Technology Adoption and Factor Proportions in Open Economies: Theory and Evidence from the Global Computer Industry

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Abstract

Standard theories of international trade assume that all countries use similar and exogenous technologies in the production of any good. This paper relaxes this assumption by allowing for the adoption of various factor-complementary machines. The marriage of literatures on biased technical change and trade yields a tractable theory, which predicts that differences in factor endowments bias technical change towards particular factor intensities, and thus unit factor input requirements vary across economies. Using data on net-exports of a single industry, computers, and factor endowments for 73 countries over the period 1980-2000, the paper shows that once technological choices are considered, countries with different factor endowments can become net exporters of the same product. (**JEL Code**: F1, F11, F12)

Keywords: Rybczynski; Factor Endowments; Biased Technical Change.

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1 Introduction

Theories of international trade such as the factor proportions model often assume that countries use similar technologies in production or that technological differences are Hicks neutral. In contrast, models of biased technical change assert that innovation and technology adoption are determined by local factor endowments. This paper marries these two literatures. It proposes a matching mechanism between factor endowments and technologies in open economies, and it studies how the cross-country pattern of trade changes once technology choices are considered.

The theory concerns economies that are open and differ in their factor endowments. Economies are composed of multiple goods, which can be produced with a range of factor-complementary machines. These machines are traded in a global market, which is characterized by a monopolistic competitive structure. The model is tractable even though it predicts that unit factor input requirements within industries vary across countries.

The econometric analysis utilizes data on factor endowments and net-exports of computers and components, an industry that has received much attention in the technology adoption and growth literature. The data set covers 73 countries during 1980-2000. The empirical model tests for the existence of multiple technological country groups in the data, and estimates the factor proportions model in a two-stage estimation procedure. The technology selection function is modeled as an Ordered Probit. The trade specialization equation follows closely the standard specification of Rybczinski functions found in the trade literature.

The econometric results suggest the existence of up to four distinct technological groups that differ in terms of their unit factor input requirements in the production of computers. The evidence rejects the hypothesis that the set of estimated Rybczinski coefficients are statistically equivalent across technological country groups.

The paper is organized as follows. Section 2 discusses the related literature. Section 3 introduces the model. Section 4 solves the equilibrium of the model. Section 5 presents the empirical strategy. Section 6 discusses the empirical results. Section 7 concludes.

2 Related Literature

At least two distinct literatures are related to our model and empirical application. The first one is the trade literature on factor proportions and trade patterns. The second one concerns biased technical change.

2.1 Trade and factor proportions

This literature can be divided into two different strands of research. One explores the implications of the factor proportions theory under the assumption that all countries have access to the same technologies. A second literature conducts the same analysis but assumes that there are Hicks-neutral technology differences across countries.

In the first strand of research, Harrigan[14] examines the production side of the factor proportions model. The author employs manufacturing outputs and factor endowments data for up to 20 OECD countries during 1970-1985. The most robust evidence suggests that capital abundance is a source of comparative advantage in most of the sectors, but the effects of skilled- and unskilled-labor are not clear. The sign of the Rybczynski coefficients change across econometric specifications. In particular, under the time-varying parameter model, which yields the most precise coefficient estimates, skilled-labor is a modest source of comparative advantage in only two industries (Iron and Steel, and Fabricated Metal Products), while it is a source of comparative disadvantage in the other sectors. Its largest negative effect is observed in the Food industry. By contrast, unskilled-labor has positive effects on industry output in six of the nine industries, while land has a negligible effect in all the manufacturing sectors.

In the same vein, but motivated by a slightly different question, Schott[25] investigates whether developed and developing countries specialize in different subsets of products as a result of their differences in factor endowments. He proposes a methodology that distinguishes single- from multiple-cone equilibria and allows for the effect of factor accumulation on a given sector's output to vary with a country's endowments. Schott[25] uses value-added, capital stock, and employment data from UNIDO for up to 45 developed and developing countries across 28 manufacturing industries in 1990. The findings reject the single-cone framework in favor of a two-cone model with labor-abundant countries producing relatively little of the most capital-intensive goods. Interestingly, the estimated development paths for industries such as Transportation, Food, Electrical Machinery and Machinery display a twin-peaked pattern, thus suggesting that within these sectors labor-abundant countries produce the less capital-intensive goods, while capital-abundant economies specialize in the production of the most capital-intensive products.

A paper that also belongs to this literature is Romalis[24]. The author examines how factor proportions determine the structure of commodity trade by integrating a many-country version of a Heckscher-Ohlin model with a continuum of goods with Krugman[18]'s model of monopolistic competition and transport costs. Two main predictions emerge from this work. The first one tells that countries capture larger shares of world production and trade of commodities that more intensively use their abundant factors. The second prediction shows that countries that rapidly accumulate a factor see their production and export structures systematically shift towards industries that intensively use that factor.

In the second strand of the trade literature, Harrigan[15] provides the first empirical test of the factor proportions theory in a framework that accounts for international technology differences. To estimate this model, the author uses manufacturing output shares and factor endowments data for up to 10 developed countries across 7 industries with data from 1970-1988. The most reliable inferences across sectors that can be obtained from this study are roughly consistent with Leamer[19] and Harrigan[14]. Specifically, the results indicate that capital and medium-educated workers are associated with larger GDP output shares in most of the seven industries (Food, Apparel, Paper, Chemicals, Glass, Metals and Machinery); while non-residential construction and high-educated workers are related to lower output shares.

Harrigan[15] improves substantially upon previous empirical frameworks, but his implementation has the disadvantage that the model does not exploit cross-country variation to help identify the effect of factor supplies on specialization because it only uses data on OECD countries, which tend to have similar factor endowments and sectoral output shares. To overcome this drawback, Harrigan and Zakrajsek[16] extend that study and work with a larger sample, which includes data for up to 28 OECD and non-OECD countries and 12 industries from 1970-1992. Their evidence favors the neoclassical theory. In Food, Wood-Paper and Oil-Coal capital abundance reduces output shares while labor abundance raises them; Fabricated Metals and Machinery sectors are capital intensive but not land intensive. The impact of factor endowments on the Apparel-Textile sector is difficult to ascertain because the signs of the estimated coefficients change across specifications. The between (cross-sectional) estimates confirm the intuition about this sector, namely that countries that are land and capital scarce but labor abundant specialize in this industry. The country fixed-effects estimates however show that increases in skilled-labor over time reduce output.

In a related work, Fitzgerald and Hallak[12] estimate the effect of factor proportions on the pattern of manufacturing specialization in a cross-section of OECD countries, taking into account that factor accumulation responds to productivity. The author show that the failure to control for productivity differences produces biased estimates. Their model explains 2/3 of the observed differences in the pattern of specialization between the poorest and richest OECD countries. However, because factor proportions and the pattern of specialization co-move in the development process, their strong empirical relationship is not sufficient to determine whether specialization is driven by factor proportions, or by other mechanisms also correlated with level of development.

Using the framework proposed by Harrigan[14], but concerned with analyzing the role of factor endowments on specialization dynamics, Redding[23] utilizes distribution dynamics to explore this issue. In his framework, a country's pattern of specialization at any point in time is characterized by the distribution of shares of GDP across industries. Its dynamics are represented by the evolution of the entire cross-sectional distribution over time. To implement the model Redding[23] employs data on 20 industries in 7 OECD countries from 1970-1990. A comparison of GDP shares between 1970 and 1990 reveals substantial variation across sectors and countries. For example, the share of manufactures in GDP declines in all countries, although the rate of decline varies considerably across economies, from a decline of 30.6% in the United Kingdom to 10.1% in Denmark. There are also notable changes in the relative importance of individual sectors within manufacturing. Some sectors (e.g. Textiles and Ferrous metals) declined while others (e.g. Drugs and Radio/TV) rose. The rate of decline or increase varies noticeably across countries. For example, in Radio/TV, the rate of increase ranges from 19.8% in the United Kingdom to 62.5% in Japan and 297.6% in Finland.

