Innovation, Diffusion and Trade: Theory and Measurement*

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Abstract

In the last decade, some countries in Asia and Europe grew much faster than average, and experienced a significant increase in the variety of goods that they import. A well known stylized fact is the existence of a positive correlation between trade and growth across countries. However, the mechanisms by which these two variables are connected are not well understood. I propose a general equilibrium model of innovation and international diffusion to analyse these connections. Technological progress drives growth and technology is embodied in new goods, which diffuse internationally through trade. The model is analysed outside the steady state, to capture differences in growth rates across countries. Using disaggregated trade data, and data on R&D, and output growth, I estimate the parameters of innovation and diffusion with Bayesian techniques. Finally, I carry out counterfactual analysis to examine the connections between trade and growth by changing various exogenous parameters. A 50% permanent decrease in the barriers to technology adoption in Asia increases world growth rates by around 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%. The higher productivity in Asia increases the demand for imports from the rest of the world. Either change leads simultaneously to both higher growth and more trade.

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1 Introduction

A well known stylized fact in the development literature is the existence of a positive correlation between trade and growth across countries. Economies that grow faster tend to trade faster. In the last decade, some countries in Asia and Europe, such as China, India, and Ireland, grew much faster than average, and experienced a significant increase in the number of varieties that they imported.[1] Motivated by the empirical evidence, recent studies have emphasized the impact that imports in new goods have in explaining productivity growth around the world. However, the mechanisms by which these two variables are connected are still not well understood.

I propose a multicountry model in which shocks to innovation and adoption can explain the mechanisms behind the connections that we observe in the data. The model is developed in a general equilibrium framework, with trade and growth being outcomes of the equilibrium.

Models of growth based on innovation and technology transfer face the problem that there are no good measures of diffusion. The trade literature has filled this gap, using imports as an indirect measure.[2] However, studies that quantify the impact of imports on growth are based on regression analysis that suffer endogeneity problems, since these two variables are both equilibrium outcomes.[3] A recent attempt to give a more structural approach is the paper by Broda, Greenfield, and Weinstein (2008), who analyse the impact of trade in new and improved varieties on TFP growth for a large sample of countries. Although they provide a good measure of trade in varieties, their model is too stylized to make precise statements about the channels of growth. My paper constitutes an attempt to structurally analyse and quantify the mechanisms behind the connections between trade and growth, in which both are endogenous variables.

In the model, technology is embodied in new intermediate goods that result from domestic innovation. Countries also benefit from technology embodied in foreign innovations, by adopting them through trade. A novel element of my framework is

[1]Santacreu (2006) obtains that more than 60% of the economic growth in Ireland in the last decade can be explained by an increase in the variety of goods that it imports from very innovative countries in the OECD.

[2]See Keller (2004) for a survey of models that use imports to measure diffusion.

[3]Coe, Helpman, and Hoffmaister (1997) and Keller (1998) are good examples.

the fact that innovation and adoption are both endogenous processes. This introduces a trade-off by which countries decide how many resources to allocate to one activity or the other. This decision depends on the stage of development, and country-specific parameters.

International diffusion implies that, in steady state, all countries grow at the same rate; barriers to technology adoption create persistent income differences across countries.[4] So far, models of innovation and diffusion have been analysed in steady state, restricting their attention to explaining differences in income per capita across countries. To analyses differences in growth rates, however, we need to look at the transition. In this paper, I go one step further and solve the model outside the steady state. This allows me to account for the experience of countries such as China or India, which have been growing faster than average but are likely to share the same world growth rates in the long-run.

The model is fitted to thirty-seven countries that are grouped, for tractability, into five regions: Asia, Eastern Europe, Western Europe, Japan, and the US. Each region is treated as a different country. I use disaggregated trade data, data on a measure of the fraction of workers allocated to R&D, and output growth to estimate the parameters that govern innovation and diffusion with Bayesian techniques. I then decompose the sources of productivity growth in each region. The results show that almost 90% of productivity growth in Asia can be explained by imports from the US and Japan. These two regions are also the main sources of foreign technology for other regions of the model. The results suggest that technology transfer through trade is an important source of productivity growth for countries lagging behind the technology frontier. Domestic innovation, instead, is the main source of growth for economies that are closer to the frontier.[5]

[4]See Parente and Prescott (1994) and Eaton and Kortum (2007), and Easterly and Levine (2001). There has been an extensive literature trying to identify whether differences in growth rates are driven mainly by factor accumulation (capital, in particular) or by TFP differences. An example is Young (1991). As a response to this literature, 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. Even though capital accumulation has been important in several Asian economies, TFP growth affects the marginal rate of capital and it could explain why the rental rate of capital was so high in these countries.

[5]Cameron, Proudman, and Redding (2005) analyse a model for a panel of UK manufacturing

Finally, using counterfactuals I examine the connections between trade and growth by changing various exogenous parameters. A 50% permanent decrease in the barriers to technology adoption in Asia increases world growth rates by 1%; in the transition to the new steady state, trade rises, while Asia grows faster than the rest of the world. A 50% permanent increase in the innovation productivity in Asia increases 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 trade and growth.

The rest of the paper is organized as follows. Section 2 presents the related literature. In section 3 I examine the data. In section 4, I present the model. Section 5 solves for the steady state. The model is estimated in section 6 and I present a decomposition of the growth rate of each country into the contribution of own and foreign innovation in section 7. In section 8, I compute the speed of convergence predicted by the model. I perform counterfactuals in sections 9. Section 10 concludes.

2 Related Literature

The paper builds on several literatures: First, the literature on endogenous growth in which technology is embodied in new goods. Technological progress is driven by the introduction of new types of intermediate products through innovation, as in Romer (1987)

Second, the model relates to the literature on innovation and technology diffusion. The theoretical model is inspired in the work of Eaton and Kortum (1996) and Eaton and Kortum (1999). From an empirical perspective, Keller (2004) surveys the empirics of the effects of international diffusion on productivity. The lack of direct measures that can exploit the bilateral nature of adoption have led some economists to use indirect measures, such as trade in intermediate goods (Rivera-Batiz and Romer (1991), Eaton and Kortum (2001), and Eaton and Kortum (2002)).[6] Countries benefit

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.

[6] Comin and Hobijn (2004) provide direct measures of adoption for a large sample of countries

from technologies developed elsewhere by importing the products that embody the technology. Coe, Helpman, and Hoffmaister (1997) studied empirically the role of trade as a measure of diffusion. They find that total factor productivity in a panel of seventy-one developing countries is significantly related to the stock of R&D carried out by trading partners. In their analysis, trade, particularly the imports of machinery and equipment, facilitates the diffusion of knowledge. My model complements this literature by explicitly modeling the mechanisms that explain how trade and growth are connected.

The paper also relates to the literature of trade in varieties. A variety is defined as a 6-digit category product from a particular source-country, reflecting the Armington assumption that products differ according to their source. It is important to note that the Armington assumption implies that each country produces a different variety. Therefore, a country that imports a good can never learn to produce, exactly, that good itself. To measure growth in imported varieties, I follow the methodology developed by Feenstra (1994) and adapted by Broda and Weinstein (2006) and Broda, Greenfield, and Weinstein (2008). In a recent paper, Broda, Greenfield, and Weinstein (2008) estimate the effects of trade on productivity growth. They find that trade in imported varieties accounts for 20% of TFP growth in the typical developing country and only 5% in the typical developed country. My paper follows Broda, Greenfield, and Weinstein (2008) to measure growth in varieties but differs in that I model explicitly the incentives of the different agents in the economy to undertake either research or adoption.

Finally, and in contrast to previous studies in the literature, I model technology diffusion as an endogenous process: firms need to undertake a costly investment to be able to import a good. The incentives for the importer differ across sources and depend on the value of adopting a new technology. I adapt the approach in Comin and Gertler (2006) and Comin, Gertler, and Santacreu (2008) to an open economy setting. 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).

and a large sample period; they do not distinguish, however, between technologies created in the country and those from abroad.

