1, growing at higher rates.[17] Consistent with the development literature, rich countries produce more goods, and therefore, have a higher level of domestic embodied technology.

3 The Model

In this section, I construct an endogenous growth model of trade in varieties that captures the main features of the data. The economy is composed of M countries that interact with each other through trade. Technology is embodied in new goods that are used in final production. There are two channels of growth: embodied and disembodied. Innovation and adoption of new intermediate products are the source of embodied productivity growth, while and exogenous TFP shock represents disembodied technological progress, as in Greenwood, Hercowitz, and Krusell (1997).[18] Without loss of generality, I assume that there is not an exogenous death probability of products in the model.[19]

Throughout the paper, whenever a variable has both a subscript and a superscript, the superscript indexes the destination of imports and the subscript indexes the source of exports.

and people between ***Asia, Europe and North America****'.*

[16]In Appendix E, I explain how I obtain the hazard of adoption using tools of survival analysis (or duration analysis) with censored data.

[17] R&D intensity is measured as the fraction of workers that are allocated into R&D (data from the World Development Indicators in the World Bank.)

[18]Other authors studying the role of trade in explaining differences in growth rates, have focused on capital accumulation as the source of economic growth. See Ventura (1997).

[19]The data show that the rate at which products drop out the sample is around 1%. The results would remain the same if I added the exogenous death probability.

The goods are indexed by j and the time is indexed by t.

3.1 Preferences

In each country there is a representative consumer that supplies labor inelastically and, solves the following maximization problem

$$\max U(C_{it}) = \sum_{t=0}^{\infty} \beta^t C_{it}$$

$$s.t. \sum \beta^t C_{it} = \sum \frac{Y_{it}}{(R)^t}$$

where β is the discount factor, C_{it} is consumption in country i at time t, R is the risk-free interest rate, and Y_{it} is final output. Note that consumers are risk neutral as they face a linear utility function on consumption.

From the FOC, the following relationship between the discount factor and the risk-free interest rate emerges,

$$\beta = \frac{1}{R}$$

3.2 Final production sector

Each country i at time t produces a non-traded final good Y_{it} using traded intermediate goods, j, according to the CES function[20]

$$Y_{it} = e^{\bar{g}a_{it}} \left(\sum_{n=1}^{M} \sum_{j=1}^{A^i_{nt}} (b^i_{ntj})(x^i_{ntj})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where M is the number of countries from which country is buying intermediate goods; $\sigma > 1$ is the elasticity of substitution among differentiated intermediate goods; x^i_{njt} is the amount of input j that is used in the production of final output; b^i_{ntj} represents a preference for variety j.[21] A^i_{nt} is the total number of varieties available for final production in country i from country n at time t; it is a measure of embodied technology and it includes both domestic and foreign adopted intermediate goods. Finally, a_{it} captures country-specific manufacturing

[20] This function was introduced by Ethier (1982).

[21] For a reference see Feenstra (1994) and Broda, Greenfield, and Weinstein (2008)

productivity or disembodied technology, which is assumed to be common across sectors, and follows an AR(1) process

$$a_{it} = \rho a_{i,t-1} + u_{it}$$

with $\rho \in (0,1)$ and $u_{it} \sim N(0,\sigma^2)$

The CES production function introduces a love-for-variety effect by which, holding expenditures constant, an increase in intermediate goods translates into an increase in productivity. At the same time, countries with a higher level of varieties for final production, have a higher level of productivity.[22]

Final producers are perfectly competitive. They demand intermediate goods taking as given the price set by intermediate produces, p^i_{ntj}

$$x^i_{ntj} = \exp(\bar{g}a_{it})^{\sigma}(b^i_{ntj})^{\sigma} X_{it} \left(\frac{p^i_{ntj}}{P_{it}}\right)^{(-\sigma)} \tag{2}$$

where $X_{it} = \omega_{it} L_{it}$ is total spending by country i, ω_{it} represents wages, and P_{it} is the price index

$$P_{it} = \left(\sum_{n=i}^{M} \sum_{j}^{A^i_{nt}} c^i_{ntj} \left(p^i_{ntj}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

where A^i_{nt} is the number of intermediate goods from country n that have been adopted by country i at time t, $c^i_{ntj} = (b^i_{ntj})^{\sigma}$, and $\frac{1}{A^i_{nt}} \sum_j c^i_{ntj} = c^i_{nt}$.[23]

3.3 Intermediate production sector

In the intermediate goods sector, there is a continuum of monopolistic competitive firms, who each sell a different variety to the competitive final good producer. Intermediate goods

[22] When $\sigma \to \infty$, goods are perfect substitutes.

[23] Note that c^i_{ntj} is the expenditure share in variety j from country n by country i. In fact, $x^i_{nt} = \sum_j x^i_{ntj} = \sum_j \exp(\bar{g}a_{it})^{\sigma} c^i_{ntj} X_{it} \left(\frac{p^i_{ntj}}{P_{it}}\right)^{(-\sigma)}$, but since as I show later $p^i_{ntj} = p^i_{nt}\ \forall j$, $x^i_{nt} = \exp(\bar{g}a_{it})^{\sigma} X_{it} \left(\frac{p^i_{nt}}{P_{it}}\right)^{(-\sigma)} \sum_j c^i_{ntj}$. Then, $\frac{x^i_{ntj}}{x^i_{nt}} = \frac{c^i_{ntj}}{\sum_j c^i_{ntj}} = \frac{1}{A^i_{nt}}$. Therefore, $c^i_{ntj} = c^i_{nt}\ \forall j$. The fraction that each country spends in each good is the same across goods; however, each country spends a different amount on each source n.

are produced according to the same CRS production function,[24]

$$x_{ijt} = l_{ijt} \tag{3}$$

with $\sum_j l_{ijt} = L_{it}$, and l_{ijt} is the amount of labor that each firm j employs to produce in country i. L_{it} is the total supply of labor in the country.

These assumptions have implications for pricing, firm profits and the value of having an innovation adopted in a country. Under monopolistic competition each good is produced by a separate monopolist. Markets are segmented so that producers can set a different price in each market. Producers in each country endogenously choose to produce a different set of goods.[25]

Taking as given the demand by the final producers, equation (2), each intermediate good firm chooses a price, p^i_{ntj}, to be a constant mark-up over the marginal cost. Trade is assumed to be costly: there is an iceberg transport cost for the products shipped from country n to i equal to $d^i_n > 1$, with $d^i_i = 1$. Intermediate firms' prices differ in the domestic and the foreign market by the transport cost d^i_n. That is, they set a price

$$p^i_{itj} = \bar{m}\omega_{it} \tag{4}$$

in the domestic market and

$$p^n_{itj} = \bar{m}(\omega_{it} d^n_i) \tag{5}$$

in each foreign market, with $\bar{m} = \frac{\sigma-1}{\sigma}$ being the constant mark-up. Note that the price set by intermediate goods is the same for every good and it only depends on the exporter's wage and the iceberg transport costs.

Instantaneous profits by intermediate firms are given by the following expression

$$\pi^i_{ntj} = \left(\frac{1}{\sigma}\right) e^{\bar{g}a_{it}} (b^i_{ntj})^{\sigma} \left(\frac{p^i_{ntj}}{P_{it}}\right)^{-(\sigma-1)} \omega_{it} L_i$$

They depend on the expenditure on each intermediate good, which is a function of wages, ω_{it} and the size of the country, L_{it}. Larger countries are a bigger source of profits.

[24] Labor is the only factor of production in the economy. It is assumed to be immobile across countries and perfectly mobile across sectors within a country. Labor is used for manufacturing of intermediate goods, innovation, and adoption.

[25] While the Armington assumption of goods differentiated per source of exports implies that countries exogenously specialize in a different set of goods, the monopolistic competition setting implies that firms produce differentiated goods.

3.4 Innovation and adoption

The connections between trade in varieties and growth in the model are underpinned by the mechanisms of innovation and adoption. This section explains the mechanisms by which new goods are developed in an economy and how they diffuse to other countries. Both processes are endogenous and depend on profit maximization decisions by the economic agents.

Before explaining in detail the domestic innovation and foreign adoption processes, let me introduce some notation. Z_{it} is the stock of technologies that have been developed in country i, and are available to be adopted at time t. It represents the theoretical level of technology, which is the level of technology that would prevail in a country if diffusion were instantaneous. A^i_{nt} is the stock of foreign technologies that country i has successfully adopted from country n. It represents the actual level of technology in a country. Note that technologies enter the final production process, and therefore are productive, only once they have been adopted.

Instantaneous diffusion within the country implies that, at each moment in time, the theoretical and actual number of technologies in a country is the same. That is, for country i,

$$A^i_{it} = Z_{it}$$

Slow diffusion across countries implies that at each moment in time, the actual level technology is a subset of the potential technology. That is,

$$A^i_{nt} \leq Z_{nt}$$

The effective level of technology in a country is composed of both domestic and foreign technologies. For country i,

$$T_{it} = A^i_{it} + \sum_{n \neq i} A^i_{nt}$$

3.4.1 Innovation process

In a given country, new goods are introduced endogenously by a monopolist who allocates labor to R&D. As in Phelps (1964), the arrival of new goods at date t in location i, $Z_{i,t+1} - Z_{it}$, is determined by the fraction of workers that are allocated to research, and how productive the economy is at doing research.

$$Z_{i,t+1} - Z_{it} = \alpha_i^R T_{it} \left(\frac{R_{it}}{L_{it}}\right)^{\gamma_r} L_{it} \tag{6}$$

where $\frac{R_{it}}{L_{it}}$, represents research intensity, R_{it} is the number of researchers, and L_{it} is the total number of workers; $\alpha_i^R T_{it}$ represents the productivity of research.