Perhaps more importantly, Redding[23] concludes that in the short run, common cross-country effects such as technology progress are more important in explaining observed changes in specialization than factor endowments for the majority of the countries. Over longer periods, factor endowments become relatively more important, and in the infinite horizon, factor endowments account for most of the observed variation in specialization. This evidence is in line with the idea that changes in relative factor abundance occur gradually and take time to impact on outputs structures.

Overall, the factor proportions model provides a story about static and dynamic specialization around the world. Some evidence shows that technological differences across countries can produce similar patterns of specialization in spite of large differences in factor endowments (Schott[25]). Our model extends the standard factor-proportions theory to allow for technology differences across countries.

2.2 Biased technical change

This literature concerns the hypothesis that countries use different factor-complementary machines to produce the same products. This strand of research can also be divided into two different approaches. The first one assesses whether factor shares vary systematically with the level of development (e.g. Young[26], Gollin[13], Bernanke and Gurkaynak[3], and Ortega and Rodriguez[21]). The second investigates whether complementarities between inputs and technology bias technical change (e.g. Acemoglu[1], Caselli[6]).

The first literature initially found that labor shares in national income vary widely, ranging from 0.05 to 0.80 in international cross-sectional data (e.g. Elias[10] and Young[26]). Gollin[13] questioned these estimations by arguing that the widely used approach, which is based on Cobb-Douglas production functions, tends to underestimate the labor income of self-employed workers, and the corrected labor shares fall in the range of 0.65 to 0.80. This evidence was later reaffirmed by Bernanke and Gurkaynak[3], but rejected by Ortega and Rodriguez[21]. The later uses industrial survey data to explore the same question, and controlling for the measurement problem of self-employed workers it found a significant negative cross-sectional relationship between capital share and per capita income within industries. In a related paper, Dobbelaere and Mairesse[9], find that imperfections in the product and labor markets generate a wedge between factor elasticities in the production function and their corresponding shares in revenue, both at firm and industry level.

In the second approach, Acemoglu[1] shows how cross-country differences in factor endowments can bias technical change. In his framework, two forces shape technical change, price and market-size effects. The price effect reflects the incentives to generate technologies that create more expensive goods. The second effect captures the incentives to produce technologies for which there is a big market. While the former encourages innovations to complement scarce factors, the latter leads to technical change favoring abundant factors. The elasticity of substitution between two different factors determines how powerful these effects are. In the long run, technical change favors the abundant factor if the elasticity of substitution is sufficiently large.

Evidence of complementarities between factors of production and technology has been provided by Caselli[6], who explored the relationship between factor endowments and the composition of capital imports. The author finds that human-capital abundant countries devote a larger share of their investment to acquire complex technologies, which can only be employed by skilled-workers.

We depart from the neo-classical trade literature by relaxing the assumption of Hicks neutral technologies, and by allowing countries to make their own technology choices. We complement the biased-technical change literature by analyzing how countries' technology choices alter the impact of factor endowments on trade.

3 The Model

Let c=1 , . . . , C index countries, let f=1 , . . . , F index factors, and let j= 1 , . . . , J index industries. Assume that countries are open. Output of industry j in country c, Y_j^c, can be written as a constant elasticity of substitution (CES) production function of factor inputs f, V_{jf}^c, and factor-f-complementary machines, A_{jf}^c. Thus,

$$Y_j^c = [\sum_{f=1}^{F} \gamma_f (A_{jf}^{c^{1-\beta_j}} V_{jf}^{c^{\beta_j}})^{\frac{\sigma_j-1}{\sigma_j}}]^{\frac{\sigma_j}{\sigma_j-1}}. \tag{1}$$

$\gamma_f \in (0,1)$ is a distribution parameter that captures how important factor f is in the production process. Specifically, we assume $\sum_{f=1}^{F} \gamma_f = 1$. Parameter σ_j is the elasticity of substitution between two factors and A_{jf}^c has the following functional form:

$$A_{jf}^c = [\int_0^{N_f^W} a_{jf}^c(i)^\alpha di]^{\frac{1}{\alpha}}. \tag{2}$$

N_f^W stands for the number of varieties of factor-f-complementary machines available in the global market, and $a_{jf}^c(i)$ for the units of variety i. Parameter α determines the elasticity of substitution between any two varieties of such machines.

Final goods producers face a two-stage decision process. First, they decide how many units of each factor of production to hire. Second, they choose how many machines to buy to complement each factor. In doing so, they take technology prices as given, because countries are small. The machines belong to the category of general purpose technology, and they can be used in different sectors. The world's technological market has a monopolistic competitive structure. Each monopolist from country x, with $x = 1, ..., C$, that produces technology to complement factor f sets a rental price $p_{jf}^{c,x}(i)$ per unit of machine i supplied to firms of industry j in country c. She faces a production cost, μ_f^x, and a transport cost, $\tau_f^{c,x}$, per unit of invented machine she sells to firms in country c.

4 Equilibrium

To find the equilibrium of the model we proceed in the following manner. First, we solve the equilibrium for a representative sector. Second, we characterize the equilibrium for the whole economy. To solve the equilibrium for a sector we need to find the solutions to the final good producers' problem and technology suppliers'problem. This is presented in the following sections.

4.1 Final Good Producers

Firms choose how many machines to buy in order to complement each production factor.[1] The problem for a representative firm in sector j can be written as follows:[2]

$$min_{\{a^c_{fj}(i)\}}\{\sum_{f=1}^{F}[\int_0^{N_f^W} p_{jf}^{c,x_i}(i)a^c_{jf}(i)di]\} \tag{3}$$

subject to the following constraints:

1. $[\sum_{f=1}^{F}\gamma_f(A_{jf}^{c^{1-\beta_j}}Q_{fj}^{c^{\beta_j}})^{\frac{\sigma_j-1}{\sigma_j}}]^{\frac{\sigma_j}{\sigma_j-1}} \geq 1$
2. $A^c_{jf}=[\int_0^{N_f^W} a^c_{jf}(i)^\alpha di]^{\frac{1}{\alpha}}$

The first order conditions for problem (3) deliver the following expression for the demand of machine i that complements factor z per unit of output:

$$a^c_{jz}(i)=\frac{E^c_z}{P^c_{jz}}\frac{p_{jz}^{c^{-\varepsilon}}(i)}{P_{jz}^{c^{-\varepsilon}}}. \tag{4}$$

E^c_z represents the expenditures that country c devotes to complement factor z, $P_{jz}^{c^{1-\varepsilon}} \equiv \int_0^{N_z^W} p_{jz}^{c^{1-\varepsilon}}(i)di$, and $\varepsilon \equiv \frac{1}{1-\alpha}$ is the elasticity of substitution between two varieties of machines z.[3][4] Equation (4) implies that the demand of machine i is an increasing function of real expenditure on technology z, $\frac{E^c_z}{P^c_{jz}}$, and a negative function of the price of the machine, $p^c_{jz}(i)$.