3 A Look at the Data

This section presents data on innovation, trade, and productivity for a sample of 37 countries. Based on these data, we can divide the world in three groups of countries: first, very innovative rich economies in Europe, Japan, and the US, which grow and import at lower rates; second, less innovative countries in Europe and Asia, which grow and trade fast; third, less developed countries in Africa and Latin America, which do not invest either in innovating or in adopting.

3.1 Trade and Productivity Growth

In the last decade, some countries in Asia and Europe have experienced a significant increase in the variety of goods that they import from the rest of the world. These countries have also been growing faster than average.[7] Figure 1 shows that there is a positive correlation between the average growth rate of income per capita and the variety of imports, in a sample of thirty-seven countries.[8]

Countries that have been growing and importing fast have relatively low levels of income per captita. This evidence suggests that there is a catching-up effect of thos economies that invest in expanding their variety of imports.[9] Figure 2 plots the average growth rate for the period 1994-2003 against the initial level of GDP per capita in 1994. There is a clear positive correlation between these two variables.

If we look at productivity levels, rather than growth rates, figure 4, we observe that rich countries import a higher variety of goods than less advanced economies. The average level of imports and the average level of income per capita are positively correlated. Thus, one part of the technology of a country is composed by imports.

[7]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 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.

[8]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.

[9]This catching-up effect does not apply to Africa and Latin America. These countries grow and import at negligible rates.

3.2 Diffusion and trade

One of the drawbacks of the diffusion literature is that there are not direct measures of adoption. The evidence that I have presented so far suggests that trade could be used as an indirect measure. In this section, I present some of the characteristics of the diffusion process in the last decade.

Consistent with theoretical models of adoption, I find that diffusion through trade is not an instantaneous process. In table 1, I report the hazard rate of adoption over the period 1994-2003, for a sample of 37 countries that are grouped in five regions.[10] The inverse of the hazard rate represents the average time that it takes, for each importer, to adopt goods from each exporter.[11] The table shows that the average diffusion lag has been between three and ten years.

3.3 Innovation and productivity

In the last decade, a common caracteristic of fast growing countries is that they do not invest a significant amount of resources in doing R&D. In fact, figure 3 shows that there is a negative correlation between R&D investment and growth in trade of varieties. While innovations are concentrated in a few rich countries, especially in Japan, the US, and Sweden, less innovative economies also grow, sometimes at a higher rate than their innovative counterparts.

If we look at levels of productivity, we see that there is a positive correlation between the level of income per capita in the countries and the amount of resources

[10]For a sample of the countries that are included in each regions, see the Appendix.

[11]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.

that they invest in R&D. Consistent with the development literature, one part of the domestic technology comes from investing resources in domestic innovation.

4 The Model

In this section, I construct an endogenous growth model of trade in varieties that captures the main features of the data. I consider a world economy composed of M countries that interact with each other through trade. Technology is embodied in new goods that are used for final production. As in Romer (1987), creation and adoption of new intermediate products are the source of embodied productivity growth.[12] I also introduce a residual that represents disembodied technological progress, as in Greenwood, Hercowitz, and Krusell (1997).

In each country there is a consumer that supplies labor inelastically, and consumes a non-traded final good. Each final product is produced using traded intermediate goods, which are introduced in the economy by investing resources in innovation and adoption of foreign innovations through trade. The model predicts that, in steady state, all the countries grow at the same rate and differ in relative productivity, depending on their ability to innovate and import goods. Differences in growth rates arise in the transition.

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

4.1 Preferences

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

$$\max U(C_t) = \sum_{t=0}^{\infty} \beta^t C_t$$
$$s.t. \sum \beta^t C_t = \sum \frac{Y_{it}}{(R)^t}$$

[12]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)

The FOC implies the relationship between the discount factor and the risk-free interest rate.

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

4.2 Final production sector

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

$$Y_{it} = e^{\bar{g}a_{it}} \left(\sum_{j=1}^{T_{it}} (b^i_{nj})^{\frac{1}{\sigma}} (x^i_{njt})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where $\sigma > 1$ is the elasticity of substitution among differentiated intermediate goods;[13] x^n_{ijt} is the amount of input j that is used in the production of final output; b^i_{nj} is a preference parameter that represents expenditure shares; and T_{it} is the total number of varieties available for final production in country i at time t.[14] It is a measure of embodied technology and it includes both domestic and foreign adopted intermediate goods. Finally, a_{it} captures country-specific manufacturing productivity or disembodied technology, which is assumed to be common across sectors. It follows the AR(1) process

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

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

The CES production function was first proposed by Ethier (1982). It 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, present a higher level of productivity.

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

[14] b^i_{nj} is assumed to be unknown ex-ante and it is only realized once innovation of a new variety has taken place.

4.3 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 are produced according to the same CRS production function,[15]

$$x_{ijt} = l_{ijt} \tag{2}$$

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.[16]

Taking as given the demand by the final producers, each intermediate good firm chooses a price to be a constant mark-up over the marginal cost. The value of goods that domestic final producers demand from n is

$$x_{nt}^{i} = (a_{it})^{\sigma} b_{n}^{i} X_{it} \left(\frac{p_{nt}^{i}}{P_{it}} \right)^{(-\sigma)} \tag{3}$$

where $b_{n}^{i} = \int_j b_{nj}^{i} dj$ is the aggregate preference parameter, $X_{it} = \omega_{it} L_{it}$ is total spending by country i, and P_{it} is the price index

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

Trade is assumed to be costly: there is an iceberg transport cost for the products shipped from country n to i equal to $d_{n}^{i} > 1$, with $d_{i}^{i} = 1$. Intermediate firms' prices

[15] 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.

[16] 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.

differ in the domestic and the foreign market by the transport cost d_n^i.[17] That is, they set a price

$$p_{i,t}^{i} = \bar{m}\omega_{it} \tag{4}$$

in the domestic market and

$$p_{i,t}^{n} = \bar{m}(\omega_{it} d_i^n) \tag{5}$$

in each foreign market, with $\bar{m} = \frac{\sigma - 1}{\sigma}$ as the constant mark-up.

Instantaneous profits by intermediate firms are given by the following expression

$$\pi_{nt}^{i} = \left(\frac{1}{\sigma}\right) e^{a_{it}} \left(\frac{p_{nt}^{i}}{P_{it}}\right)^{-(\sigma-1)} \omega_{it} L_i$$

They depend on the expenditure on each intermediate good, which at the same time depend on the size of the country. Larger countries are a bigger source of profits.

4.4 Innovation and adoption

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

The microfoundations of innovation and adoption are as follows. In a given country, new goods arrive endogenously by investing resources in R&D. A competitive set of entrepreneurs bid for the right to produce the good. They need to pay the market price for an innovation, which is given by the discounted present value of profits that the entrepreneur who gets the production right will obtain by selling the good. Positive profits arise because the producers of the intermediate goods are monopolistic competitors, who set prices taking as given the demand by final producers in each potential market. There is a fixed cost to start producing the good, given by the

[17] The iceberg cost effects how much of the intermediate good is shipped across countries but it does not affect whether a new product is imported. This is determined by barriers to technology adoption, as I explain in section 4.4.2.

investment needed to acquire the 'design' from the research sector. Note that in this framework, the research department is treated as a separate sector from the intermediate producers and technologies embodied in intermediate goods are transferred to the firm for a specific transfer price.

Once the firm acquires the right to use the technology, it starts producing the intermediate good. This good can be sold immediately to the domestic final producers. In this sense, there is instantaneous diffusion within countries. 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. Diffusion to the foreign market, however, is a slow process. To sell the good abroad, the firm needs to make a costly investment to adopt the foreign product.[18] Think of this as a cost of adapting the product to the specifications of the importer country. Whether the good is ready to be adopted by the destination is a random draw with a probability that depends on the amount of resources that are allocated to learn how to use the product, and a spillover effect. This is a novelty in my paper.[19]

The introduction of an endogenous process of adoption, instead of the purely exogenous one, implies that there are two profit maximizing decisions in this setting. On the one hand, innovators choose how much labor they want to employ in R&D by comparing the marginal cost of adding one more worker into research with the marginal benefit, which depends on the market price for an innovation. On the other hand, intermediate producers choose how much labor they want to hire in the potential destination to make their product usable there. They compare the marginal cost of adoption with the marginal benefit, which is given by the difference between the value of a good that has already been adopted and the value of a non-adopted good. The amount of labor that is allocated to one or the other activity depends on country specific parameters and the level of development.