The microfoundations of this function are the following: in country i, workers are ranked according to their productivity at doing research. A worker with productivity j produces ideas at the stochastic rate $\alpha_i^R T_{it} \gamma_r \left(\frac{j}{L_{it}}\right)^{\gamma_r - 1}$, where $\gamma_r \in (0,1)$ is a parameter reflecting the extent of diminishing returns to allocating a larger share of workers into research.[26]

Research productivity, $\alpha_i^R T_{it}$, depends on two elements. First, a country-specific parameter, α_i^R, that is identified by economic policies or institutions promoting innovation.[27] The second element is a spillover effect given by the effective number of technologies in the country, T_{it}. Countries learn on the basis of the total number of goods that are available for final production. In this respect, there is learning by doing (domestically produced goods) and learning by using (imports). This assumption implies that countries with a higher extensive margin, which has been shown to be the case for rich countries, have a lower cost of innovation. Thus, other things equal, they invest a larger amount of resources in R&D. This specification is consistent with Grossman and Helpman (1991) and Romer (1994), and the data.

Another implication of the international spillovers component is that countries expanding their variety of foreign intermediate goods through imports are becoming better innovators, and therefore increasing the number of goods that they produce and export. That is, non-innovative countries can learn from importing intermediate goods, even if they are not initially very innovative. This reasoning is in line with what Hallward-Driemeier (2000) found. Using data from five Asian countries, she observes that, prior to entry into export markets, productivity gains are associated with higher imports.

Finally, through the spillover effect, it is possible that countries that start adopting very fast, eventually shift from main adopters to main innovators. Acemoglu, Aghion, and Zilibotti (2002) consider this process as a shift from an 'investment-growth strategy' (adoption)

[26]This assumption implies that a worker's talent as a researcher is drawn from a Pareto distribution. Workers in a country are equally productive at making intermediates but they differ in their talent for research. They are assumed to be compensated in proportion to their marginal productivities. Thus, those who are more productive at doing research will become researchers. At the same time we correct for population, because for the same research intensity, larger countries have more to draw from.

[27] Reasons for differences in the productivity parameter across countries could be better infrastructures or education.

to an ‘innovation-shift strategy’ (innovation).

Once a new technology has been innovated, a competitive set of entrepreneurs bid for the right to produce the good. They pay the market price for an innovation, given by the discounted present value of profits that the entrepreneur who gets the production right expects to obtain from selling the good. Positive profits arise because the producers of the intermediate goods are monopolistic competitors, and set prices taking as given the demand by final producers in each potential market. In this sense, there is a fixed cost to start producing the good, given by the investment needed to acquire the ‘design’ from the research sector. Once the firm acquires the right to use the technology, it starts producing the intermediate good. Note that the monopolist captures fully the results for the innovation.

3.4.2 Technology Diffusion

Intermediate goods that are invented and produced in a country need to be adopted in order to be used by the final producers. In the model, diffusion within the country is instantaneous and costless, but it takes time across countries. That is, when a new technology is produced in a country, it is immediately ready to be sold to the final sector in that country.[28] This is not an unreasonable assumption. Eaton and Kortum (1996) estimate that the probability of diffusion within a sample of five very innovative OECD countries is very high, between 0.8 and 0.9. However, to use a foreign good, adopters need to make a costly investment in each potential destination.[29] Whether or not adoption is successful is a random draw with positive probability, ε^i_{nt}. Note that the variable c^i_{nt} in equation (1) means that some markets n are more profitable than others. I assume that the value of this variable is realized only after the adopter makes the decision of investing resources to adopt the good. That way, even goods with a low c^i_{nt} will be intgroduced in the market.

The probability of any idea from n to be diffused to i can be expressed in the following way

$$\varepsilon^i_{nt} = \alpha^A_i \frac{A^i_{nt}}{Z_{n,t+1}} \left(\frac{H^i_{nt}}{L_{it}}\right)^{\gamma_a} L_{it} \tag{7}$$

where H^i_{nt} represents the amount of labor that adopters hire in country i, to learn to use

[28]As I showed in section 2, the average diffusion lag in the sample of analysis is between 3 and 10 year.

[29]There is a fixed cost of adoption. The key assumption is that the cost is measured in terms of labor from the destination country. Other than that, the results are the same whether it is the exporter who hires the labor from the destination (fixed cost of exports) or it is the importer who incurs in the cost (fixed costs of imports).

the product; α_i^A is a country-specific parameter, that represents barriers to adopt a new technology (a higher value of the parameter implies a lower level of barriers to adoption); γ_a is the elasticity of adoption with respect to effort, assumed to be common across countries.[30] It is a measure of how an increase in investment in adoption translates into an increase in the probability of importing a foreign good; $\frac{A^i_{nt}}{Z_{n,t+1}}$ represents the fraction of technologies that country i has already adopted from country n.[31]

Finally, I describe the process by which foreign technologies are introduced in a country through imports. Following Nelson and Phelps (1966) and Benhabib and Spiegel (1994), the rate at which the potential level of technology in country n is realized in actual technology in country i depends on the probability of adoption, ε^i_{nt}, and the stock of technologies from country n that country i has not adopted yet, $Z_{n,t+1} - A^i_{nt}$. This technological gap explains the dynamics of imports of new technologies, embodied in intermediate goods.[32]

$$A^i_{n,t+1} - A^i_{nt} = \varepsilon^i_{nt}(Z_{n,t+1} - A^i_{nt}) \tag{8}$$

Expression (8) implies that goods invented in n that have not yet been imported by country i, contribute to an expansion in the variety of exports to country i at a rate ε^i_{nt}.[33]

By solving equation (8) forward, the variety of imports is endogenously determined by the research effort done around the world, in the following way

$$A^i_{nt} = \sum_{j=1}^{t} \varepsilon^i_{n,t-j} \prod_{k=1}^{j} (1 - \varepsilon^i_{n,t-k}) Z_{n,t-j+1} \tag{9}$$

[30]Examples of economic policies that affect this parameter are an increase in investment in education, an improvement in telecommunication infrastructures that facilitate communication across countries, trade policies, etc. Eaton and Kortum (1996) and Benhabib and Spiegel (1994) analyse the dependence of the probability of adoption on different factors, such as human capital. They find that human capital has a positive and significant impact on the adoption ability.

[31]Think of this term as a measure of 'remoteness'. As the destination starts importing goods and becomes familiar with the exporter's products, the investment needed to start selling the good abroad is lower. Interaction among the countries allows the importer to learn about the source, which is reflected everything else constant, in an increase in the probability of adoption.

[32]Cummins and Violante (2002) focus on the adjustment of productivity growth to technological innovations. They calculate that the gap between the productivity of the best technology and average productivity rose from 15 percent in 1975 to 40 percent in 2000. This finding is consistent with technology diffusion models which state that learning about new technologies can generate long implementation lags as resources are channelled into the process of adapting new technologies into existing production structures.

[33]Note that if diffusion were instantaneous, then $\varepsilon^i_{nt} = 1$ and from equation (8), $A^i_{nt} = Z_{nt}\ \forall t$. If, on the contrary, there were not investment in adoption, then $\varepsilon^i_{nt} = 0$ and from equation (8), $A^i_{n,t+1} = A^i_{nt}\ \forall t$.

From equation (9), the dynamics of imports are determined by innovation around the world, through the theoretical level of technology.

To understand better the adoption mechanism, I substitute equation (7) into the law of motion for new imports, equation (8),

$$A^i_{n,t+1} - A^i_{nt} = \alpha^A_i \left(\frac{H^i_{nt}}{L_i}\right)^{\gamma_a} L_i \frac{A^i_{nt}}{Z_{n,t+1}} (Z_{n,t+1} - A^i_{nt}) \tag{10}$$

Rearranging

$$A^i_{n,t+1} - A^i_{nt} = \alpha^A_i \overbrace{\left(\frac{H^i_{nt}}{L_i}\right)^{\gamma_a} L_i}^{\text{Investment in adoption}} \overbrace{A^i_{nt}}^{\text{International Spillover}} \overbrace{\left(1 - \frac{A^i_{nt}}{Z_{n,t+1}}\right)}^{\text{Relative Backwardness}} \tag{11}$$

The number of new goods that country i imports (adopts) from country n at time t depends on three components. First, investment in adoption. Second, the number of goods that country i has already imported from country n up to time t. Third, relative backwardness since as the country is further away from the exporter's technological frontier (lower $\frac{A^i_{nt}}{Z_{n,t+1}}$), an increase in the number of imports will have a higher impact in growth rates. Empirically, countries that are expanding their range of imports fast are relatively backward countries that are also experiencing growth rates higher than average. Note that this term arises from the product of two terms: $\frac{1}{Z_{n,t+1}} (Z_{n,t+1} - A^i_{nt})$.[34] The first term implies that as country n's technology becomes more advanced, country i needs to invest more resources to adopt a given number of goods from n; the second term reflects the fact that when a country's imports are low relative to the technology frontier of the source, every successful technology adoption implies a higher expansion in the number of imports.[35]

3.4.3 The value of an idea

There are two profit maximization decisions in the economy: how much labor to invest in R&D and how much labor to invest in adoption. The decisions are based on the value of inventing and adopting a new technology.