Given the demand for machines, firms minimize unit cost functions to determine the optimal unit factor input requirements. Specifically, they solve the following problem:

$$min_{\{V^c_{fj}\}_{f=1,\ldots,F}}\{\sum_{f=1}^{F} w^c_f V^c_{fj}\} \tag{5}$$

subject to the following constraints:

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[1] We solve the model backward because producers are rational agents.

[2] For the sake of simplicity firms' subindexes are omitted.

[3] For the sake of simplicity we assume that E^c_z is given.

[4] See the Appendix for the complete proof.

1. $[\sum_{f=1}^{F}\gamma_f(A_{jf}^{c^{1-\beta_j}}Q_{fj}^{c^{\beta_j}})^{\frac{\sigma_j-1}{\sigma_j}}]^{\frac{\sigma_j}{\sigma_j-1}} \geq 1$
2. $A_{jf}^c = [\int_0^{N_f^W} a_{jf}^c(i)^{\alpha}di]^{\frac{1}{\alpha}}$
3. $a_{jz}^c(i) = \frac{E_z^c}{P_{jz}^c}\frac{p_{jz}^{c^{-\varepsilon}}(i)}{P_{jz}^{c^{-\varepsilon}}}$,

where w_f^c stands for the cost per unit of factor f in country c. In the optimum, the marginal product of each factor equals its marginal cost. From the optimal conditions we can obtain the optimal Q_{jf}^c:

$$Q_{jf}^c = A_{jf}^{c^{-\frac{(1-\beta_j)}{\beta_j}}}\{\sum_{z=1}^{F}\gamma_z[(\frac{A_{jz}^c}{A_{jf}^c})^{\frac{\sigma_j}{\sigma_j(1-\beta_j)+\beta_j}}(\frac{\tilde{w}_f^c\gamma_z}{\tilde{w}_z^c\gamma_f})^{\frac{\sigma_j\beta_j}{\sigma_j(1-\beta_j)+\beta_j}}]^{\frac{(\sigma_j-1)}{\sigma_j}}\}^{-\frac{\sigma_j}{(\sigma_j-1)\beta_j}}. \quad (6)$$

$\tilde{w}_f^c$ is the cost per efficiency unit of factor *f*. Equation (6) shows that factor-f-complementary machines affect unit factor input requirements through two opposing effects. On the one hand, larger values of A_{jf}^c increase the productivity of the factor and reduce its requirements. On the other hand, factor f becomes relatively more productive than other factors, which increases firms' incentives to hire more units. The sign of the net-effect depends on which effect dominates. Lower values of $\tilde{w}_f^c$ (γ_z), and increasingly negative (positive) differences between $\tilde{w}_f^c$ (γ_f) and $\tilde{w}_z^c$ (γ_z), for $z \neq f$ and $z = 1, ...F$, make the second effect more prominent.

4.2 Technology Suppliers

Recall that any monopolist localized in country x faces a marginal cost $\mu_z^x\tau_z^{c,x}$ for manufacturing and delivering one unit of technology z to country c.[5] The profits of this monopolist supplying machine i to country c are as follows:

$$\pi_{jz}^{c,x}(i) = [p_{jz}^{c,x}(i) - (\mu_z^x\tau_z^{c,x})]\frac{E_z^c}{P_{jz}^c}\frac{p_{jz}^{c^{-\varepsilon}}(i)}{P_{jz}^{c^{-\varepsilon}}}. \quad (7)$$

Maximization of equation (7) with respect to $p_{jz}^{c,x}(i)$ delivers the following optimal price,

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[5] Since we are not concerned with modeling the innovation-entry decision, we assume the number of innovators is exogenously given.

$$p_{jz}^{c,x}(i) = (\mu_z^{x_i}\tau_z^{c,x_i})(\frac{\varepsilon}{\varepsilon-1}), \tag{8}$$

which is a constant markup over the marginal cost of producing and transporting a unit of technology. This markup depends negatively on the elasticity of substitution between varieties of z-machines. Inserting equation (8) into (4) gives the solution for $a_{jz}^c(i)$,

$$a_{jz}^c(i) = (\frac{\varepsilon-1}{\varepsilon})\frac{E_z^c(\mu_z^{x_i}\tau_z^{c,x_i})^{-\varepsilon}}{\int_0^{N_z^W}(\mu_z^{x_n}\tau_z^{c,x_n})^{1-\varepsilon}dn}. \tag{9}$$

Inserting equation (9) into (2) provides the solution for A_{jz}^c,

$$A_{jz}^c = (\frac{\varepsilon-1}{\varepsilon})\frac{E_z^c}{N_z^W}[\int_0^{N_z^W}(\frac{\mu_z^{x_n}\tau_z^{c,x_n}}{N_z^W})^{1-\varepsilon}dn]^{\frac{1}{\varepsilon-1}}. \tag{10}$$

To finish characterizing the equilibrium for this sector, we insert equation (10) into (6) to obtain the final expression for Q_{jz}^c,

$$Q_{jz}^c = \{(\frac{\varepsilon-1}{\varepsilon})\frac{E_z^c}{N_z^W}[\int_0^{N_z^W}(\frac{\mu_z^{x_n}\tau_z^{c,x_n}}{N_z^W})^{1-\varepsilon}dn]^{\frac{1}{\varepsilon-1}}\}^{\frac{-(1-\beta_j)}{\beta_j}}\Upsilon_{jz}^{c\,\frac{-\sigma_j}{(\sigma_j-1)\beta_j}} \tag{11}$$

where

$$\Upsilon_{jz}^c = \{\sum_{f=1}^{F}\gamma_f[(\frac{E_f^c}{E_z^c})(\frac{\int_0^{N_f^W}(\mu_z^{x_n}\tau_z^{c,x_n})^{1-\varepsilon}dn}{\int_0^{N_z^W}(\mu_z^{x_m}\tau_z^{c,x_m})^{1-\varepsilon}dm})^{\frac{1}{\varepsilon-1}}]^{\frac{\sigma_j}{\sigma_j(1-\beta_j)+\beta_j}}(\frac{\tilde{w}_z^c\gamma_f}{\tilde{w}_f^c\gamma_z})^{\frac{\sigma_j\beta_j}{\sigma_j(1-\beta_j)+\beta_j}}\}^{\frac{\sigma_j-1}{\sigma_j}}. \tag{12}$$

A comparison of equation (11) with the neo-classical factor proportions model reveals that cross-country differences in technology prices are a source of cross-country variation in unit factor input requirements. This result constitutes an important departure from the model with Hicks neutral technology.