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

[18]The same results would hold if we think of the intermediate firm that wants to export the good as hiring the services of a third firm in the destination to adapt the products.

[19]The important role of spillovers has been recently analysed by Klenow and Rodriguez-Clare (2005)

developed in country i, up to time t, by investing resources in innovation. Following Nelson and Phelps (1966), Z_{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. Instantaneous diffusion within the country implies that the theoretical and actual number of technologies in country i are the same, that is $A^i_{it} = Z_{it}$. Slow diffusion across countries, instead, implies that the number of adopted goods is a subset of the number of innovations, that is $A^i_{nt} <= Z_{nt}$. The effective level of technology in country i is composed of both domestic and foreign technologies, that is $T_{it} = A^i_{it} + \sum_{n \neq i} A^i_{nt}$.

4.4.1 Innovation process

The creation of new varieties is defined by an endogenous process of innovation in which a firm allocates labor to the research activity. The number of new goods depends on the investment in innovation and the productivity of research.

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

As in Phelps (1964) and Eaton and Kortum (1996), 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, $\frac{R_{it}}{L_{it}}$, where R_{it} is the total number of researchers and L_{it} is the total number of workers. 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 $\alpha_i^R T_{it} \beta_r \left(\frac{j}{L_{it}} \right)^{\beta_{r-1}}$, where $\alpha_i^R T_{it}$ represents research productivity, and $\gamma_r \in (0, 1)$ is a parameter reflecting the extent of diminishing returns to allocating a larger share of workers into research.[20] If R_{it} workers are doing research in country i at time t, they create new intermediate goods at a rate $\alpha_i^R T_{it} L_{it}^{1-\gamma_r} R_{it}^{\gamma_r}$, that is

[20]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.

Research productivity, $\alpha_i^R T_{it}$, is a function of two elements.[21] First, a country-specific parameter that is identified by economic policies or institutions promoting innovation in a country, α_i^R.[22]

The second element in the productivity of research is a spillover effect, T_{it}, that depends on the total number of intermediate goods available to the country, either domestically or through imports. 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, through domestically produced goods, and learning by using, through imports. This assumption implies that countries with a wider variety of intermediate goods, and therefore a higher level of GDP per capita, have a lower cost of innovation. Thus, other things equal, they invest a larger amount of resources into R&D. This is consistent with what we see in the data: richer countries invest a larger amount of resources in doing R&D.

Another implication of the international spillovers component is the possibility that countries that are expanding their variety of foreign intermediate goods through imports can speed up the innovation process and therefore increase the number of goods they produce and export. That is, non-innovative countries 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 efforts aimed at penetrating the export market, such as imported goods.

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) to an 'innovation-shift strategy' (innovation).

[21] For estimation purposes and as I explain in section 6.2, I introduce an i.i.d shock to the productivity of research, ξ_{it}.

[22] Reasons for differences in the productivity parameter across countries could be a more efficient venture capital market, as in the US, or policies aimed at increasing R&D investments as in Japan.

4.4.2 Technology Diffusion

Intermediate goods that are invented in a country need to be adopted in order to be used by the final sector. I assume that 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.[23] To sell it abroad, however, intermediate producers need to make a costly investment to make the product usable in the potential destination.[24] Whether or not adoption is successful is a random draw with positive probability, ε_{nt}^{i}. The probability or rate of adoption can be expressed in the following way

$$\varepsilon_{nt}^{i} = \alpha_{i}^{A} \left(\frac{H_{nt}^{i}}{L_{it}} \right)^{\gamma_a} L_{it} \frac{A_{nt}^{i}}{Z_{n,t+1}} \quad (7)$$

where H_{nt}^{i} represents the amount of labor that country n hires in country i to train to use 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);[25] γ_a is the elasticity of adoption with respect to effort, assumed to be common across countries. It is a measure of how an increase in investment in adoption translates into an increase in the probability of importing a foreign good; $\frac{A_{nt}^{i}}{Z_{n,t+1}}$ represents how far country i is from country n's technology frontier. The motivation for this component of the rate of adoption is the following: consider the case of a country with a very different culture, language, or institutions from those of the exporter. The source country needs to invest resources to adapt its products to the destination economy in order to make them usable there. As the destination starts importing goods and becomes familiar with the exporter's products, the investment

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

[24] 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).

[25] 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, increasing α^{A}.

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.[26]

To summarize, the rate of adoption depends on the amount of labor that is allocated to adoption, the cost of technology transfer, and the distance to the technology frontier.

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 gap between the exporter's level of technology that can be exported and the level of technologies that the importer has already adopted from the exporter, $Z_{n,t+1} - A^i_{nt}$. The technological gap explains the dynamics of imports of new technologies, embodied in intermediate goods.[27]

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

Expression (8) implies that goods invented in n that have not yet been imported by country i, $Z_{n,t+1} - A^i_{nt}$, contribute to an expansion in the variety of exports to country i at a rate ε^i_{nt}.[28] This is a generalization of Krugman (1979), with the difference that in my model, the rate of adoption is endogenously determined by profit maximizing firms.

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

[26] If the rate of adoption were one, the total number of varieties available for final production would be the same in each region.

[27] 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.

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

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

Equation (9) implies that the dynamics of imports are determined by the speed of innovation, through Z.

We can combine the law of motion for new imports, equation (8), and the expression for the probability of adoption, (7), in order to better understand the adoption mechanism

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

and rearranging

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

The first component in the RHS represents the effect that investment in adoption has in determining an expansion in the number of imports. The second term reflects the impact of foreign sources of technology diffusion. The last term represents the role of relative backwardness. As the country is further away from the exporter's technological frontier (lower $\frac{A^i_{n,t}}{Z_{n,t+1}}$) an increase in the number of imports will have a higher impact in growth rates. This is something that we see in the data: countries that are importing fast are relatively backward countries, that are also experiencing growth rates faster than average. This term arises, as in Howitt (2000), from the product of two terms: $\frac{1}{Z_{n,t+1}} \left(Z_{n,t+1} - A^i_{n,t}\right)$. The first term implies that as the country n's technology becomes more advanced, country i needs to invest more resources in adoption to be able to use the 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.[29]

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

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

4.4.3 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. In this section, I present the value functions that determine the optimal investment in adoption and innovation decisions.

The owner of a technology can earn profits only after the idea has been adopted. Since there is instantaneous diffusion within the country, the value of a new good that is used domestically is given by the present discounted value of future domestic profits.

$$W_{it}^{i} = \pi_{it}^{i} + \beta W_{i,t+1}^{i} \tag{13}$$

where β is the discount factor and π_{it}^{i} represents domestic profits for a firm in country i.

Slow diffusion across countries implies that a technology invented in country n at time t can only be adopted by country i at $t+1$ with probability ε_{nt}^{i}. At time t, firms invest H units of labor to adopt the good. If successful, that is, with probability ε_{nt}^{i}, country n obtains profits forever. On the other hand, with probability $(1-\varepsilon_{nt}^{i})$, this idea will not be adopted at $t+1$. The value of an idea invented in n at time t that has not been adopted by i yet is

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

where W_{nt}^{i} is the value of an idea adopted at time t and is given by

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

The market price of an innovation 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, $V_{it} = W_{it}^{i} + \sum_{n=1}^{M} W_{nt}^{i}$.

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with $\tau_{nt}^{i} = \frac{A_{nt}^{i}}{Z_{n,t+1}}$.

4.4.4 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

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

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}.

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

A higher value of α_i^R means that the country is more productive at doing research, and everything else constant they invest a higher fraction of the labor force into R&D.