[34] As in Howitt (2000).

[35] Equation (11) can be expressed in terms of growth rates

$$g_{in,t} = \alpha^A_i \left(\frac{H^i_{nt}}{L_i}\right)^{\gamma_a} L_i (1 - \tau^i_{nt}) \tag{12}$$

with $\tau^i_{nt} = \frac{A^i_{nt}}{Z_{n,t+1}}$.

The owner of a technology can earn profits only after the good has been adopted. Since there is instantaneous diffusion within the country, the value of a new good that is used domestically W^i_{it}, is the present discounted value of future domestic profits.

$$W^i_{it} = \pi^i_{it} + \beta W^i_{i,t+1} \tag{13}$$

where β is the discount factor, π^i_{it} are domestic profits for a firm in country i at time t, and $W^i_{i,t+1}$ is the continuation value.

Slow diffusion across countries implies that a technology invented in country n at time t will be adopted by country i at $t+1$ with probability ε^i_{nt}. The value of an idea invented in n at time t that has not been adopted by i yet is J^i_{nt},

$$J^i_{nt} = max_{H^i_{nt}}\{-H^i_{nt}\omega_{it} + \beta\varepsilon^i_{nt}(H^i_{nt})W^i_{n,t+1} + \beta(1-\varepsilon^i_{nt}(H^i_{nt}))J^i_{n,t+1}\}$$

At time t, firms invest H^i_{nt} units of labor to adopt the good. There is a fixed cost of adoption, given by $-H^i_{nt}\omega_{it}$. At time $t+1$, with probability ε^i_{nt}, the country is successful and obtains profits forever. With probability $(1-\varepsilon^i_{nt})$, this technology will not be adopted, and the country can keep investing resources to adopt the good in the future. The value of a technology from n that has been adopted by i at time t is

$$W^i_{nt} = \pi^i_{nt} + \beta W^i_{n,t+1}$$

In this specification, J^i_{nt} is the price that adopters in country i are willing to pay to intermediate firms in country n to buy their products and sell them in country i. It is also the profit that intermediate producers in the source country receive.

Finally, the market price of an innovation, V_{it}, is given by the value of selling the good in the domestic market and the expected value of selling the good in each of the foreign markets, $V_{it} = \sum_{n=1}^{M} J^i_{nt}$, with $J^i_{it} = W^i_{it}$.

It is important to note that there are two trade costs in the model. One is the iceberg transport cost, which determines, once the good is traded, how much of the intermediate good is shipped across countries. The other cost is a fixed cost, and affects whether or not a new product is imported. This is determined by barriers to technology adoption, as I explain in section 3.4.2.

3.4.4 Optimal investment in innovation

Innovators choose the amount of labor that maximizes profits. Taking as given the market price of an innovation, V_{it}, they solve the maximization problem

$$\max_{R_{it}} \quad V_{it}(Z_{i,t+1} - Z_{it}) - \omega_{it} R_{it}$$

$$\text{s.t} \qquad Z_{i,t+1} - Z_{it} = \alpha_i^R T_{it} \left(\frac{R_{it}}{L_{it}}\right)^{\gamma_r} L_{it}$$

Country i invests in R&D up to the point where the marginal benefit of research is equal to the marginal cost, given by the wage, ω_{it}.

$$\gamma_r \alpha_i^R T_{it} \left(\frac{R_{it}}{L_{it}}\right)^{\gamma_r - 1} V_{it} = \omega_{it} \tag{14}$$

The marginal benefit of doing research depends on the productivity of research, $\gamma_r \alpha_i^R T_{it} \left(\frac{R_{it}}{L_{it}}\right)^{\gamma_r - 1}$ and the market price for an innovation, V_{it}.

3.4.5 Optimal investment in adoption

Intermediate producers in country n hire H_{nt}^i units of labor in country i to maximize the profits that they could obtain by selling the good in that country, J_{nt}^i.

They solve the following problem,

$$\max_{H_{nt}^i} \quad J_{nt}^i = -H_{nt}^i \omega_{it} + \beta \varepsilon_{nt}^i W_{n,t+1}^i + \beta(1 - \varepsilon_{nt}^i) J_{n,t+1}^i$$

$$\text{s.t} \qquad \varepsilon_{nt}^i = \alpha_i^A \left(\frac{H_{nt}^i}{L_{it}}\right)^{\gamma_a} L_{it} \frac{A_{nt}^i}{Z_{n,t+1}}$$

Intermediate producers in n hire labor in i up to the point where the marginal benefit equals the marginal cost.

$$\gamma_a \alpha_i^A \left(\frac{H_{nt}^i}{L_{it}} \right)^{\gamma_a - 1} \frac{A_{nt}^i}{Z_{n,t+1}} (W_{n,t+1}^i - J_{n,t+1}^i) = \omega_{it} \tag{15}$$

Note that the marginal benefit depends positively on the productivity of adoption,

$$\gamma_a \alpha_i^A \left(\frac{H_{nt}^i}{L_{it}} \right)^{\gamma_a - 1} \frac{A_{nt}^i}{Z_{n,t+1}}$$

,

and the difference between what they can earn if adoption is successful W_{nt}^i, and the value of a non adopted intermediate good, J_{nt}^i.

It is important to note that the relevant decision is not whether or not to adopt a new technology, but whether to adopt it now or to postpone the decision for the future. The optimal action ultimately depends on the expected future profits.

3.5 The Labor Market

Labor is the only factor of production in this economy and it is used for manufacturing, innovation and adoption. Equilibrium in the labor market implies that

$$L_{it} = L_{it}^M + L_{it}^R + L_{it}^A \tag{16}$$

where L_{it}^M is the amount of labor employed in manufacturing, $L_{it}^R = R_{it}$ is the amount of labor used by the innovators, and $L_{it}^A = \sum_{n=1}^M H_{nt}^i$ is the amount of labor demanded by the adopters. In equilibrium, the sum of these three terms must be equal to the total labor force, L_{it}.

3.6 Labor market clearing condition

Balanced trade and the assumption that labor is the only factor of production in the economy imply that we can close the model with the labor market clearing condition: the amount of labor used in production must equal the total amount of labor available in the economy.

$$\sum_{i=1}^M A_{nt}^i x_{nt}^i = \bar{m} \omega_{nt} L_{nt}^M \tag{17}$$

The LHS of equation (17) represents total expenditure in manufactures from country n by each country i. The RHS is the value of total supply of labor from country n.

This condition determines the equilibrium relative wage. Note that, in the model, relative wages represent also relative income per capita.

3.7 The equilibrium

A general equilibrium in this economy is defined, $\forall i, n$, as an exogenous stochastic sequence, $\{a_{nt}, \xi_{nt}\}_{t=0}^{\infty}$, an initial vector $\{A_{n0}^{i}, Z_{n0}\}$, a sequence of parameters common across countries $\{\sigma, \gamma_a, \gamma_r, \rho\}$, a sequence of parameters that differ across countries, $\{\alpha_i^R, \alpha_i^A, L_i, d_n^i\}$, prices $\{p_{nt}^i, \omega_{nt}\}_{t=0}^{\infty}$, a sequence of endogenous variables $\{Y_{nt}, x_{nt}^i, L_{nt}^M, R_{nt}, H_{nt}^i, \pi_{nt}^i, W_{nt}^i, J_{nt}^i\}_{t=0}^{\infty}$, and laws of motion $\{A_{n,t+1}^i, Z_{n,t+1}\}_{t=0}^{\infty}$ such that

- $\forall t$, given prices and initial conditions, x_{nt}^i solves the final producer's problem (equation (2))
- $\forall t$, given prices and initial conditions, x_{nt}^i, and profits π_{nt}^i, p_{nt}^i and L_{nt}^M solve the intermediate producers problem (equations (4) and (5))
- $\forall t$, given prices and initial conditions, R_{it} solves the innovator's problem (equation (14))
- $\forall t$, given prices and initial conditions $\{H_{nt}^i, \pi_{nt}^i, W_{nt}^i, J_{nt}^i\}$ solve the adopter's problem (equation (15))
- The laws of motion for A_{nt}^i and Z_{nt}, given by equations (6) and (8) are satisfied
- Feasibility is satisfied by equation (1)
- Prices are such that the labor market clears

4 Balanced Growth Equilibrium

In this section, I solve for the balanced growth equilibrium of the economy. In steady state, all endogenous variables grow at a constant rate.

Population is assumed to be constant. Therefore, from equation (16), the allocation of labor in manufacturing, adoption, and research are also constant.

Technology diffusion and catching-up assure that all countries eventually grow at the same rate. Countries differ in the relative levels of technology, depending on the country-specific parameters, L_i, d_n^i, α_i^R and α_i^A.[36]

Equation (6) implies that the number of domestically created varieties grows at the same rate as the total number of goods available in the final production sector. Similarly, from equations (12) and (7), the number of adopted domestically produced varieties grow at the same rate, which translates into a constant probability of adoption.