4.3 The Economy

To analyze how technology choices affect the impact of factor endowments on trade, we need to solve the equilibrium for the whole economy. Employing matrix notation, we define $\mathbf{Q}^c$ as the matrix of unit factor input requirements for economy c. Market clearing conditions in this economy are as follows:

$$\mathbf{Q}^c\mathbf{Y}^c = \mathbf{V}^c, \tag{13}$$

where $\mathbf{Y}^c$ is the vector of sectoral outputs and $\mathbf{V}^c$ is the vector of factor endowments. Assuming that the number of goods is equal to the number of products, and denoting by $\mathbf{R}^c$ the inverse of matrix $\mathbf{Q}^c$, it is possible to express output of country c as a linear function of country c's factor endowments. Specifically,

$$\mathbf{Y}^c = \mathbf{R}^c\mathbf{V}^c. \tag{14}$$

If countries can be clustered in K groups, such that two countries belong to the same group if they make identical technology choices, we can express output of country c, which belongs to group k, $\mathbf{Y}^{c,k}$, with $k = 1, ..., K$, and worldwide output, $\mathbf{Y}^w$, as follows:

$$\mathbf{Y}^{c,k} = \mathbf{R}^k\mathbf{V}^{c,k} \tag{15}$$

and

$$\mathbf{Y}^w = \sum_{k=1}^{K} \mathbf{R}^k\mathbf{V}^{w,k}, \tag{16}$$

respectively. $\mathbf{V}^{w,k}$ is the vector of factor endowments of group k. Denoting by TB^c the trade balance of country c and by s_c country c's share of world consumption, net-exports of this economy are

$$\mathbf{NX}^c = \mathbf{Y}^c - s_c\mathbf{Y}^w = R^k(\mathbf{V}^{c,k} - s_c\mathbf{V}^{w,k}) - \sum_{z=1,z\neq k}^{K} R^z s_c \mathbf{V}^{w,z}. \tag{17}$$

The previous system provides the following estimating equation for the net-exports in sector j by country c, which belongs to technology group k:

$$NX_j^{c,k} = \sum_{f=1}^{F} r_{fj}^k (V_f^{c,k} - s_c V_f^k) + \sum_{z=1,z\neq k}^{K} \sum_{f=1}^{F} r_{fj}^z (-s_c V_f^z). \tag{18}$$

A comparison of equation (18) with the standard Rybczynski equation suggests that the concept of relative abundance of a factor in a country must be redefined when technology choices are introduced in the standard factor proportions model. Notably, a country's factor abundance is measured relative to the aggregate endowment of the technological group to which it belongs.

5 Empirical Strategy

This section presents an empirical implementation of our theory. We focus the analysis on the computer sector because it has received much attention in the technology adoption and growth literature. The section is structured as follows. First, we present the estimating procedure. Second, we describe the indicators and proxies we construct to test the theory. Third, we provide a preliminary analysis of the data.

5.1 Estimating procedure

The theoretical framework motivates an empirical model with two equations because net-exports determination is governed by different sets of parameters, and the set of parameters which determine a particular country's net-exports depend on the technological group to which it belongs. The most efficient method to estimate this model is the Full-Information Maximum Likelihood (FIML) estimator (see Chiburis and Lokshin[7]). However, we employ a less efficient method, the Two-Step approach. An implication of using the last technique is that it increases the chance of rejecting our theory.

In the first step, we estimate an Ordered-Probit equation, and we cluster countries across technological groups. To find the locations of the cut-off points that split the sample between technological regimes, we proceed in the following manner. First, we assume the sample splits in a particular number of groups i.e., 2, 3, or 4. Second, we follow the methodology implemented by Hotchkiss[17], which consists in estimating the model for every reasonable cut-off parameter. We start the process dividing the sample in a way that delivers the maximum number of groups with no more than 10% of the observations per each one. This provides the highest degree of freedom to move the cut-off points along the range of possible values.[6] Then we estimate the first step.

In the second step, we estimate the Rybczynski coefficients for each technological group. We use the OLS approach but we control for selection.[7] Finally, we apply the goodness of fit criterium to identify the set of estimated parameters that yields the least sum of squared residuals.

The first stage of the econometric model can be written as:

$$R_t^c = \Theta Z_t^c + \mu_t^c \tag{19}$$

$$\tilde{R}_t^c = \begin{cases} 0 & \text{if} \quad -\infty < R_t^c \leq R_{1t} \\ 1 & \text{if} \quad R_{1t} < R_t^c \leq R_{2t} \\ . & \\ . & \\ . & \\ K-1 & \text{if} \quad R_{K-1t} < R_t^c \leq \infty, \end{cases}$$

where R_t^c is a continuous variable that we construct to cluster countries across technological groups. This variable is intended to capture the technology choices that countries make. The following section explain the methodology, the variables, and the economic arguments we employ to build it. Θ is a vector of parameters, and Z_t^c is a vector that includes some of the variables we use to build R_t^c. In particular, these variables are: stock of capital, labor, and intellectual property rights (IPRs) of each country, as well as weighted averages of the stock of capital, labor, and IPRs of its technology suppliers. μ_t^c is a standard normal shock, and R_{1t}, R_{2t}, ..., R_{K-1t} are the unknown cut-off points, which satisfy the following condition: $R_{1t}< R_{2t}<, ...,< R_{K-1t}$. We also define $R_{0t} \equiv -\infty$ and $R_{Kt} \equiv \infty$ to avoid having to handle the boundary cases separately.

The second-stage Rybczynski equation is:

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[6] The cut-off points are moved in steps of 1 percentile of the continuous variable we employ to cluster countries across technological regimes.

[7] Specifically, we introduce the estimated $\hat{\lambda}_i^c \equiv \frac{\phi(\hat{R}_k - R^c) - \phi(\hat{R}_{k+1} - R^c)}{\Phi(\hat{R}_{jk+1} - R^c) - \Phi(\hat{R}_k - R^c)}$ as an explanatory variable of the Rybczynski equation corresponding to regime i.

$$NX_t^{c,k} = r_0 + \sum_{f=1}^{F} r_f^k (V_{ft}^{c,k} - s_c V_{ft}^k) + \sum_{f=1, z\neq k}^{F} r_f^z (-s_c V_{ft}^z) + \upsilon_t^{c,k} \tag{20}$$

$$NX_t^c = \begin{cases} NX_t^{c,k_0} & \text{if} \quad \tilde{R}_t^c = 0 \\ NX_t^{c,k_1} & \text{if} \quad \tilde{R}_t^c = 1 \\ . & \\ . & \\ . & \\ NX_t^{c,K-1} & \text{if} \quad \tilde{R}_t^c = K-1, \end{cases}$$

where $NX_t^{c,k}$ are the net-exports of computers for country c which belongs to group k in period t. r_f^k is the Rybczynski coefficient for factor f in technological group k. We include four factors of production: stock of capital, skilled-labor, unskilled-labor, and arable land. Given that in the economy there are more than four sectors, we follow the trade literature and we assume that the constant term, r_0, captures the mean effect of omitted factors.[8] The model relies on the following assumptions: **A1.** $\upsilon_t^{c,k} \sim N(0, \sigma_{\upsilon,k}^2)$, for $k = 1, ..., K$; **A2.** $\mu_t^c \sim N(0,1)$; **A3.** $\sigma_{\upsilon,kz}^2 = 0$, for $k \neq z$ and $k, z = 1, ..., K$; **A4.** $\sigma_{\upsilon,\mu}^2 \neq 0$.

As we mention at the beginning of this section, we estimate equations (19) and (20) using the Two-Step approach, which is less efficient than the FIML method. This implies that if we find evidence in line with our predictions, our theory is very robust. However, evidence against the theoretical results is not enough to reject the theory.

5.2 Indicators and proxies

This section describes the proxies we construct to estimate equations (19) and (20). It also documents the sources of data we employ for such purpose.

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[8] See Fitzgeral and Hallak[12], Harrigan[14], and Reeding[23] among others.

5.2.1 The technology selection variable

To construct variable R_t^c we rely on equation (10), which shows that the amount of machines that a country buys to complement a particular factor of production is a function of the marginal cost of manufacturing one machine, the transport cost, and the elasticity of substitution between two varieties of the same type of equipment.