4.4.5 Optimal investment in adoption

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

They solve the following problem,

$max_{H_{nt}^i}\ J_{nt}^i = -H_{nt}^i \omega_{it} + \beta \varepsilon_{nt}^i W_{n,t+1}^i + \beta(1 - \varepsilon_{nt}^i) J_{n,t+1}^i \text{s.t}\ \varepsilon_{nt}^i = \alpha_i^A \left(\frac{H_{nt}^i}{L_i}\right)^{\gamma_a} L_i \frac{A_{nt}^i}{Z_{n,t+1}}$

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

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

Note that the marginal benefit depends positively on the difference between what they can earn if adoption is successful, W_{nt}^i and the value of a non adopted intermediate good, $J_{n,t}^i$. Similarily, the higher is the average probability of adoption $\frac{\varepsilon_{nt}^i}{H_{nt}^i}$, the higher is the marginal benefit.

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

4.5 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}.

4.6 Labor market clearing condition

Balanced trade implies that we can close the model with the labor market clearing condition: the amount of labor used in production must equal labor supply in each period in the production for intermediate goods.

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

The LHS of equation (17) represents total expenditure in manufactures from country i by each country n. The RHS is the value of total supply of labor from country n. L_{nt}^{M} is the number of workers that are used to produce intermediate goods.

4.7 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 (3))

- $\forall t$, given prices and initial conditions, x^i_{nt}, and profits π^i_{nt}, p^i_{nt} and L^M_{nt} 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 $\{H^i_{nt}, \pi^i_{nt}, W^i_{nt}, J^i_{nt}\}$ solve the adopter's problem (equation (15))
- The laws of motion for A^i_{nt} 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

5 Balanced Growth Equilibrium

The steady state in this economy is characterized by a constant growth rate of the endogenous variables. Population is constant in steady state. Therefore, from equation (16), the allocation of labor in manufacturing, L^M_i, adoption, H^i_n and research, R_n are also constant.

Technology diffusion and catch-up assure that all countries eventually grow at the same rate, as in Nelson and Phelps (1966). Countries differ in the relative levels of technology, depending on the country-specific parameters of innovation and diffusion, α^R_i and α^A_i.[30] In the transition, the lower a country's initial productivity, the larger is the technology gap from the leader, and the faster the growth.

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 varieties grows at the same rate as the number of domestically produced varieties, which translates into a constant probability of adoption. A constant rate of adoption, ε^i_n, implies that diffusion is exponentially distributed with parameter λ^i_n and $\varepsilon^i_n = \frac{\lambda^i_n}{1+\lambda^i_n}$.[31] Adoption

[30] Jovanovic (Forthcoming) 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.

[31] See Benhabib and Spiegel (1994).

is a stochastic process with mean diffusion lag between country i and country n equal to $\lambda_n^{i\ -1}$. Instantaneous diffusion within a country implies that $\lambda_n^i \to \infty$ for $n = i$. The lag affects the speed of convergence to the steady state and the dynamics to the long run equilibrium. Assuming $\lambda_n^i > 0$ every good will eventually be available in any country.

From the expression $T_{it} = Z_{it} + \sum_{n=1}^{M} A_{nt}^i$, the growth rate of intermediate goods in steady state can be obtained as follows,

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

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 guarantes that we can obtain a value for the growth rate g and relative productivities $\frac{T_i}{T_n}$.

It is important to note that, if there were no sources of heterogeneity in the country, that is, if $\alpha_i^R = \alpha^R$, $\alpha_i^A = \alpha^A$, $L_i = L$ and $d_n^i = d \ \forall i, n$, then we would reach a steady state 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.

6 Empirical strategy

6.1 Bayesian Estimation

I estimate the model using Bayesian techniques developed by Schorfheide (1999). I use Dynare (Juillard 1996) to solve and estimate the model.[32]

6.2 Data and priors

To make the model more tractable, I group the sample of thirty-seven countries into five regions in such a way that countries in the same group share common characteristics (similar innovation intensity and GDP per capita growth): The United States, Japan, Western Europe, Eastern Europe and Asia.[33] 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 and people between* ***Asia, Europe and North America****'*

6.2.1 Data

The model is fitted to annual data for the period 1994-2003, since 1993 is the first year that 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.[34] There are one hundred and thirty-five observations corresponding to nine years, five regions of countries and three observable variables.[35]

[32]The code is available upon request. The variables in the code are expressed in stationarized terms, in order to be able to compute the loglinearization around the steady state.

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

[34]For more details on how to compute growth in varieties, see Broda, Greenfield, and Weinstein (2008).

[35]Note that there is a cross-sectional dimension in the data. DSGE models that are estimated in macroeconomics with Bayesian techniques have a long time series for one or two countries; in my case, I have a short time series sample but I add five countries in the analysis.

Bilateral trade data are obtained from the UN COMTRADE database. I follow the HS-2000 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). 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.)

I estimate the parameters behind the innovation and adoption processes, the elasticity of substitution across intermediate goods, and the shock processes.

6.2.2 Shocks

In order to have invertibility in the likelihood function, the ML approach requires as many shocks as observable variables. With three series of observable variables, we need to introduce three series of shocks. One of them is given by the neutral technology shock, a_i in final production, for each region. Another is an i.i.d shock to innovation productivity, a^{α}_{it}. Finally, I add measurement errors to the growth rates of imported varieties, one for each region. The structural shocks and measurement errors incorporated in the estimation are

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

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

$$\xi_{i,t} \sim N(0, \sigma^2)$$

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

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

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

6.2.3 Parameters

STRICT PRIORS

A set of the parameters of the model is treated as fixed in the estimation (also called strict priors or calibrated parameters). The strict priors are reported in 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 productivity of the innovation process α_i^R, is set to satisfy equation (6). There are not available data on the number of goods that have been invented by the country. However, we can find data for the number of exported varieties. I use these data as a proxy for ΔZ_{it} (the key assumption is that the number of exports is proportional to the number of godds produced within the country). The results show that Asia and Eastern Europe have the lowest productivity of innovation, while the US and Japan are the most productive regions.[36] At the same time, note that from the optimal investment in innovation, given by equation (14), the higher the productivity α_i^R, the higher the fraction of workers that are allocated in R&D, everything else constant. This is consistent with the experiences of the US and Japan in the last decade: they have a higher productivity of research and a higher investment in R&D.

PRIORS

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, the persistence, ρ_i and the standard deviations, σ_i, of the neutral technology shock and productivity of innovation shocks. The priors assumed for the parameters can be found in tables 3 and 4.

I assume a uniform prior for the elasticity of substitution across intermediate goods. This parameter can take any value higher than 1, which covers the whole range of possible values. The prior for the cost of adoption in each region, α_i^A is distributed Gamma with mean 1.2 and standard deviation 0.25. 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 uniform (0,1). There are discrepancies on the value of this parameter. Eaton and Kortum (1999) find a value for this parameter around 0.2. Different from this result, Griliches (1990) estimates this parameter using the number of new patents as a proxy for technological change, and obtains estimates between 0.5 and 1. The elasticity of adoption with respect

[36] The increase in venture capital investments in the US and policies that encourage public R&D in Japan in the last decade, could be explaining a higher value for this parameter.

to effort γ_a, is assumed to follow a Beta distribution with mean 0.5 and standard deviation 0.15. This parameter has been calibrated by Comin and Gertler (2006) and Comin, Gertler, and Santacreu (2008), 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, and therefore is the measure of embodied adoption. The regression yields a constant of 0.8.

Finally, in the shock processes, I assume a Beta distribution with mean 0.5 and standard deviation 0.25 for the persistence parameter, and an Inverse Gamma distribution is assumed for the standard deviation of the shocks. This 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 4.2. 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 and 1.4 for the blocs considered in the analysis. It does not follow a particular pattern. These results 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 7. The results imply that the average time that it takes for a country to be able to use an intermediate good developed elsewhere, which corresponds to the inverse of the probability of adoption, lies between two and ten years.