In steady state, the growth rates are the same across countries. To see this,

$$g_i = \frac{\Delta T_i}{T_i} = \frac{\Delta Z_i}{T_i} + \sum_{n=1}^{M} \frac{\Delta A_n^i}{T_i} \tag{18}$$

Substituting equations (6) and (12) into equation (18), productivity growth in steady state can be expressed as a function of the amount of research that has been done around the world:

$$g = g_i = \alpha_i r_i^{\gamma_r} + \sum_{n=1}^{M} \varepsilon_n^i \sum_{s=1}^{t} (1-\varepsilon_n^i)^{-(t-s)} \alpha_{ns} r_{ns}^{\gamma_r} \frac{T_{ns}}{T_{it}} \tag{19}$$

Since $T_{ns} = T_{nt}(1+g)^{(t-s)}$ and $r_{ns} = r_n \forall s$ in steady state, and taking into account that instantaneous diffusion within the country implies that $\varepsilon_{ii} = 1$, we can rewrite equation (18) as

$$g = \sum_{n=1}^{M} \varepsilon_{in} \alpha_n r_n^{\gamma_r} \sum_{s=1}^{M} \left(\frac{(1-\varepsilon_n^i)}{(1+g)} \right)^{-(t-s)} = \sum_{n=1}^{M} \varepsilon_n^i \alpha_n r_n^{\gamma_r} \frac{(1+g)}{g+\varepsilon_n^i} \frac{T_{nt}}{T_{it}} \tag{20}$$

With positive values for γ_r, α_n, ε_{in} and $r_n = \frac{R_n}{L_n}$, the Frobenious Theorem guarantees that we can obtain a value for the growth rate g and relative productivities $\frac{T_i}{T_n}$. A key feature of the equilibrium is that the growth rate in steady state depends on the investment in world R&D. There are two components of growth: domestic and foreign sources of R&D (equation (20)).

It is important to note that if there were no sources of heterogeneity in the world ($\alpha_i^R = \alpha^R$, $\alpha_i^A = \alpha^A$, $L_i = L$ and $d_n^i = d \ \forall i, n$) we would reach a steady state equilibrium with all the countries investing the same amount of labor into R&D and adoption, demanding the same amount of intermediate goods, and reaching the same level of income per capita.

[36] Jovanovic (2009) develops a model in which diffusion lags depend on income differences. In my case, differences in the rate of adoption determine dispersion in income per capita across countries.

5 Transitional Dynamics

Differences in growth rates across countries arise in the transition, and depend on differences in investment of innovation and adoption, which ultimately depend on differences in development. Countries in early stages of development have a lower cost to adoption relative to innovation, and as a result, invest more resources in adopting foreign goods. Catching-up then allows them to grow more than average. As they start importing more goods, the productivity of doing research increases through the spillover effect, and this reduces the gap between the costs of innovation and adoption. As a result, they start reallocating more resources into innovation.

Therefore, countries located in different points in the transition path invest and adopt at different rates, and as a consequence, grow at different rates. Rich countries are mainly innovators, and less developed countries are mainly adopting foreign innovations.

6 Empirical strategy

6.1 Bayesian Estimation

I estimate the model using Bayesian techniques. The methodology can be found in Schorfheide (1999). Dynare (Juillard 1996) is used to solve and estimate the model.[37]

6.2 Data and priors

To make the model more tractable, I group the sample of thirty-seven countries into five regions so that countries in the same region share common characteristics (similar innovation intensity, extensive margins of trade, and productivity): The United States, Japan, Western Europe, Eastern Europe and Asia.[38]

6.2.1 Data

The model is fitted to annual data for the period 1994-2003, since 1993 is the first year for which data at a high level of disaggregation became available for a large sample of countries. The observable variables of the model are the annual growth in imported varieties, data on output growth and the fraction of workers employed in R&D. There are one hundred

[37]The code is available upon request.

[38]The sample of countries included in each region is reported in the Appendix.

and thirty-five observations corresponding to nine years, five regions and three observable variables.[39]

Bilateral trade data are obtained from the UN COMTRADE database. I follow the HS-1996 classification, which contains goods at the 6-digit level of disaggregation, and restrict the analysis to intermediate products (the correspondent codes can be found in the appendix). Output is measured with GDP per capita PPP adjusted at constant prices of 2005 (the data come from the World Development Indicators in the World Bank). This measure is adjusted to account for the extensive margin of trade as I explain in appendix D. Finally, the research intensity of a country is measured by the fraction of workers that are allocated into research (data taken from the World Development Indicators in the World Bank.)

6.2.2 Shocks

In order to have invertibility in the likelihood function, the Maximum Likelihood approach requires as many shocks as observable variables. With three series of observable variables, I introduce three series of shocks, one for each region: a neutral technology shock, a_i in final production, an i.i.d shock to innovation productivity, a_{it}^{α}, and a measurement error to the growth rates of imported varieties.

The structural shocks and measurement errors incorporated in the estimation are

$$a_{it} = \rho_i a_{i,t-1} + u_{it}$$

with $u_{it} \sim N(0, \sigma_{u,i}^2)$

$$\xi_{it} \sim N(0, \sigma_i^2)$$

$$g_{it}^{obs} = g_{it} e^{me_{it}}$$

with $me_{it} \sim N(0, \sigma_{me,i}^2)$

where me is the measurement error and $i = 1 \ldots 5$.

6.2.3 Parameters

A set of parameters is treated as fixed in the estimation (also called strict priors or calibrated parameters). These parameters cannot be identified from the data. They are reported in

[39] DSGE models that are estimated with Bayesian techniques usually have a long time series for one or two countries. In my case, I have a cross-section dimension, as I have a short time series sample for five regions.

table 2; they are obtained from other studies or from steady state relations.

The iceberg transport cost, d_n^i varies across pairs of countries and is proportional to distance. The value is chosen to match the intensive margin of trade.

As in Greenwood, Hercowitz, and Krusell (1997), $\bar{g}$ is chosen so that disembodied growth in steady state represents 40% of the growth of income per capita in equilibrium, which is 2% (this is the growth rate of the US and rich OECD countries, which are close to the steady state). That implies a value for $\bar{g}$ of 0.8%. While their analysis is for the US, we can assume the same value for all the regions in steady state, since technology diffusion guarantees that embodied productivity growth in steady state is the same across countries.

The productivity of the innovation process α_i^R, is set to satisfy equation (20). It is obtained by iteratively estimating the model, using the steady state variables and finding new values for α_i^R until the point at which we obtain embodied productivity growth of 1.2%. The results show that Asia and Eastern Europe have the lowest productivity of innovation, while the US and Japan are the most productive.

The parameters to be estimated are the elasticity of substitution across intermediate goods, σ, the elasticity of adoption, γ_a, the extent of diminishing returns in the innovation process, γ_r, the cost of adoption, α_i^A, and the standard deviations, σ_i, of the neutral technology shock and productivity of innovation shocks. The prior mean and standard deviation for the parameters are reported in tables 3 and 4.

I assume a beta distribution for the elasticity of substitution across intermediate goods, with mean 3 and standard deviation 0.05. The prior for the cost of adoption in each region, α_i^A is distributed Gamma with mean 2 and standard deviation 0.15. The mean is set to match the hazard rates in table 1, which determine the rate of adoption. The prior for the diminishing returns in the innovation process, γ_r, is set to a beta distribution with mean 0.1 and standard deviation 0.15 (Eaton and Kortum (1999) find a value for this parameter around 0.2, while Griliches (1990), using the number of new patents as a proxy for technological change, obtains estimates between 0.5 and 1). The elasticity of adoption with respect to effort γ_a, is assumed to follow a Beta distribution with mean 0.4 and standard deviation 0.05.[40]

[40] This parameter has been calibrated by Comin and Gertler (2006) and Comin, Gertler, and Santacreu (2009), who find that a reasonable value in a closed economy model is 0.8. Since there are not any good measures of adoption expenditures or adoption rates, they use as a partial measure the development costs incurred by manufacturing firms to make the goods usable (this is a subset of R&D expenditures). Then, they regress the rate of decline of the relative price of capital with respect to the partial measure of adoption costs. The idea is that the price of capital moves countercyclically with the number of new adopted technologies,

Finally, I assume an Inverse Gamma distribution for the standard deviation of the shocks, which guarantees a positive variance.

6.3 Estimation results

Tables 3 and 4 report the results from the estimation. The table contains the prior and posterior mean of the estimated parameters as well as 95% confidence intervals.

The posterior mean for the elasticity of substitution across intermediate goods is 3.5. Broda, Greenfield, and Weinstein (2008) estimate that the median elasticity of substitution for a sample of 73 countries is 3.4. The value that I obtain lies between the value obtained in microeconomic models and the value obtained in macroeconomic models.

The posterior mean for the adoption costs, reported in table 4, lies between 1.7 and 2. It does not follow a particular pattern across regions. These figures can be used to compute the probability of adoption predicted by the model, ε_{nt}^{i}. The average probability of adoption for the period 1994-2003 is presented in the last column of table 5. The results imply that the average time that it takes for a country to be able to use an intermediate good developed elsewhere, the inverse of the probability of adoption, lies between two and ten years.

The posterior mean for the elasticity of innovation γ_r, is 0.025, closer to the results in Eaton and Kortum (1999), and much lower than in Griliches (1990). Finally, the elasticity of adoption is estimated to be 0.45. This parameter has previously been estimated in a closed economy by Comin and Gertler (2006), where they find a value of 0.8. The lower value for α_A implpies that the elasticity of adoption is lower in an open economy than in a closed economy, suggesting that countries need to invest more resources in adoption to import a foreign than a domestic good.