The marginal cost of producing one unit of a machine is a function of the factor endowments of the country that supplies the equipment because they determine the prices of the inputs involved in the process. As our empirical implementation focuses on the computer sector, which is one of the most technologically advanced industries, we assume that to produce a computer, a country needs to acquire machines from the same sector. These equipments complement different factors of production, and they can be acquired domestically or imported from abroad. Therefore, the technology choices of a country are a function of its factor endowments as well as the weighted averages of the factor endowments of its technology suppliers, where each weight accounts for the transport cost, and is define as the inverse of the distance between the country that buys and the one that sells the machine.

Technology choices can also be affected by the IPRs of innovators' countries. One reason to justify this statement is that inventors of countries with weak IPRs may have incentives to provide more sophisticated and expensive technologies to avoid imitation. Another argument is that strong IPRs can encourage monopolists to charge a higher mark-up because they face no competition. In any case, a country's technology choice can also depend on its own IPRs as well as the inverse-distance-weighted average of the IPRs of its technology suppliers.

Once we identify the variables that affect countries' technology choices, wee proxy variable R_t^c with the predicted value for the principal factor in a principal component analysis of these variables (stock of capital, labor, arable land, and IPRs of each country as well as the corresponding distance-weighted averages of its technology suppliers).

The sources of data we employ to construct R_t^c are the following. Data on capital stocks come from Serven and Calder$\acute{o}$n[25], who extend the series provided by Penn-World Tables, version 5.6, using the perpetual inventory method. The labor force is from the International Labor Organization

(ILO). The endowment of arable land comes from the World Bank's World Tables. Data on intellectual property rights protection come from Park and Ginarte[22], who construct an index of patent rights using a coding scheme applied to national patent laws. Five categories of the patent laws were examined: (1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection. Each of these categories (per country, per time period) was scored a value ranging from 0 to 1. The un-weighted sum of these five values constitutes the overall value of the IPRP index. Bilateral data on computers imports come from Feenstra et al.[11]. The data are available at 4-digit level of the Standard International Trade Classification, Revision 2. We consider the following categories, 7521, 7522, 7523, and 7528.[9] The source for bilateral distances is the CIA World Factbook.

5.2.2 Net-exports of computers

To estimate equation (20) we need data on net-exports of computers. The source of these data is Feenstra et al.[11]. This data set provides information on bilateral trade flows at 4-digit level of the Standard International Trade Classification, Revision 2. Our net-exports variable includes the following categories, 7521, 7522, 7523, and 7528.

5.2.3 Factor endowments

To estimate the Rybczynski coefficients we need data on factor endowments. We consider four factors: stocks of capital, skilled-labor, unskilled-labor, and arable land. Data on capital stocks come from Serven and Calderón[25]. The labor force is from the International Labor Organization (ILO). To calculate endowments of high- and low-skilled labor, we use data on educational attainment from Barro and Lee[2]. Skilled-workers are defined as the population economically active which have attained at least secondary school. The rest

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[9] Code 7521 refers to Analogue and hybrid data processing machines; code 7522 refers to Complete digital data processing machines, comprising in the same housing the central processing unit and one output unit; code 7523 refers to Complete digital central processing units, digital processors consisting of arithmetical, logical, and control elements; codes 7528 refers to Off-line data processing equipment, n.e.s.

is considered unskilled-labor. The endowment of arable land comes from the World Bank's World Tables.

The resulting sample covers 73 developing and developed countries over the period 1980-2000. Table 1 presents summary statistics of the variables described in previous sections, and the Appendix provides a list of the countries included for the analysis.

[Insert Table 1 about here]

5.3 Net exports of computers and endowments

A preliminary review of the data suggests that countries with notably different factor endowments have comparable net-exports of computers. It also shows that countries close to each other in the ranking of factor endowments are net-exporters and net-importers of computers. Table 2 displays the countries that are located at the top and the bottom of the distribution of countries ranked by their net-exports of computers. For each of these economies, the table reports their capital and skilled-labor abundance.

[Insert Table 2 about here]

A comparison of columns (3) and (5) shows that within the group of top net-exporters, there are countries such as India, China, Indonesia, and Philippines, which belong to the bottom of the capital-labor ratio ranking, while other economies such as Japan, Singapore and Korea Republic belong to the top of such distribution. A similar observation can be derived from the comparison of columns (3) and (7). Among the group of top net-exporters, there are economies such as India, Indonesia and Costa Rica, which belong to the bottom of the skilled-labor distribution, and other countries such as Japan, Korea Rep., and Ireland, which belong to the top of this distribution.

6 Results

We organize our discussion of the results in the following manner. First, we analyze the statistical significance of the estimated parameters that allow us to test the econometric specification we implement. Second, we interpret the outcomes from the estimation of the selection equation. Third, we discuss the results from the estimation of the Rybczynski equations. Table 3 presents the estimation outputs. Each column splits the results across technological regimes.

[Insert Table 3 about here]

6.1 Specification tests

The econometric results suggest the existence of up to four technological regimes. Table 3 shows that the model that fits best the data is the one with four regimes. The optimal cutoffs are found at the 35th, 50th, and 90th percentiles of the distribution of variable R_t^c, and they are statistically different from zero at 1% level. Some of the estimated coefficients that correct for selection (Lambdas) are also statistically significant at 5% level. As the number of regimes increases, trading partners' endowments and IPRs become significant and rise the probability of belonging to the highest regime. This can explain why countries such as Albania, Costa Rica, and Jamaica appear in the third regime.

6.2 Technology selection

Table 3 shows that many of the explanatory variables are statistically significant in the three specifications. Interestingly, the results show that as the number of technological regimes increases, the coefficients corresponding to the endowments and IPRs of trading partners become statistically more significant. This result has an important economic implication. As it shows that in open economies, the adopted technologies are not necessarily the ones that complement relatively abundant factors. The outcomes indicate that the endowments and institutions of close economies are also very important. Table 4 shows the final distribution of countries across technological groups.

[Insert Table 4 about here]

6.3 Rybczynski equation

The results indicate that capital abundance is a source of comparative advantage in the production of computers for countries that belong to the lowest technological regimes. However, it is a source of disadvantage for countries that belong to the highest regimes. By contrast, skilled-labor abundance is statistically significant and has a positive impact on the net-exports of computers of the highest regimes. Both results appear systematically in the three specifications. Notably, as the number of regimes increases, unskilled-labor abundance becomes significant and has a positive impact on the net-exports of computers for the lowest regime, while skilled-labor abundance affects net-exports of computers in an opposite direction. Land is significant and has a negative effect on most regimes. This result is robust to different specifications. All these effects are statistically different from zero at 1 % level.

Combining information on the dependent and explanatory variables for each technological group together with the estimated Rybczynski coefficients of column (3) we find that a 1$ increase in the relative endowment of capital leads to a 0.0001$ increase in the net-exports of computers of the lowest regime, and a 0.0028$ reduction in the net-exports of the highest regime. These effects are economically large: a 1 standard deviation increase in the relative abundance of capital generates a 266.542 standard deviations increase in the net-exports of the first regime, and a 7,463.15 standard deviations reduction in the net-exports of the highest regime.[10] An increase of 1 worker in the relative abundance of skilled-labor leads to a 14.45$ reduction in the net-exports of regime 1, and a 28.312$ and 577.65$ increment in the net-exports of regimes 3 and 4, respectively. The economic effects are small: a 1 standard deviation increase in the relative abundance of skilled-labor delivers a 0.513 standard deviation reduction in the net-exports of regime 1, and a 0.41- and 3.03 standard deviations increase in the net-exports of regimes 3 and 4, respectively. By contrast, an increase of 1 worker in the relative abundance of unskilled-labor generates a 4.043$ increase in the net-exports of regime 1. The economic effect is very modest: a 1 standard deviation increase in the relative abundance of unskilled-labor is associated to a 0.161 standard deviation increase in the net-exports of regime 1. Finally, an increment of 1 hectare in the relative abundance of arable land leads to a 3$ reduction of net-exports in regime 1 and a 119$ reduction in the net-exports of regime 4.