The posterior mean for the elasticity of innovation γ_r, is 0.24, similar to the results in Eaton and Kortum (1999), and lower than in Griliches (1990). The elasticity of adoption is estimated to be 0.2, lower than what Comin and Gertler (2006) find.

6.4 Monte Carlo Simulations

This section evaluates the performance of the estimation procedure by running Monte Carlo simulations. The non-linear model is solved and simulated, to a first order approximation, for a given set of parameters. I then simulate the model taking the following steps: first, I generate a set of errors, u_i and measurement errors, me_i for each region. Second, I choose a value for the structural parameters (see table 5) and create a simulated series for the share of researchers allocated to innovation and the growth rate in the number of varieties. Finally, I estimate the parameters behind the innovation and adoption processes, and the persistence and standard deviation of the shocks based on the simulated dataset and compare the estimated parameters to the 'true' values.

The specification for the 'true' parameters can be found in table 5. From this set of values, I estimate the elasticity of innovation γ_r, and asoption, γ_a, the elasticity of substitution, σ, and the adoption costs α_i^A in each region, as well as the parameters governing the shock process (persistence and standard deviation). The results are reported in table 6. The results show that the estimated parameters are very close to the 'true' value and all of them lie within the 95% interval or are very close , suggesting that identification is successful and the parameters can be recovered with high accuracy.

6.5 How well does the model fit the data?

This section checks how well the model fits the data. by comparing several variables of the model for which we can find a counterpart in the data. I compare the rate of adoption and the relevant correlations between trade, innovation and productivity, shown in section 3.

RATE OF ADOPTION

First, I compare the actual value for the hazard rate or probability of adoption, computed with Survival Analysis techniques, as explained in section 3 to the estimated probability of adoption predicted by the model. The results are reported in table 7.

The model does a good job in capturing the average adoption probability for the five regions considered in the analysis. We can also see the performance of the model in capturing the rate of adoption in figure 5. The figure reports the actual data and the rates predicted by the model. The two values are very close for most pairs of regions.

UNCONDITIONAL MOMENTS

In this section, I compute the correlations between trade, productivity and innovation that are predicted by the model. Using the posterior mean of the estimated parameters and the standard deviations of the shocks, I simulate the model, and obtain the correlations of the simulated variables representing R&D, output growth, and growth in imported varieties. The results are presented in table 8. Overall, the model does fairly well in reproducing the relevant moments.

6.6 Identification

In this section, I explain how the estimated parameters are identified from the data on R&D, productivity and trade. I take advantage of the panel dimension of the data to compute unconditional moments across time and across countries.

The parameter in the final production function, σ, represents both, the love-for-variety effect, and the elasticity of demand for imports. In the first case, it captures one direction in the positive correlation between trade and growth:, that is, higher trade induces higher growth (extensive margin). In the second case, it captures the fact that higher growth is going to increase the demand of each imported intermediate good, and therefore higher trade (intensive margin). As goods become less substitutes (as σ decreases), there is a stronger correlation between trade and growth across countries. On the one hand, as σ decreases, the lover-for-variety effect will be stronger. Keeping growth in imports constant, lower σ implies a higher increase in productivity growth. This increase will be higher for developing countries, through the catching-up effect. At the same time, for the same growth rate, the increase in demand for imports will be higher, the lower the elasticity.

The parameter γ_a represents the curvature of the adoption function. An increase in γ_a implies that adding one more worker into adoption is going to have a higher impact on the probability of adoption. Countries invest more in adoption and less in innovation, especially the further they are from the technology frontier. This implies that the correlation between trade and innovation across countries becomes more negative.

The parameter γ_r represents the elasticity of innovation. It depends on correlation between R&D and growth across countries, which becomes less negative, the higher is β_r.

So far, I have focused on the identification of the parameters that are common across countries. I identify these parameters from the cross-section dimension of the panel of data. The country-specific parameters, α_i^a are identified from the time series dimension of the data. α_i^A and α_i^R are not separately identified. We do not have data on Z_i. α_i^A is identified from correlation across time between R&D and trade. The higher is the parameter for each country, the more negative will be the correlation between innovation and trade; countries will allocate more resources into adoption and less into innovation.

7 Contribution of domestic and foreign sources of innovation to growth

This section analyses the sources of productivity growth in each region, in order to assess the quantitative importance of trade in intermediate goods. Using the posterior mean of the estimated parameters, I decompose the growth rate in the total number of varieties into the contribution of domestic and foreign sources of innovation (through growth in domestically produced varieties and growth in imported varieties from each exporter).

Equation (6) can be used to evaluate the domestic contribution to embodied growth. The relevant parameters are the productivity parameter, α_i^R and the scale effect, γ_r. The contribution of foreign sources of innovation is given by expressions (8) and (7). The relevant parameters are the adoption costs, α_i^A and the elasticity of adoption. γ_a.

Table 11 reports the growth of productivity growth in each importer (rows) that is explained from technologies developed in each exporter (columns) and diffused through trade, averaged over the period 1994-2003. Each element A_{ij} of the table can be interpreted as the percentage of growth in country i that is explained by innovations done in country j. The diagonal, in bold numbers, measures the contribution of domestic sources innovation for each region.

The results show that nearly 83% of the productivity growth in Asia can be explained by imports, especially from the US and Japan. The US has by far the highest percentage of growth accounted for by domestic innovation, with 47% of its embodied productivity coming from its own innovative effort. Japan, with 32 %, and Western Europe, with 43% follow the US. 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.

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% and 20% to embodied productivity growth in the other regions.

Table 11 reports the contribution of each column-exporter's innovations to each row-importer's technological progress. The US and Japan are the main sources of innovations, while Asia is the country that contributes the least to technological progress in the other regions. These results are consistent with what we see in the data. Table 11 reports the percentage that each column-exporter represents in each row-importer's total imports. In Asia, 4.08% 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. There is a distance effect, however, that is not present in table 11. More innovative Europe represents a higher percentage than Japan in the imports of less innovative Europe. Asia and more innovative Europe contribute almost the same to Japan's imports, even though Asia only represents 7% of the research intensity in the five regions world. Furthermore, more than 60% of the innovation effort is done in the US and Japan. It is not surprising then that these countries are benefiting, mainly, from domestic sources of innovation.

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

The model predicts that Asia will reach the steady state in 80 years, while the US will reach it in 20. The results are reported in table 13. The US and Japan are relatively close to the steady state, while Asia and Eastern Europe are lagging behind. If we take the US as the baseline country to analyse how far we are from the steady state, we can see in the second column in table 13 that Asia's income per capita in 1995 was 25% of the income per capita in the US. Japan was closer, at 80% of that of the US.

The third column of table 13 shows that Asia will improve its position with respect to the US by 70%. That means that in 2075, when Asia reaches the steady state, its income per capita will be 70% that of the US. Japan, which is closer to the steady state, only improves by 20%. Countries that lag behind (Asia and Eastern Europe) take longer to reach the steady state, their improvement is higher and it decreases as they get closer to the steady state.

9 Counterfactuals

In this section, I perform two experiments to show how shocks to innovation and adoption have something to say about the connections between trade and growth. I analyse both the steady state and the transition dynamics. The starting point in each of the experiments is the steady state of the model; that is, assuming that the economy has reached the steady state, I explore the transition to a new equilibrium after changing the exogenous parameters, α^A and α^R.

- First, I analyse 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).

Under the assumption that the US, being the economy with the highest income per capita, represents the technology frontier, I analyse the effect that the two shocks have for world growth rates, research intensity, adoption, the extensive margin and the relative income per capita in Asia and the US. I show how the two experiments lead simultaneously to higher trade and faster growth.

9.1 Counterfactual: Reduction in adoption costs in Asia

9.1.1 Steady State

A 50% reduction in the cost of adoption in Asia increases world growth rates by 0.7%. Table 13 presents the comparative statics for the key variables in the analysis.