6.4 How well does the model fit the data?

This section analyses the fit of the model, by comparing several variables for which we can find a counterpart in the data: the rate of adoption, and several moments relating growth in imports, R&D intensity, and GDP per capita growth.

The rate of adoption has been computed in section 2. The estimated value is computed by simulating the model using the value of the parameters and the series of shocks from the estimation. The results are reported in table 5.

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and therefore is the measure of embodied adoption. The regression yields a constant of 0.8.

Overall, the model captures the average adoption probability for the five regions. In the data and in the model, the lag lies between three and ten years on average, and the US and Japan tend to have the highest rates. Other studies that have quantifyed the speed of adoption are Eaton and Kortum (1999) and Comin and Hobijn (2004). The first uses international patenting data to measure international diffusion, while the second uses direct measures of technology for many countries and a long period of time. To my knowledge, my paper is the first to estimate hazard rates of adoption using trade data.

I now compare several moments in the data and the model. Using the estimated parameters and standard deviations of the shocks, I run 1000 draws from the shocks in the model, and compute the correlations between growth in imports and real GDP per capita growth, R&D intensity and real GDP per capita growth, and R&D intensity and growth in imports. The results are reported in table 6. As in the data, R&D and trade are negatively correlated across countries; the same is true for R&D and productivity growth. Countries that invest less resources in doing R&D are also importing and growing at higher rates, since they benefit from lower costs of adoption to innovation, and catching-up. The model also captures the positive correlation between growth in imports and GDP per capita, as countries that have expanded imports are also growing faster. Not only the model captures the signs in the relations, but also the magnitudes. In the data, the correlation between growth and trade is 0.6, while the model predicts a correlation of 0.7. In the case of R&D and trade, and R&D and growth, the correlations in the data are -0.32 and -0.28, respectively, while the model predicts a correlation of -0.21 and -0.31.

7 Decomposition of productivity growth

7.1 Embodied versus Disembodied productivity

Economic growth in the model can be decomposed in embodied growth, captured by an expanison in the number of intermediate goods, and disembodied growth, captured by an exogenous TFP shock.[41] Taking the estimated series of the TFP shock, and data on output growth from the empirical analysis, I compute the contribution of both sources of growth. Table 7 reports the results.[42]

[41] Think of this TFP shock as capturing all sources of growth not explained by love-for-variety. In that sense, we could consider this section as an empirical test for the love-for-variety models.

[42] The numbers represent averages over the period 1994-2003. Note that for the case in steady state, I had calibrated disembodied technology to represent 60% of productivity growth in the country, as in Greenwood,

Embodied growth has contributed to around 80% productivity growth in Asia and Eastern Europe, while it has contributed to two thirds of total growth in the the US, Japan and Western Europe. These numbers suggest that rich countries are closer to the steady state values found by Greenwood, Hercowitz, and Krusell (1997). In developing countries, however, growth is mainly driven by transitional dynamics.

7.2 Contribution of domestic and foreign sources of innovation to growth

Table 11 reports the contribution of domestic and foreign sources of innovation into embodied productivity growth. The rows represent the destination-country (importer), and the columns represent the source-country (exporter). Each entry in the matrix contains the percentage of the embodied productivity growth in each row that is explained from technologies developed in each column, averaged over the period 1994-2003. The elements in the diagonal, in bold numbers, measure the contribution of domestic sources of innovation.

The results show that more than 80% of embodied growth in Asia (which given the results from the last section, corresponds to 64% of total growth) can be explained by foreign innovations embodied in imports, especially from the US, Japan, and Western Europe. These regions have by far the highest percentage of growth accounted for by domestic innovation, with around 30% of embodied productivity coming from its own innovative effort. The results are consistent with the empirical evidence: Asia does relatively little research, but has experienced a rapid increase in imported varieties, especially from the US and Japan, which are the most innovative regions.

The results off the diagonal in table 11 can be further decomposed to obtain the ocntribution of each exporter. Table 11 reports the results. Around two thirds of the contribution of foreign sources of innovation in Europe and Asia proceed from Japan and the US. Asia and Eastern Europe's innovations only contribute around 10% to embodied productivity growth in the other regions.

Note that to obtain the results in tables 11 and 11, I have used data on research intensity as a measure of innovation, but not data on the number of exported products. In table 10, I compute the same decomposition using data on exported varieties, at the bilateral level. Table 10 reports the percentage of each importer's total imports that is explained by each exporter. The results are qualitatively very similar to the ones in which only innovation data

Hercowitz, and Krusell (1997).

were used. In Asia, 4% of total imports in varieties comes from less innovative countries in Europe. The US and Japan together represent more than 50% of imported varieties in each region. Asia and less innovative EU contribute the least. By comparing the results in tables 11 and 10, the assumption that R&D is embodied in exports seems a plausible one, since the main exporters are the main innovators and both foreign innovation and exports from these countries have the largest impact in embodied growth of developing countries.

8 Speed of convergence: Where will the world be in the long run?

This section shows how long it will take for each region to reach the levels of income per capita of the US. To do that, I use the estimated value of the structural parameters and the standard deviation of the shocks, and simulate the model for 1000 periods.

Table 11 reports . Asia's income per capita in 1995 was 25% of the income per capita in the US. At the other extreme lies Japan, with 80% of the US income. Europe lies in the middle: Eastern Europe is closer to Asia and Western Europe is closer to Japan.

The first and third columns in table 10 show how close each region will get to the technology frontier once they reach half life to the new steady state. Asia will improve its position by 72% and it will take 80 years. Japan, which is closer to the US, only improves by 5% and it takes 35 years. Countries that lag behind (Asia and Eastern Europe) take longer to get closer, but their improvement is higher. The gap is reduced at a lower rate the closer countries get to the steady state, as convergence predicts.

Note that the technology frontier is moving forward due to investment in innovation in every country. In steady state, countries close the gap, but there is not complete catching up in levels of income per capita. This can be explained by differences in policies and institutions, which are reflected in country specific parameters of innovation, and adoption.[43]

9 Counterfactuals

I perform two experiments to show how changes to the parameters of innovation and adoption can explain the connections between trade and growth. The experiments have implications

[43] This fact was already observed by Klenow and Rodriguez-Clare (2005).

for world growth rates, research intensity, income per capita and the extensive and intensive margins of trade.

Starting from the steady state of the model, I introduce two policy changes:

- First, a 50% permanent decrease in the barriers to technology transfer in Asia, that is, an increase in $\alpha^A(Asia)$ in equation (7).
- Second, a 50% permanent increase in the productivity of innovation in Asia, that is, an increase in $\alpha^R(Asia)$ in equation (6).

I explore the transition path to the new equilibrium, and perform comparative statics between the two steady states in Asia, as the country incorporating the policy change, and the US, as the technology frontier. The two experiments lead simultaneously to higher trade and faster growth.

9.1 Counterfactual: Reduction in adoption costs in Asia by 50%

9.1.1 Steady State

Table 12 presents the comparative statics for the key variables.

A 50% reduction in the cost of adoption in Asia increases world growth rates by 0.7%.

Research intensity is higher in the new steady state. Asia benefits from the 'spillover effect' in equation (6), and experiences a 2.3% increase in the intensity of innovation. This results in a higher diversification of exports in the region. The US benefits from a 'demand effect', as the higher ability to adopt goods in Asia increases the demand for imports, especially from Japan and the US, who are the main exporters. The positive 'demand effect' increases the present discounted value of future profits from selling a good abroad, which increases the market price for an innovation and, ultimately, research intensity of the exporters.

The extensive margin in Asia increases for two reasons. First, a higher probability of adoption raises imports.[44] Second, higher imports increase the productivity of innovation, through the 'spillover effect' and this increases domestic innovation. This is in line with what Goldberg, Khandelwal, Pavcnik, and Topalova (2009) found when analysing trade liberalization in India. Lower trade costs increase imports of inputs, and the scope of products.

[44] The probability of adoption in Asia increases for two reasons: directly, from an increase in $\alpha^A(Asia)$; indirectly, first, from an increase in the investment in adoption, H^i_{nt} and, second, from an increase in the proportion of new goods that Asia imports from the US, $\frac{A^i_{nt}}{Z_{nt}}$.

In summary, Asia closes the distance with respect to the US, both in the number of varieties that it produces domestically, and in the proportion of goods that it adopts from the technology frontier. This catching-up effect translates into an increase in the relative wage of Asia with respect to the US by 70%. In the new steady state, growth rates are constant and common across countries. However, there is still a gap in levels of income per capita, due to differences in the country-specific parameters. There is convergence in growth rates but not of levels.

9.1.2 Transitional Dynamics

Figure 5 represents the transition path to the new steady state.

In the first panel of figure 5, we see that the research intensity in Asia (solid line) decreases upon impact. There is an initial reallocation of resources away from research, and into adoption. As a result, Asia starts importing more varieties, and the extensive margin of trade increases. After some periods, the 'spillover effect' kicks in, increasing the productivity of innovation in the region. Research intensity goes up and reaches a higher level in the new steady state.