Having presented preliminary evidence in support of our theory, we now

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[10] See the Appendix for a description of the standard deviation of the dependent and independent variables per technological regime.

move to provide a formal test of the null hypotheses that the Rybczynski coefficients are equivalent across technological groups. Table 5 reports the p-values corresponding to the hypothesis that the Rybczynski coefficients are statistically equivalent.

[Insert Table 5 about here]

The Table shows that in spite the fact that we use the less efficient method there is substantial evidence supporting our theory. The Rybczynski coefficients vary across technological groups.

7 Conclusion

The neoclassical model of trade predicts that international specialization will be jointly determined by cross-country differences in relative factor endowments and exogenous technology levels. In this paper we develop a model that relaxes the Hicks neutral technology assumption by allowing countries to adopt their own technologies. The marriage of literatures on biased technical change and trade yields a tractable theory whereby differences in factor endowments bias the technical change towards particular factors of production, and thus unit factor input requirements vary across economies. Using data on net exports of a single industry, computers, and factor endowments for 73 countries over the period 1980-2000 we test the theory. The descriptive and econometric evidence suggests that once technological choices are considered, countries with different factor endowments can become net exporters of the same product.

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8 Appendix

Proof first stage of FGP's problem

The first order condition for variety i is

$$p^c_{jz}(i) = \frac{\partial A^c_{jz}}{\partial a^c_{jz}(i)} K[\Phi^1_{jz}(i) + \Phi^2_{jz}(i) + \sum_{f=1;f\neq z}^{F} \Phi^3_{jfz}(i)] \tag{21}$$

where

$$\Phi^1_{jz}(i) = \gamma_z(1-\beta_j)\frac{(\sigma_j-1)}{\sigma_j} A^{c^{(1-\beta_j)\frac{(\sigma_j-1)}{\sigma_j}-1}}_{jz} Q^{c^{\beta_j\frac{(\sigma_j-1)}{\sigma_j}}}_{jz} \tag{22}$$

$$\Phi^2_{jz}(i) = \gamma_z\beta_j\frac{(\sigma_j-1)}{\sigma_j} A^{c^{(1-\beta_j)\frac{(\sigma_j-1)}{\sigma_j}}}_{jz} Q^{c^{\beta_j\frac{(\sigma_j-1)}{\sigma_j}-1}}_{jz} \frac{\partial Q^c_{jz}}{\partial A^c_{jz}} \tag{23}$$

$$\Phi^3_{jfz}(i) = \gamma_f\beta_j\frac{(\sigma_j-1)}{\sigma_j} A^{c^{(1-\beta_j)\frac{(\sigma_j-1)}{\sigma_j}}}_{jz} Q^{c^{\beta_j\frac{(\sigma_j-1)}{\sigma_j}-1}}_{jz} \frac{\partial Q^c_{jf}}{\partial A^c_{jz}} \tag{24}$$

$$K = \lambda\frac{\sigma_j}{(\sigma_j-1)}[\sum_{f=1}^{F}\gamma_f(A^{c^{1-\beta_j}}_{jf} V^{c^{\beta_j}}_{jf})^{\frac{\sigma_j-1}{\sigma_j}}]^{\frac{\sigma_j}{\sigma_j-1}-1} \tag{25}$$

and λ is the shadow price of the constraint. Since $[\Phi^1_{jz}(i) + \Phi^2_{jz}(i) + \sum_{f=1;f\neq z}^{F}\Phi^3_{jfz}(i)] = [\Phi^1_{jz}(n) + \Phi^2_{jz}(n) + \sum_{f=1;f\neq z}^{F}\Phi^3_{jfz}(n)]$, we can divide the first order condition for variety i by that for variety n and obtain the following expression

$$\frac{p^c_{jz}(i)}{p^c_{jz}(n)} = \frac{\frac{\partial A^c_{jz}}{\partial a^c_{jz}(i)}}{\frac{\partial A^c_{jz}}{\partial a^c_{jz}(n)}} = \frac{a^{c^{-(1-\alpha)}}_{jz}(i)}{a^{c^{-(1-\alpha)}}_{jz}(n)} \tag{26}$$

Multiplying both size of equation (21) by $p^c_{jz}(i)$ and integrating over i, we obtain the following result

$$a^c_{jz}(i) = \frac{E^c_z p^{c^{-\varepsilon}}_{jz}}{P^{c^{1-\varepsilon}}_{jz}} \tag{27}$$

where $E^c_z \equiv \int_0^{N^W_z} p^c_{jz}(i)a^c_{jz}(i)di$.

Table 1. Summary Statistics

Variable	Obs	Mean	Std.Dev	Min	Max
Net_Exports	365	1.70E+04	2.58E+06	-3.11E+07	1.32E+07
Stock_of_K	365	7.94E+11	2.16E+12	1.58E+09	2.13E+13
Unskilled_Labor	365	1.39E+04	5.06E+04	6.59E+01	4.14E+05
Skilled_Labor	365	7.69E+03	2.65E+04	1.42E+01	2.58E+05
Land (hect.)	365	1.30E+07	3.19E+07	1.00E+03	1.89E+08
IPRP	365	2.30E+00	1.24E+00	0.00E+00	4.88E+00
IPRP_of_Trading Partners	365	7.06E-02	1.25E-01	3.23E-04	7.94E-01

Table 2. Net Exporters and Factor Endowments

Country	Net-Exports	Ranking	Capital/ Labor	Ranking	Skilled Lab/ Labor	Ranking
China	1.24E+07	73	1.45E+07	23	38.4	37
Malaysia	1.18E+07	72	5.76E+07	47	50.5	49
Singapore	1.05E+07	71	2.03E+08	71	59.1	57
Korea Rep.	9187286	70	2.42E+08	73	75.3	69
Philippines	6350562	69	1.61E+07	26	53.6	51
Ireland	5953102	68	1.04E+08	53	64.1	59
Japan	5000000	67	1.85E+08	69	71.9	66
Mexico	4675278	66	4.48E+07	45	40.3	38
Indonesia	2329506	65	1.61E+07	25	26.8	24
India	33958	64	7649168	16	22.2	18
Costa Rica	21775	63	1.99E+07	30	29.9	30
Min.	21775		7.65E+06		22.2	
Max.	12400000		2.42E+08		75.3	
Mean	6204679		4.48E+07		50.5	
Std.Dev.	4384442		8.71E+07		18.2	
Austria	-1029426	11	1.65E+08	68	70.1	63
Denmark	-1196473	10	1.44E+08	62	68.1	62
UK	-1200000	9	1.11E+08	54	58.2	56
Sweden	-1592865	8	1.32E+08	58	80.3	71
Spain	-1613921	7	1.13E+08	56	46.9	44
Switzerland	-2773254	6	2.03E+08	72	71.0	65
Australia	-3062108	5	1.48E+08	64	73.4	68
France	-3942278	4	1.52E+08	65	55.7	54
Italy	-4117605	3	1.53E+08	66	46.7	43
Canada	-5744931	2	1.40E+08	60	79.6	70
USA	-3.11E+07	1	1.60E+08	67	89.7	73
Min.	-31100000		1.11E+08		46.7	
Max.	-1196473		2.03E+08		89.7	
Mean	-5634344		1.48E+08		70.1	
Std.Dev.	9069688		2.53E+07		13.9	

Note: This table reports the values of net-exports of computers, capital-labor ratios, and skiiled_labor-labor ratios for the countries located at the top and the bottom of the distribution of countries ranked according to their net-exports of computers during the year 2000. Figures corresponding to net-exports are measrued in nominal of U.S dollars. Figures for the skilled-labor/labor are measured in percentage units.