Faster adoption results in a higher research intensity in the new steady state of every country. In Asia, this increase is driven by the 'spillover effect' in equation (6). Research intensity in this region is 2.3% higher than in the initial steady state. The result is a higher diversification of exports of the region, driven by a decrease in the costs of adoption. The higher ability to adopt goods increases the demand for imports, especially from Japan and the US. Recall from previous sections that these two regions are the main exporters in the sample. This 'demand effect' increases the present discounted value of future profits from selling a good abroad, which increases the market price for an innovation and, therefore research intensity in the trading partners of Asia.

The rate of adoption in Asia increases for two reasons: directly, from a decrease in the costs of adoption, that is, 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, $\frac{A^i_{nt}}{Z_{nt}}$.

Higher adoption has positive implications for the extensive margin in Asia, relative to the US. Asia closes the distance with respect to the technology frontier, both in the number of varieties that it produces domestically, and in proportion of goods that it adopts from the technology frontier. This catching-up is reflected in an increase in relative wages of Asia with respect to the US by 12%. Despite getting closer, there is still a gap in levels of income per capita between both countries. At the new steady state, growth rates are constant and common across countries. There is convergence in growth rates but not of levels.

9.1.2 Transitional Dynamics

Figure 6 represents the transition path for the main variables after a 50% permanent reduction in the barriers of adoption in Asia.

In the first panel of figure 6, we see that the research intensity in Asia (solid line) decreases upon impact. There is an initial reallocation of resources into adoption and away from research. Asia starts importing more varieties, and after one period, the increase in imported varieties reduces the cost of innovation, through the spillover effect. Research intensity increases then, and it 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 increase. This occurs at the intensive and extensive margins (solid and dashed line in the first panel): Asia imports more goods and more of the same goods. The 'demand effect' increases research intensity in the US, which reaches a higher level in steady state (dashed line in the first panel).

Eventually, Asia becomes closer to the US, through an increase in both imported and domestic varieties. Asia has been growing faster than the US. However, although the gap is smaller, wages, a proxy for income per capita, are still higher in the US (fourth panel).

This experiment generates both higher trade and faster growth, but the initial causation goes from more trade to more growth.

Note that this scenario reproduces the situation that we observe in the data. In the transition, rich countries are allocating more resources into R&D, while less advanced countries in Asia are adopting new goods. This translates into faster growth. However, Asia still lies behind the US in levels of income per capita, due to the initial differences caused by country-specific parameters reflecting innovation productivity. Thus, adoption alone is not sufficient to completely close the gap. As I show in the next section, to achieve complete catch-up in levels, it is necessary to implement policies that foster innovation in this region.

9.2 Counterfactual: Increase in productivity of innovation in Asia

9.2.1 Steady State

A 50% increase in the productivity of innovation in Asia increases world growth rates by 3%. Table 13 presents the comparative statics for the key variables in the analysis.

Research intensity in the new steady state is higher for Asia, but lower for its trading partners. First, a higher productivity of innovation, reduces the cost for this activity in Asia. Second, there is a 'spillover effect'. All this results in an increase in the research intensity of the region by 90%.

As in the previous experiment, 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 from the technology frontier. Relative wage with respect to the US increases by 30%. In this experiment, Asia completely closes the gap with respect to the US, and it becomes the technological leader. As a consequence, the research intensity of its trading partners falls in the new steady sate, because they need to allocate more resources than before into adoption, in order to import goods from Asia. There is convergence both in growth rates and overtaking in levels.

Note that the results would be different if instead of a 50% increase in the productivity of innovation, there was only a 30% increase. In this case, the gap would not be closed completely. Given these results, one could argue that Asia should invest in innovation policies, in order to reach the technology frontier. However, implementing these policies at a very early stage of development, is probably much more costly that starting adopting new goods and eventually increasing innovation. One reason is that the cost of innovation is partially explained by the 'spillover effect'; at a very early stage in development, this component is very small and we need a bigger increase in α^R to reactivate innovation.

9.2.2 Transtional Dynamics

Figure 7 represents the transition path of the positive productivity shock in Asia. In the transition, the research intensity in this region goes up (solid line in the second panel). A higher $\alpha^R(Asia)$ decreases the cost of innovation, which implies a reallocation of labor into research. In the US, there is, upon impact, a reduction in research intensity. The initial drop is driven by an initial reallocation in Asia from adoption into research, which initially decreases the demand by this region. After some periods, it starts increasing, mainly because Asia starts demanding products from this country (first panel in figure 7). In the transition, Asia is closing 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 and Asia closes the gap completely.

10 Conclusions

The effects of trade on growth have been studied extensively in economics. However, there are still two gaps in these studies. First, the mechanisms by which countries benefit from each other's technologies through trade are not fully understood. Second, the magnitudes are unknown. This paper show that innovation, through creation of new varieties, and diffusion, through adoption of foreign goods through imports, provide the mechanisms to explain the connections between trade and growth. In my paper, trade in varieties arises as the new way to measure the extent of trade, and therefore diffusion, in an open economy.

This paper is one step forward in analysing the connections between trade in varieties and growth. It constitutes a theoretical contribution to the empirical literature in the area. First, it does not face the endogeneity problem of regression analysis. Second, the model is tractable enough to analyse the mechanisms outside of steady state. This is important to capture differences in growth rates across countries. Third, Bayesian techniques allow me to incorporate prior knowledge into the analysis and pin down the value of the parameters that govern innovation and adoption.

I find that diffusion in the last decade has been particularly important in Asia and Eastern Europe, allowing these countries to benefit from their backward situation and grow faster than average. Innovation, instead, is more important in the US, Japan, and Western Europe. The model suggests that, as cpuntries become technologically more advanced, they should focus on policies that increase innovation. For countries that lag behind, their best option is to adopt foreign technologies, through imports. As countries get closer to the technological frontier, a policy that fosters innovation is more appropiate.

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11 Tables and graphs

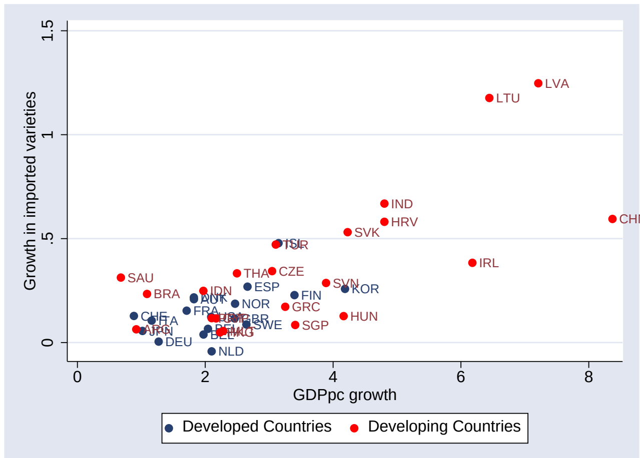

Figure 1: Relation between GDPpc growth and variety growth

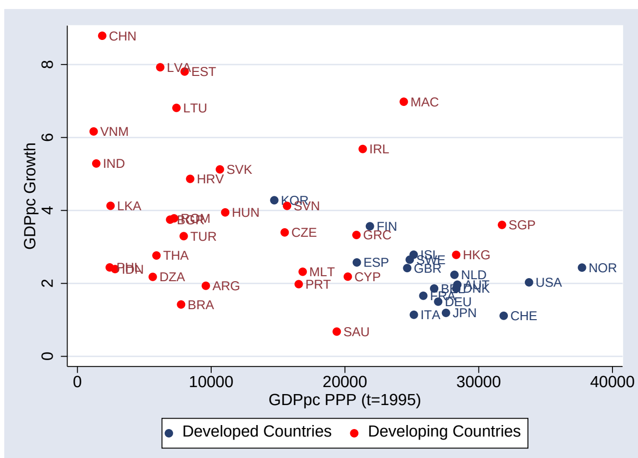

Figure 2: Relation between GDPpc growth and initial level of GDPpc: PPP adjusted; Average over 1994-2003es