A higher value of $\alpha^A(Asia)$ implies that the value to adopt new technologies and therefore investment in adoption, increases. This occurs at the intensive and extensive margins of trade (solid and dashed line in the first panel): Asia imports more goods and more of the same goods. At the same time, this positive 'demand effect' increases investment in innovation in the US (dashed line in the first panel).

Eventually, Asia becomes closer to the US, through an increase in both imported and domestic varieties and although the gap gets smaller, wages remainl higher in the US (fourth panel).

This experiment generates both higher trade and faster growth. Note that the results are consistent with what Goldberg, Khandelwal, Pavcnik, and Topalova (2009) find. There are static gains from trade because countries benefit from access to new intermediate inputs, but there are also dynamic gains from trade because adoption enables countries to innovate more.[45]

This scenario seems to match the data. During the transition, rich countries allocate more resources into R&D, while less advanced countries adopt foreign innovations and this translates into more growth. However, Asia still lies behind the US in levels of income per

[45] Arkolakis, Klenow, Demidova, and Rodriguez-Clare (2008) show that depending on the curvature of the CES function, after a trade liberalization, innovation could be higher, lower or remain constant.

capita, due to the initial differences caused by country-specific parameters. Adoption alone is not sufficient to completely close the gap.

9.2 Counterfactual: Increase in productivity of innovation in Asia

9.2.1 Steady State

Table 13 presents the results of this exercise.

A 50% increase in the productivity of innovation in Asia increases world growth rates by 3%.

Research intensity in the new steady state is higher in Asia, but lower in the US. Higher productivity of innovation reduces the cost of doing research in the region, and after several periods the 'spillover effect' kicks in, and the cost of innovation decreases even more. The result is an 80% increase in research intensity. Note that higher productivity of innovation in Asia comes from both higher α^R and the 'spillover effect'. Both effects have a negative impact on research intensity in the trading partners. However, the negative effect is partially compensated by a higher demand, especially at the intensive margin, once Asia gets closer to the technology frontier.

Asia closes the distance with respect to the technology frontier, both in the number of varieties that it produces domestically, and in the proportion of goods that it adopts. Relative wages increase by 40%. As in the previous experiment, Asia does not fully close the gap with respect to the US. In fact, the increase in relative wages is lower than before. This suggests that, in early stages of development, adoption policies are more effective than innovation policies.

9.2.2 Transtional Dynamics

Figure 6 presents the transition path to the new steady state.

A higher $\alpha^R(Asia)$ decreases the cost of innovation; Asia starts reallocating resources away from adoption and into research. Thus, the demand for imports decreases initially, and this has a negative effect on research intensity in the US (the reason is a decrease in the market price for an innovation).

Asia starts producing new goods, and the domestic extensive margin increases. More innovation translates into more growth and more demand at the intensive margin. At this point, the demand for products from the US goes up (first panel in figure 6), and research intensity speeds up. However, this increase is not enough to compensate for the initial negative 'demand effect'.

In the transition, Asia closes the gap with respect to the leader through an increase in imported varieties (first panel) and an increase in innovations (first panel). Relative wages of the US decrease, but less than in the previous experiment. In early stages of development, adoption policies are more effective than innovation policies. However, once the country has built a certain level of technology, promoting innovation is necessary to keep growing.

10 Conclusions

The effects of trade on growth have been studied extensively in economics. However, there are still significant gaps in the literature. Both, the mechanisms and the magnitude by which countries benefit from each other's technologies through trade are not fully understood.

In this paper, I have proposed innovation, through the creation of new varieties, and diffusion, through adoption of foreign innovations, as a possible mechanism. In countries at an early stage of development, the relative cost of adoption to innovation is small. By adopting foreign innovations they benefit from a catching-up effect, and grow faster than average. As they move up in the transition path, they need to invest resources in innovation to keep growing, and expanding the technology frontier. In this explanation, technological progress derives from a love-for-variety effect, which captures embodied productivity growth. Other channels of growth are captured by an exogenous change that represents disembodied productivity.

The paper is one step forward in analysing the connections between trade in varieties and growth. It does not face the endogeneity problem of regression analysis, and the model is tractable enough to analyse the mechanisms outside of steady state. This is important to capture differences in growth rates across countries. It also provides the microeconomic mechanisms to explain how trade in varieties generates static (through an increase in previously unavailable inputs) and dynamic (through an expansion in the number of goods produced domestically) gains from trade.

After taking the model to data on innovation, productivity, and trade, I have shown that more than two thirds of growth in the last decade has been embodied growth. The percentage is even higher for Asia and Eastern Europe, which suggests that growth in these countries has been dominated by the transitional dynamics. Japan and the US, instead, are closer to the steady state. The empirical analysis also shows that regions at early stages of development benefitdfrom foreign innovations. Domestic innovation, instead, is more important in the US, Japan, and Western Europe. For countries that lag behind, the best option to get closer to the technology frontier, is to adopt foreign technologies through imports. As they become more developed, they need to innovate to keep growing.

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11 Tables and graphs

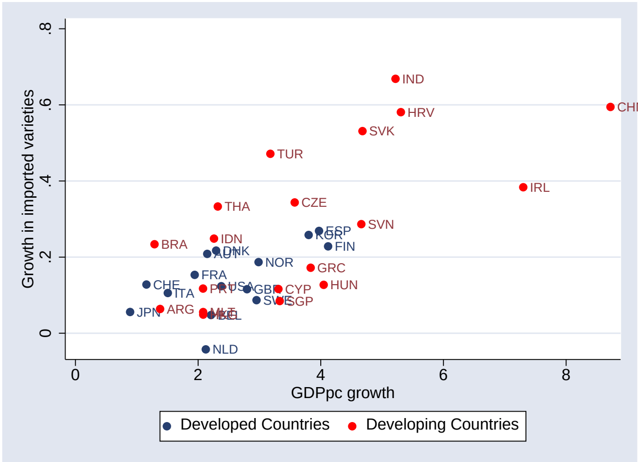

Figure 1: GDP per capita growth and growth in imported varieties (1994-2003)

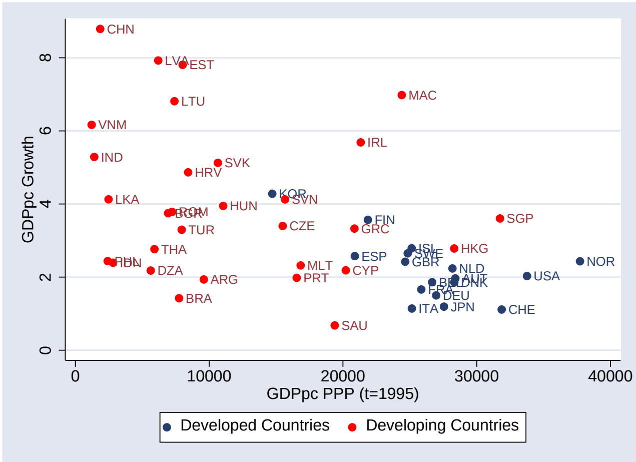

Figure 2: GDP per capita growth and initial level of GDP per capita (1994-2003)

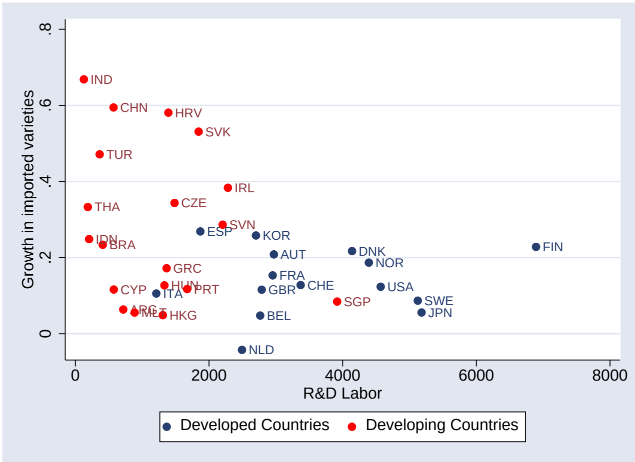

Figure 3: R&D intesity and growth in imported varieties (1994-2003)

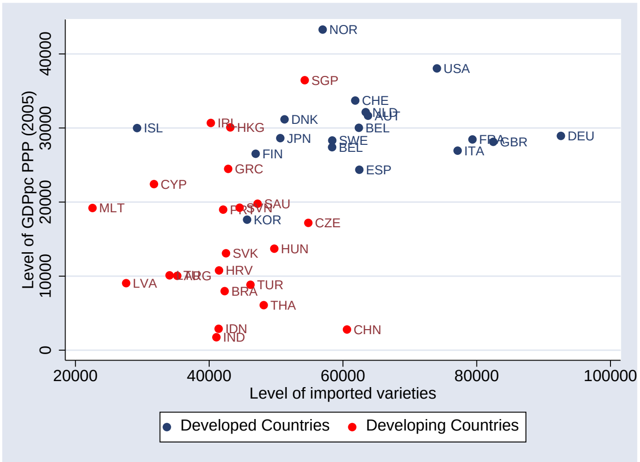

Figure 4: Level of GDP per capita and number of imported varieties (1994-2003)