Table 3. Technology Adoption and Factor Intensities: Estimation Results with 2, 3, and 4 Regimes

		(1)	(1)	(2)	(2)	(2)	(3)	(3)	(3)	(3)
	NX	Regime 1	Regime 2	Regime 1	Regime 2	Regime 3	Regime 1	Regime 2	Regime 3	Regime 4
Second-step estimations	Rabund(K)	0.0008	-0.0008	0.0009	0.0001	-0.0032	0.00013	0.00005	0.00036	-0.00285
		[0.0001]**	**[0.0003]****	**[0.0001]****	[0.00026]	**[0.0010]****	**[0.00004]*****	[0.00012]	[0.00016]	**[0.0009]*****
	Rabund(sk-L)	-9.8300	142.604	-9.339	71.899	613.177	-14.451	-5.082	28.312	577.055
		[12.506]	**[69.456]****	[13.398]	[46.522]	**[207.799]*****	**[3.780]*****	[3.966]	**[14.507]****	**[177.116]*****
	Rabund(unsk-L)	13.181	-24.651	11.632	-24.616	216.733	4.043	0.001	-10.367	127.183
		[8.548]	[18.868]	[8.806]	**[13.442]***	[179.452]	**[1.212]*****	[0.0004]	[7.701]	[159.148]
	Rabund(Land)	-33.000	-27.0000	-32.000	-2.000	-140.000	-3.0000	-0.00001	-8.000	-119.000
		[8.000]**	[18.000]	**[9.000]*****	[12.000]	**[25.000]*****	**[1.000]*****	**[7.65E-06]***	[8.000]	**[47.000]*****
	K_og	0.0029	0.0186	0.001	-0.011	-0.013	-0.0110	N.A	-0.0019	-0.0086
		[0.0031]	[0.013]	[0.0104]	[0.024]	[0.011]	**0.005**	N.A	[0.0062]	[0.0069]
	sk-L_og	-394.891	1875.000	-135.000	1213.000	82.361	954.954	N.A	87.888	580.633
		[434.703]	[1090]	[1201]	[3056]	[1059]	**[463.647]****	N.A	[1508]	[1976]
	unsk-L_og	50.2310	1666.000	68.996	134.024	137.020	-215.767	N.A	-92.298	-1120.818
		[163.507]	[1003.000]	[764.724]	[1199.000]	[457.002]	**[95.846]****	N.A	[745.621]	[3404.000]
	Land_og	41.000	-1353.000	-96.000	-235.000	176.000	278	N.A	-44	638
		[194.000]	[990.000]	[789.000]	[1071.000]	[562.000]	**[128.000]****	N.A	[1092.000]	[2594.000]
First-step estimations	K	2.82E-13		2.01E-13			1.57E-13			
		[8.19E-14]***		**[5.44E-14]*****			**[5.23E-14]*****			
	L	-1.72E-09		9.33E-10			1.27E-09			
		[1.38E-9]		[1.25E-9]			[1.11E-09]			
	Wav(K)	-1.20E-13		5.83E-12			1.09E-11			
		[4.78 E-12]		**[3.50E-12]***			**[3.93E-12]*****			
	Wav(L)	3.47E-08		5.00E-07			0.000001			
		[3.1E-08]		**[2.51E-07]****			**[0.0000002]*****			
	IPRs	11.610		4.895			2.415			
		[2.221]***		**[1.147]*****			**[1.104]****			
	Wav(IPRs)	0.009		0.113			0.356			
		0.122		[0.112]			**[0.081]*****			
Specification tests	Cut-off_1	2.072		2.170			0.667			
		[0.280]***		**[0.276]*****			**[0.169]*****			
	Cut-off_2			3.007			0.968			
				[0.305]***			**[0.173]*****			
	Cut-off_3						4.0338			
							[0.334]***			
	Cut-off (percentile)	79th		79th, 90th			35th, 50th, 90th			
	Lambda_1	-2367044		-1939318			84388			
		[252751]***		**[389255]*****			**[36523]****			
	Lambda_2	-3063927		1169147			-4860			
		[1036677]***		[781600]			[4047]			
	Lambda_3			621236			-1003200			
				[1887361]			**[432917]****			
	Lambda_4						-1157714			
							[1240490]			
	SSq.R	2.42E+15		2.41812E+15			2.41800E+15			
	N.obs.	365		365			365			

Note 1: This table reports the outcomes of a Two-Step estimation. The first step estimates an Ordered-Probit equation. The dependent variable of this equation is categorical and clusters countries across technological regimes. The independent variables are: stock of capital (K), labor (L), IPRs (IPRs) of a country, and weighted averages of the stock of capital (Wav(K)), labor (Wav(L)), and IPRs(Wav(IPRs)) of its technology suppliers. Each weight is the inverse of the distance between the country and its supplier. The second step corresponds to the estimation of the Rybczynski equations for each technology group. The dependent variable is net-exports of computers (NX). A subset of independent variables includes measures of the abundance of a factor in a country relative to the endowment of the same factor in the technology group to which it belongs. This set contains proxies for the relative abundance of capital endowment (Rabund(K)), relative abundance of skilled-labor endowment (Rabund(sk-L)), relative abundance of unskilled-labor endowment (Rabund(unsk-L)), and relative abundance of arable land endowment (Rabund(Land)). Another subset of explanatory variables includes the capital endowments (K_og), skilled-labor endowments (sk-L_og), unskilled-labor endowments (unsk-L_og) and land endowments (Land_og) of other groups.

Note 2: Column (1) presents the estimation outcomes of a 2-regimes model, column (2) displays the results of a 3-regimes model, and column (4) reports the results of of a 4-regimes model. *, **, and *** means statistically different from zero at 10, 5 and 1% level of significance. Robust standard errors are inside brackets. Cut-off_i, for i=1,2,3, refers to the estimated value of the technological variable (R) at which the sample splits between regime i and regime i+1. Cut-off (percentile) indicates what percentage of total observations are below each cut-off point. Lambda_i is the coefficient of the selection variable we include in the Rybczynski equation of regime i. N.A=not available due to collinearity. This occurs in model (3), regime 2, where all observations correspond to the same period. A negative intercept (not reported) captures the effect of the endowments of observations in the other regimes.SSqR means sum of squared residuals.