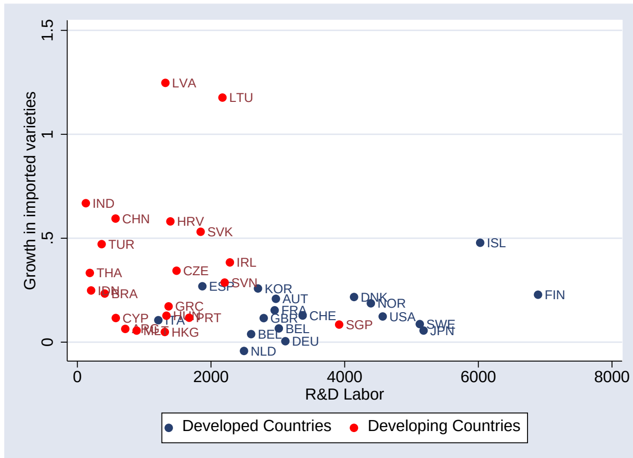

Figure 3: Relation between R&D investment and variety growth: PPP adjusted; Average over 1994-2003

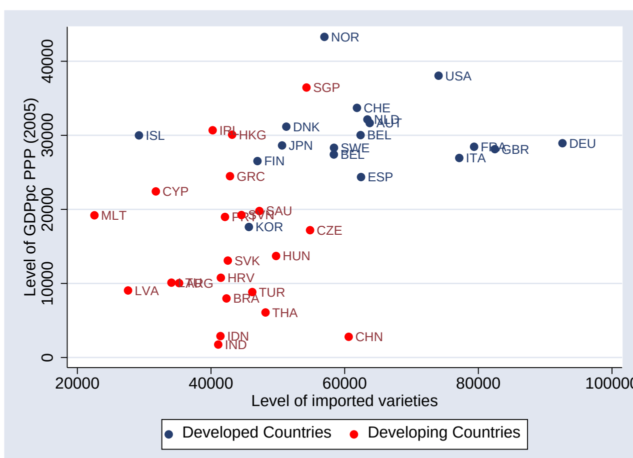

Figure 4: Relation between GDPpc and number of imported variety: PPP adjusted; Average over 1994-2003

Exporter	Importer	Hazard
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

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
$\alpha^R(Asia)$	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	Uniform(1, ∞)	4.20	4.16	4.23
$\alpha^A(Asia)$	Gamma(1.2, 0.25)	1.30	1.22	1.37
$\alpha^A(EU-)$	Gamma(1.2, 0.25)	1.18	1.02	1.35
$\alpha^A(EU+)$	Gamma(1.2, 0.25)	1.13	1.01	1.29
$\alpha^A(Japan)$	Gamma(1.2, 0.25)	1.29	1.18	1.40
$\alpha^A(USA)$	Gamma(1.2, 0.25)	1.21	1.14	1.27
γ_a	Normal(0.5, 0.15)	0.19	0.14	0.22
γ_r	Uniform(0, 1)	0.24	0.24	0.24

Table 3: Prior and posterior for the structural parameters

For the Beta distribution, 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(0.50,∞)	2.13	2.07	2.20
$me(EU-)$	IGamma(0.50,∞)	2.54	2.37	2.71
$me(EU+)$	IGamma(0.50,∞)	0.81	0.7811	0.84
$me(Japan)$	IGamma(0.50,∞)	1.77	1.64	1.91
$me(US)$	IGamma(0.50,∞)	0.62	0.59	0.65

Table 4: Prior and posterior for the shock processes

Parameter	Description	Value
σ	Elast. Subst.	3.33
β	Discount factor	0.97
d	Distance	1.100
γ_r	Elast. innov.	0.60
$\alpha^R(Asia)$	Productiv. innov.	0.003
$\alpha^R(EU-)$	Productiv. innov.	0.0034
$\alpha^R(EU+)$	Productiv. innov.	0.0087
$\alpha^R(Japan)$	Productiv. innov.	0.0069
$\alpha^R(US)$	Productiv. innov.	0.01
$\alpha^A(Asia)$	Adopt. cost	1.20
$\alpha^A(EU-)$	Adopt. cost	1.26
$\alpha^A(EU+)$	Adopt. cost	1.34
$\alpha^A(Japan)$	Adopt. cost	1.22
$\alpha^A(US)$	Adopt. cost	1.16
γ_a	Elast. of adoption	0.60
$\rho(Asia)$	Persistence shock	0.50
$\rho(EU-)$	Persistence shock	0.50
$\rho(EU+)$	Persistence shock	0.50
$\rho(Japan)$	Persistence shock	0.50
$\rho(US)$	Persistence shock	0.50

Table 5: Calibrated Parameters MCMC

Parameter	True Value	Prior	Posterior mean	5%	95%
σ	0.70	Uniform(0, 1)	0.71	0.70	0.72
γ_r	0.60	Uniform(0, 1)	0.59	0.58	0.60
γ_A	0.60	Normal(0.50,0.15)	0.57	0.56	0.58
$\alpha^A(Asia)$	1.20	Gamma(1.2, 0.15)	1.21	1.16	1.26
$\alpha^A(EU-)$	1.26	Gamma(1.2, 0.15)	1.29	1.25	1.34
$\alpha^A(EU+)$	1.34	Gamma(1.2, 0.15)	1.28	1.21	1.35
$\alpha^A(Japan)$	1.22	Gamma(1.2, 0.15)	1.20	1.15	1.25
$\alpha^A(US)$	1.16	Gamma(1.2, 0.15)	1.18	1.10	1.26
$\rho(i)$	0.5	Beta(0.45,0,15)	0.49	0.46	0.52

Table 6: Prior and posterior for the structural parameters MCMC

Exporter	Importer	Hazard	Estimated average
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 7: Hazard rates and estimated steady state values: MSE=0.01

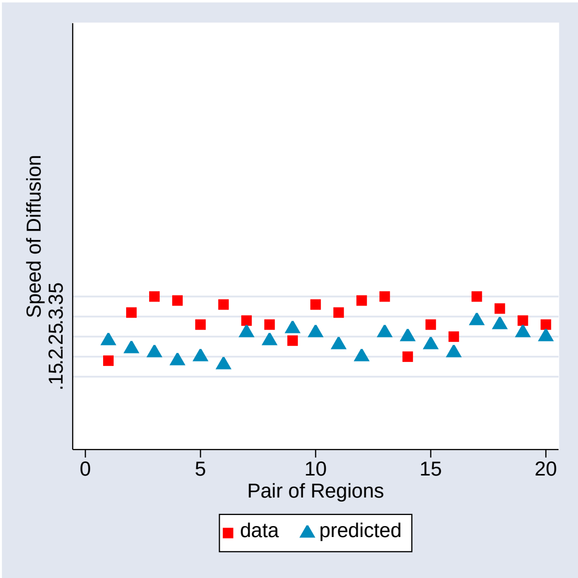

Figure 5: Rate of Adoption

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

Table 8: Comparison of unconditional moments: model versus data

To—From	Asia	EU-	EU+	Japan	US
Asia	**16.98**	9.78	26.95	17.54	28.75
EU-	11.90	**14.64**	23.36	20.50	29.60
EU+	10.09	5.62	**41.94**	17.35	25.00
Japan	9.29	8.87	24.56	**31.99**	25.29
US	9.17	7.35	21.19	15.02	**47.27**

Table 9: Sources of growth predicted by the model: domestic and foreign innovation (percentage; Columns (exporter); rows (importer))

To—From	Asia	EU-	EU+	Japan	US
Asia		11.8	32.5	21.1	34.6
EU-	13.9		27.4	24.0	34.7
EU+	17.4	9.7		29.9	43.0
Japan	13.7	13.0	36.1		37.2
US	17.4	13.9	40.2	28.5	

Table 10: Foreign Sources of Growth: bilateral contribution predicted by the model (percentage; 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 11: Foreign Sources of Growth: bilateral contribution in the data (percentage; Columns (exporter); rows (importer))

Region	Years to convergence	Relative income pc (1995)	Improvement
Asia	80	25%	70%
Eastern europe	70	26%	66%
Western Europe	35	69%	30%
Japan	30	80%	20%
US	20	Baseline	Baseline