Exporter	Importer	Hazard Rate
EU+	Asia	0.31
EU-	Asia	0.19
Japan	Asia	0.35
US	Asia	0.34
Asia	EU+	0.28
EU-	EU+	0.33
Japan	EU+	0.29
US	EU+	0.28
Asia	EU-	0.24
EU+	EU-	0.33
Japan	EU-	0.31
US	EU-	0.34
Asia	Japan	0.35
EU+	Japan	0.28
EU-	Japan	0.20
US	Japan	0.25
Asia	US	0.35
EU+	US	0.29
EU-	US	0.32
Japan	US	0.28

Table 1: Hazard rates of adoption

EU+ (Western Europe); EU- (Eastern europe); Japan (includes Korea)

Parameter	Value	Description
β	0.97	Discount factor
$d(Asia, EU-)$	1.30	Iceberg transport costs
$d(Asia, EU+)$	1.30	Iceberg transport costs
$d(Asia, Japan)$	1.10	Iceberg transport costs
$d(Asia, US)$	1.30	Iceberg transport costs
$d(EU-, EU+)$	1.05	Iceberg transport costs
$d(EU-, Japan)$	1.40	Iceberg transport costs
$d(EU-, US)$	1.30	Iceberg transport costs
$d(EU+, Japan)$	1.40	Iceberg transport costs
$d(EU+, US)$	1.30	Iceberg transport costs
$d(Japan, US)$	1.30	Iceberg transport costs
$\bar{g}$	0.02	Disembodied growth in steady state
$\alpha^R(Asia)$	0.0082	Innovation productivity
$\alpha^R(EU-)$	0.0186	Innovation productivity
$\alpha^R(EU+)$	0.0237	Innovation productivity
$\alpha^R(Japan)$	0.0288	Innovation productivity
$\alpha^R(US)$	0.0268	Innovation productivity

Table 2: Calibrated parameters

Parameter	Prior	Mean	5%	95%
σ	Beta(3, 0.05)	3.55	2.70	4.80
$\alpha^A(Asia)$	Gamma(2, 0.15)	2.11	1.86	2.33
$\alpha^A(EU-)$	Gamma(2, 0.15)	1.92	1.75	2.10
$\alpha^A(EU+)$	Gamma(2, 0.15)	1.90	1.70	2.13
$\alpha^A(Japan)$	Gamma(2, 0.15)	2.04	1.83	2.22
$\alpha^A(USA)$	Gamma(2, 0.15)	1.95	1.73	2.22
γ_a	Normal(0.4, 0.05)	0.45	0.33	0.53
γ_r	Beta(0.15, 0.10)	0.025	0.019	0.03

Table 3: Prior and posterior for the structural parameters

The number in parenthesis correspond to the mean and standard deviation

Parameter	Prior	Mean	5%	95%
$\sigma(Asia)$	IGamma(0.25,∞)	0.19	0.12	0.28
$\sigma(EU-)$	IGamma(0.25,∞)	0.20	0.14	0.27
$\sigma(EU+)$	IGamma(0.25,∞)	0.04	0.04	0.05
$\sigma(Japan)$	IGamma(0.25,∞)	0.04	0.04	0.04
$\sigma(US)$	IGamma(0.25,∞)	0.09	0.06	0.10
$\sigma^r(Asia)$	IGamma(0.25,∞)	0.83	0.66	0.96
$\sigma^r(EU-)$	IGamma(0.25,∞)	0.58	0.55	0.62
$\sigma^r(EU+)$	IGamma(0.25,∞)	0.29	0.28	0.29
$\sigma^r(Japan)$	IGamma(0.25,∞)	0.52	0.44	0.61
$\sigma^r(US)$	IGamma(0.25,∞)	0.31	0.30	0.32
$me(Asia)$	IGamma(0.025,∞)	0.66	0.52	0.81
$me(EU-)$	IGamma(0.025,∞)	0.54	0.40	0.80
$me(EU+)$	IGamma(0.025,∞)	0.81	0.78	0.84
$me(Japan)$	IGamma(0.025,∞)	0.79	0.43	1.10
$me(US)$	IGamma(0.025,∞)	0.62	0.59	0.65

Table 4: Prior and posterior for the shock processes

Exporter	Importer	Hazard rate (data)	Hazard rate (model)
EU+	Asia	0.31	0.22
EU-	Asia	0.19	0.24
Japan	Asia	0.35	0.21
US	Asia	0.34	0.19
Asia	EU+	0.28	0.27
EU-	EU+	0.33	0.26
Japan	EU+	0.29	0.23
US	EU+	0.28	0.20
Asia	EU-	0.24	0.20
EU	EU-	0.33	0.18
Japan	EU-	0.31	0.26
US	EU-	0.34	0.24
Asia	Japan	0.35	0.26
EU+	Japan	0.28	0.23
EU-	Japan	0.20	0.25
US	Japan	0.25	0.21
Asia	US	0.35	0.29
EU+	US	0.29	0.26
EU-	US	0.32	0.28
Japan	US	0.28	0.25

Table 5: Hazard rates of adoption (data and model): MSE=0.01

Correlation	Model	Data
(R&D, Trade)	-0.21	-0.32
(Growth, Trade)	0.70	0.60
(Growth, R&D)	-0.31	-0.28

Table 6: Comparison of unconditional moments: model versus data

Region	Embodied	Disembodied
Asia	80	20
EE	72	18
WE	67	33
Japan	63	37
US	68	32

Table 7: Embodied vs disembodied productivity growth in the transition (in percentage)

To—From	Asia	EU-	EU+	Japan	US
Asia	**11.2**	14.6	21.0	28.4	24.9
EU-	5.6	**21.4**	24.9	25.0	23.0
EU+	5.9	17.6	**27.5**	25.5	23.5
Japan	6.7	15.0	21.1	**32.7**	24.5
US	6.4	15.0	21.2	26.6	**30.8**

Table 8: Sources of growth predicted by the model: domestic and foreign innovation (Columns (exporter); rows (importer))

To—From	Asia	EU-	EU+	Japan	US
Asia		16.4	23.6	32.0	28.0
EU-	7.1		31.7	31.9	29.3
EU+	8.2	24.3		35.2	32.4
Japan	10.0	22.2	31.4		36.4
US	9.2	21.7	30.7	38.4	

Table 9: Foreign Sources of Growth: bilateral contribution predicted by the model (Columns (exporter); rows (importer))

To—From	Asia	EU-	EU+	Japan	US
Asia		4.1	19.2	36.3	40.4
EU-	9.3		37.1	15.9	37.6
EU+	14.3	15.5		22.9	47.4
Japan	20.0	5.4	22.6		51.9
US	20.9	10.9	31.1	37.1	

Table 10: Foreign Sources of Growth: bilateral contribution in the data (Columns (exporter); rows (importer))

Region	Years to convergence	Relative income pc (1995)	Improvement
Asia	80	25%	72%
Eastern europe	60	26%	60%
Western Europe	50	69%	50%
Japan	35	80%	35%
US	Baseline	Baseline	Baseline

Table 11: Speed of Convergence

Variable	% change
$\Delta r(Asia)$	2.3%
$\Delta r(US)$	2.6%
Δg^*	0.7%
$\Delta \frac{\omega(Asia)}{\omega(US)}$	70%
$\Delta fracZ(Asia)Z(US)$	11%
$\Delta \frac{A_{US}^{Asia}}{Z_{US}}$	10%

Table 12: Reduction in adoption barriers in Asia: Steady State Comparison

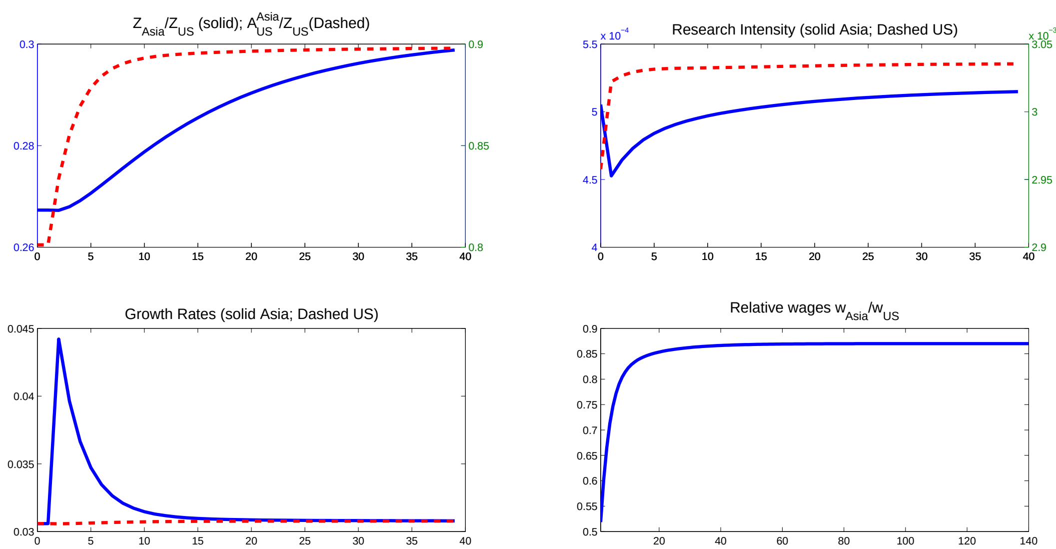

Figure 5: Permanent reduction in barriers to adoption in Asia

Variable	% change
$\Delta r(Asia)$	88%
$\Delta r(US)$	-3%
g^*	3.2%
$\frac{\omega(Asia)}{\omega(US)}$	40%
$\Delta\frac{Z(Asia)}{Z(US)}$	37%
$\Delta\frac{A_{US}^{Asia}}{Z_{US}}$	2%

Table 13: Increase in innovation productivity in Asia: Steady State Comparison

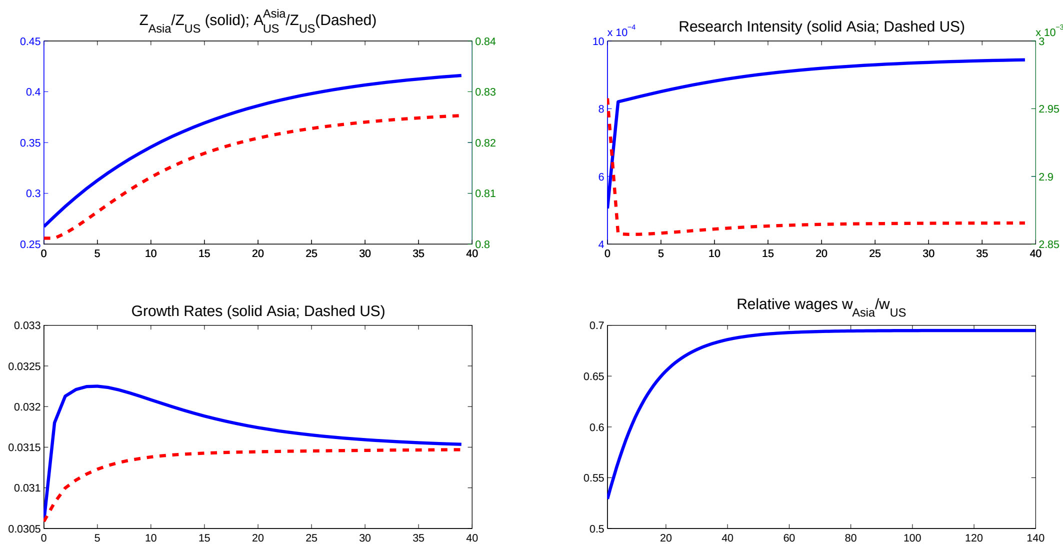

Figure 6: Permanent increase in innovation productivity in Asia

12 Appendix A: Data

Country	GDPpcgrowth	Varietygrowth	Researchers	GDPpc(1995)
Austria	1.94	0.03	2.72	28401.87
Belgium	1.93	0.16	2.89	26668.76
Bulgaria	2.17	0.83	0.56	6924.32
China	8.13	0.55	0.42	1853.45
Cyprus	2.39	0.71	4.05	20212.69
Denmark	2.03	0.30	2.21	28323.68
Estonia	6.16	0.85	6.65	7911.48
Finland	3.38	0.40	2.95	21865.56
France	1.75	0.03	3.10	25856.33
Germany	1.38	0.04	1.26	26970.08
Greece	2.88	0.24	1.32	20861.02
HK	1.79	0.59	1.32	27175.87
Hungary	3.87	0.26	0.10	11048.27
India	4.20	1.96	0.21	1403.71
Indonesia	1.78	1.93	2.28	2815.82
Ireland	6.54	0.34	2.28	21328.97
Italy	1.52	0.01	1.19	25151.35
Japan	0.72	0.13	5.17	27551.29
Korea	4.37	0.28	2.70	14716.83
Latvia	6.04	1.22	1.33	6190.58
Lithuania	4.28	1.20	2.17	7402.13
Malaysia	2.81	1.11	0.28	9296.93
Malta	2.69	1.46	0.70	16839.78
Netherlands	2.21	0.47	2.53	28186.20
Philippines	1.78	1.19	0.05	2415.27
Poland	4.53	0.41	1.48	8836.75
Portugal	2.26	0.20	1.65	16543.51
Romania	2.45	0.69	1.06	7223.41
Singapore	3.08	0.43	3.89	30922.08
Slovakia	3.99	0.54	1.86	10651.25
Slovenia	3.74	0.15	2.32	15410.37

Country	GDPpcgrowth	Varietygrowth	Researchers	GDPpc (1995)
Spain	2.75	0.08	1.78	20887.66
Sweden	2.56	0.15	4.85	24843.19
Thailand	2.39	0.50	0.22	5907.27
UK	2.72	0.05	2.99	24555.60
USA	2.04	0.07	4.50	33759.57
Vietnam	5.78	1.79	0.16	1214.14
Asia	3.53	1.12	0.98	9222.73
EU less R&D	3.64	0.57	1.91	13963.97
EU more R&D	2.21	0.18	2.83	26185.70
Japan	2.55	0.20	3.94	21134.06
USA	2.04	0.07	4.50	33759.57

13 Appendix B: Country List

Bloc	Country Code	Country Name
Africa	SAU	Saudi Arabia
Asia	CHN	China
Asia	HKG	China, Hong Kong SAR
Asia	IDN	Indonesia
Asia	IND	India
Asia	SGP	Singapore
Asia	THA	Thailand
Eastern Europe	CYP	Cyprus
Eastern Europe	CZE	Czech Rep.
Eastern Europe	GRC	Greece
Eastern Europe	HRV	Croatia
Eastern Europe	HUN	Hungary
Eastern Europe	IRL	Ireland
Eastern Europe	LTU	Lithuania
Eastern Europe	LVA	Latvia
Eastern Europe	MLT	Malta
Eastern Europe	POL	Poland
Eastern Europe	PRT	Portugal
Eastern Europe	SVK	Slovakia
Eastern Europe	SVN	Slovenia
Eastern Europe	TUR	Turkey
Japan	JPN	Japan
Japan	KOR	Rep. of Korea
LatinAmerica	ARG	Argentina
LatinAmerica	BRA	Brazil
United States	USA	USA
Western Europe	AUT	Austria
Western Europe	BEL	Belgium
Western Europe	CHE	Switzerland
Western Europe	DEU	Germany
Western Europe	DNK	Denmark

Bloc	Country Code	Country Name
Western Europe	ESP	Spain
Western Europe	FIN	Finland
Western Europe	FRA	France
Western Europe	GBR	United Kingdom
Western Europe	ISL	Iceland
Western Europe	ITA	Italy
Western Europe	NLD	Netherlands
Western Europe	NOR	Norway
Western Europe	SWE	Sweden

14 Appendix C: Product Classification

The codes are under the classification of Broad Economic Categories (BEC). There are three basic classes of goods in SNA in the categories of BEC. These are as follows:

1. Capital goods
Sum of categories: 41* Capital goods (except transport equipment) 521* Transport equipment, industrial
2. Intermediate goods
Sum of categories: 111* Food and beverages, primary, mainly for industry 121* Food and beverages, processed, mainly for industry 21* Industrial supplies not elsewhere specified, primary 22* Industrial supplies not elsewhere specified, processed 31* Fuels and lubricants, primary 322* Fuels and lubricants, processed (other than motor spirit) 42* Parts and accessories of capital goods (except transport equipment) 53* Parts and accessories of transport equipment
3. Consumption goods
Sum of categories: 112* Food and beverages, primary, mainly for household consumption 122* Food and beverages, processed, mainly for household consumption 522* Transport equipment, non-industrial 61* Consumer goods not elsewhere specified, durable 62* Consumer goods not elsewhere specified, semi-durable 63* Consumer goods not elsewhere specified, non-durable

Table 16: Classification of goods according to BEC

15 Appendix D: Measuring Real GDP

The measure of real GDP used in the empirical analysis has been computed to account for the effect of differences in the terms of trade across countries and the extensive margin of trade in the price of imported intermediate goods.

As recently argued by Feenstra, Heston, Timmer, and Deng (2009), the World Development Indicators and Penn World Table (PWT) measure of real GDP represents the ability of a country to purchase goods and services by a representative agent in the economy. But this interpretation of real GDP is different from the interpretation done in growth analysis, which use it as a measure of productivity. To compute real GDP from the output side, Feenstra, Heston, Timmer, and Deng (2009) correct the PWT measure for differences in the terms of trade across countries. The difference between both reflects the trading opportunities that countries have (their terms of trade as measured by their ratio of export prices to import prices), and it is shown that, empirically, the differences can be substantial, especially for small open economies.

To make the meausre of real GDP growth from the output side comparable with real GDP in my model, we need to adjust for the extensive margin of imports.To do that, I use the procedure followed in Broda, Greenfield, and Weinstein (2008). The difference between the adjusted and unadjusted calculations gives a measure of the impact of product variety in trade on productivity, or the gains from trade due to product variety.

16 Appendix E

I use the tools of survival analysis (or duration analysis) with censored data. I estimate a non-parametric survival function (using the Meier Kaplan estimator with right-censored data). Ideally, we would need to know the time at which each good is invented by the exporter and the time at which is first imported by each destination. There are several limitations in the data. First, I do not observe the time of invention. I assume that this is given by the first time a source starts exporting a good to any country. There are left and right censoring in the data. There is left-censoring because, for those products that are exported in 1994, we do not know if they were invented in that year or earlier. There is right-censoring because some importers have not adopted, before 2003, all the goods that are exported. It is easy to fix the right-censoring problem, but dealing with left censored data is more problematic. It is straightforward to handle if we assume that the hazard rate does not vary with survival time. The standard way of handling left-censoring is to drop the spells that started before the window of observation.