Table 12: Speed of Convergence

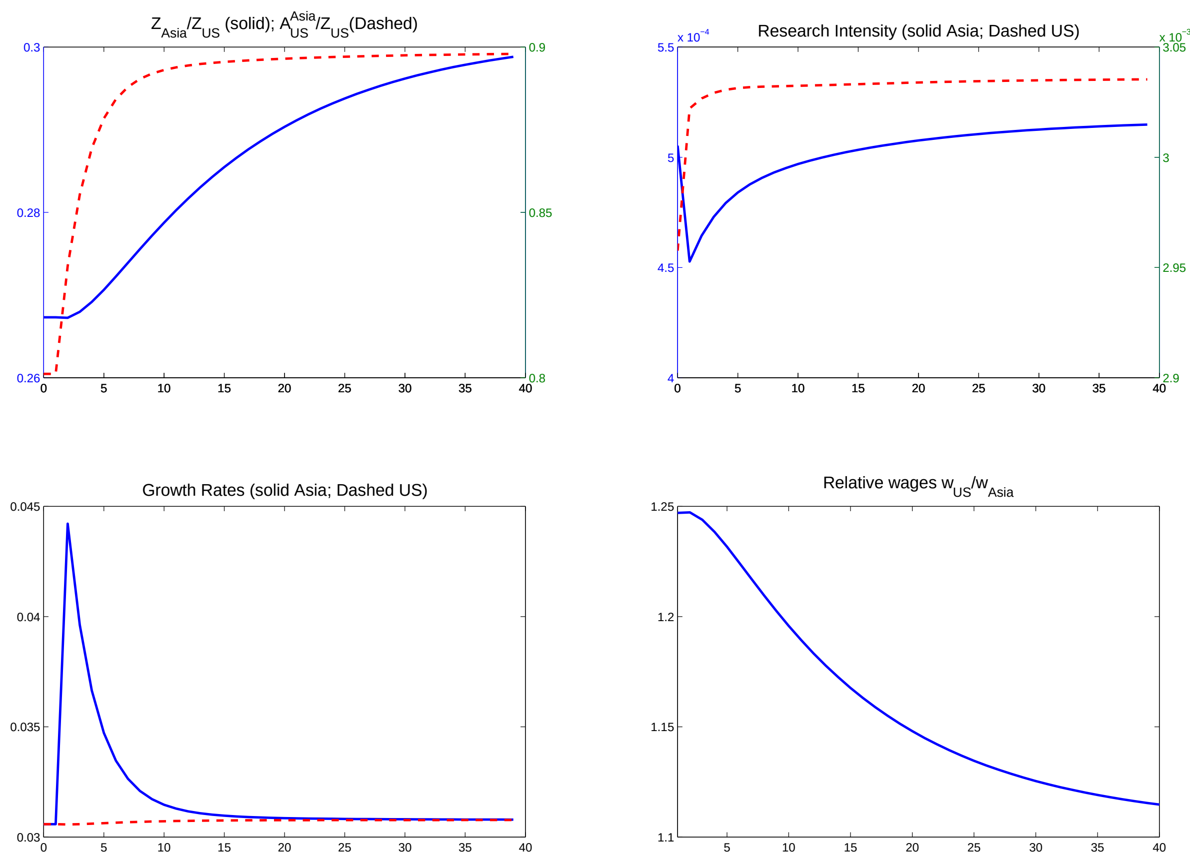

Figure 6: Permanent reduction in barriers to adoption in Asia

Variable	% change
$\Delta r(Asia)$	2.3%
$\Delta r(US)$	2.6%
Δg^*	0.7%
$\Delta \frac{\omega(Asia)}{\omega(US)}$	12%
$\Delta \frac{Z(Asia)}{Z(US)}$	11%
$\Delta \frac{A_{US}^{Asia}}{Z_{US}}$	10%

Table 13: Reduction in adoption barriers in Asia: Steady State Comparison

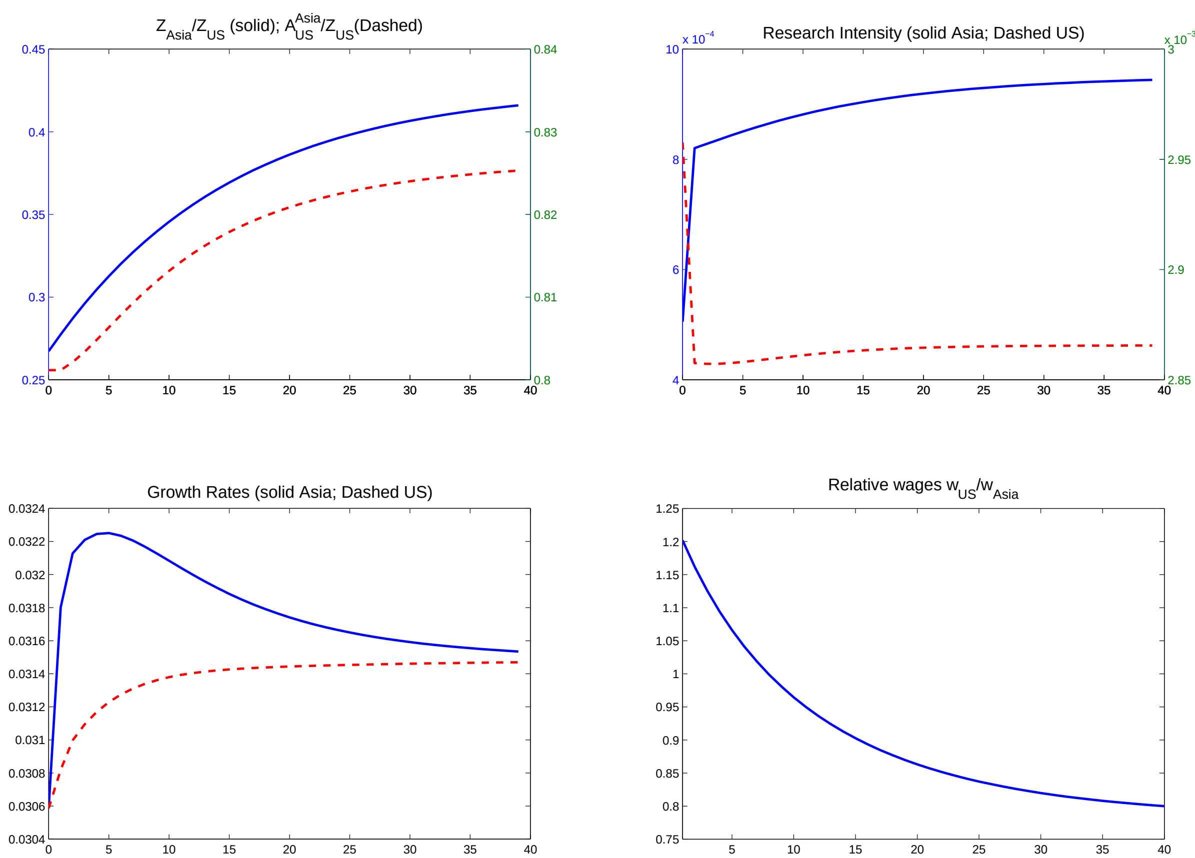

Figure 7: Permanent increase in innovation productivity in Asia

Variable	% change
$\Delta r(Asia)$	88%
$\Delta r(US)$	-3%
g^*	3.2%
$\frac{\omega(Asia)}{\omega(US)}$	30%
$\Delta\frac{Z(Asia)}{Z(US)}$	37%
$\Delta\frac{A_{US}^{Asia}}{Z_{US}}$	2%

Table 14: Increase in innovation productivity in Asia: Steady State Comparison

12 Appendix A

Country	GDPpcgrowth	Varietygrowth	Researchers (10^{-3})	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
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

Table 15: Differences across countries: PPP

13 Appendix B

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
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

Table 16: Country Sample

14 Appendix C

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 17: Classification of goods according to BEC