Table 4. Composition of technological groups

Year	Country	2-Reg.	3-Reg.	4-Reg.	Year	Country	2-Reg.	3-Regimes	4-Reg.	Year	Country	2-Reg.	3-Reg.	4-Reg.	Year	Country	2-Reg.	3-Reg.	4-Reg.	Year	Country	2-Reg.	3-Reg.	4-Reg.
1980	Algeria	1	1	3	1980	Ecuador	1	1	1	1980	Jordan	1	1	1	1980	Pakistan	1	1	1	1980	Sweden	2	2	3
1985	Algeria	1	1	3	1985	Ecuador	1	1	1	1985	Jordan	1	1	1	1985	Pakistan	1	1	3	1985	Sweden	2	2	3
1990	Algeria	1	1	3	1990	Ecuador	1	1	3	1990	Jordan	1	1	1	1990	Pakistan	1	1	3	1990	Sweden	2	2	3
1995	Algeria	1	1	3	1995	Ecuador	1	1	3	1995	Jordan	1	1	1	1995	Pakistan	1	1	3	1995	Sweden	2	2	3
2000	Algeria	1	1	3	2000	Ecuador	1	1	3	2000	Jordan	1	1	3	2000	Pakistan	1	1	3	2000	Sweden	2	1	3
1980	Argentina	1	1	3	1980	Egypt	1	1	1	1980	Kenya	1	1	1	1980	Panama	1	1	3	1980	Switzerland	2	2	3
1985	Argentina	1	1	3	1985	Egypt	1	1	3	1985	Kenya	1	1	1	1985	Panama	1	1	3	1985	Switzerland	2	3	4
1990	Argentina	1	1	3	1990	Egypt	1	1	3	1990	Kenya	1	1	1	1990	Panama	1	1	3	1990	Switzerland	2	2	3
1995	Argentina	1	1	3	1995	Egypt	1	1	3	1995	Kenya	1	1	1	1995	Panama	1	1	3	1995	Switzerland	2	1	3
2000	Argentina	1	1	3	2000	Egypt	1	1	3	2000	Kenya	1	1	2	2000	Panama	1	1	3	2000	Switzerland	2	2	3
1980	Australia	1	1	3	1980	El Salvador	1	1	3	1980	Korea Rep.	1	1	3	1980	Paraguay	1	1	3	1980	Syria	1	1	3
1985	Australia	1	1	3	1985	El Salvador	1	1	3	1985	Korea Rep.	1	1	3	1985	Paraguay	1	1	3	1985	Syria	1	1	1
1990	Australia	1	1	3	1990	El Salvador	1	1	3	1990	Korea Rep.	2	3	4	1990	Paraguay	1	1	1	1990	Syria	1	1	1
1995	Australia	1	1	3	1995	El Salvador	1	1	3	1995	Korea Rep.	2	2	3	1995	Paraguay	1	1	1	1995	Syria	1	1	1
2000	Australia	1	1	3	2000	El Salvador	1	1	2	2000	Korea Rep.	2	3	4	2000	Paraguay	1	1	2	2000	Syria	1	1	2
1980	Austria	2	3	4	1980	Finland	1	1	3	1980	Malawi	1	1	1	1980	Peru	1	1	1	1980	Togo	1	1	1
1985	Austria	2	2	3	1985	Finland	2	2	3	1985	Malawi	1	1	1	1985	Peru	1	1	1	1985	Togo	1	1	1
1990	Austria	2	2	3	1990	Finland	2	2	3	1990	Malawi	1	1	1	1990	Peru	1	1	1	1990	Togo	1	1	1
1995	Austria	2	3	4	1995	Finland	1	1	3	1995	Malawi	1	1	1	1995	Peru	1	1	3	1995	Togo	1	1	1
2000	Austria	2	3	4	2000	Finland	1	1	3	2000	Malawi	1	1	2	2000	Peru	1	1	3	2000	Togo	1	1	2
1980	Benin	1	1	1	1980	France	2	3	4	1980	Malaysia	1	1	1	1980	Philippines	1	1	3	1980	Trinidad and Tobago	1	1	3
1985	Benin	1	1	1	1985	France	2	3	4	1985	Malaysia	1	1	3	1985	Philippines	1	1	1	1985	Trinidad and Tobago	1	1	3
1990	Benin	1	1	1	1990	France	2	3	4	1990	Malaysia	1	1	3	1990	Philippines	1	1	1	1990	Trinidad and Tobago	1	1	3
1995	Benin	1	1	1	1995	France	2	3	4	1995	Malaysia	1	1	3	1995	Philippines	1	1	3	1995	Trinidad and Tobago	1	1	1
2000	Benin	1	1	2	2000	France	2	3	4	2000	Malaysia	1	1	3	2000	Philippines	1	1	3	2000	Trinidad and Tobago	1	1	2
1985	Bolivia	1	1	1	1985	Greece	1	1	3	1985	Mali	1	1	1	1985	Portugal	2	2	3	1985	Tunisia	1	1	3
1990	Bolivia	1	1	1	1990	Greece	1	1	3	1990	Mali	1	1	1	1990	Portugal	2	2	3	1990	Tunisia	1	1	3
1995	Bolivia	1	1	1	1995	Greece	1	1	3	1995	Mali	1	1	1	1995	Portugal	2	2	3	1995	Tunisia	1	1	3
1980	Bolivia	1	1	3	1980	Greece	1	1	3	1980	Mali	1	1	1	1980	Portugal	1	1	3	1980	Tunisia	1	1	3
2000	Bolivia	1	1	2	2000	Greece	1	1	3	2000	Mali	1	1	2	2000	Portugal	1	1	3	2000	Tunisia	1	1	3
2000	Brazil	1	1	3	2000	Iceland	1	1	3	2000	Mauritius	1	1	2	2000	Romania	2	2	3	2000	Turkey	1	1	3
1980	Brazil	1	1	3	1980	Iceland	1	1	3	1980	Mauritius	1	1	1	1980	Romania	1	1	3	1980	Turkey	1	1	1
1985	Brazil	1	1	3	1985	Iceland	1	1	3	1985	Mauritius	1	1	1	1985	Romania	1	1	1	1985	Turkey	1	1	3
1990	Brazil	1	1	3	1990	Iceland	1	1	3	1990	Mauritius	1	1	1	1990	Romania	1	1	1	1990	Turkey	1	1	3
1995	Brazil	1	1	3	1995	Iceland	1	1	3	1995	Mauritius	1	1	1	1995	Romania	1	1	1	1995	Turkey	1	1	3
1980	Cameroon	1	1	1	1980	India	2	2	3	1980	Mexico	2	2	3	1980	Rwanda	1	1	1	1980	Uganda	1	1	1
1985	Cameroon	1	1	1	1985	India	1	1	3	1985	Mexico	1	1	3	1985	Rwanda	1	1	1	1985	Uganda	1	1	1
1990	Cameroon	1	1	1	1990	India	1	1	3	1990	Mexico	1	1	3	1990	Rwanda	1	1	1	1990	Uganda	1	1	1
1995	Cameroon	1	1	1	1995	India	1	1	3	1995	Mexico	1	1	3	1995	Rwanda	1	1	1	1995	Uganda	1	1	1
2000	Cameroon	1	1	2	2000	India	1	1	3	2000	Mexico	1	1	3	2000	Rwanda	1	1	2	2000	Uganda	1	1	2
1980	Canada	2	3	4	1980	Indonesia	1	1	1	1980	Mozambique	1	1	1	1980	Senegal	1	1	1	1980	United Kingdom	2	3	4
1985	Canada	2	3	4	1985	Indonesia	1	1	3	1985	Mozambique	1	1	1	1985	Senegal	1	1	1	1985	United Kingdom	2	3	4
1990	Canada	2	3	4	1990	Indonesia	1	1	3	1990	Mozambique	1	1	1	1990	Senegal	1	1	1	1990	United Kingdom	2	3	4
1995	Canada	2	3	4	1995	Indonesia	1	1	1	1995	Mozambique	1	1	1	1995	Senegal	1	1	1	1995	United Kingdom	2	3	4
2000	Canada	2	3	4	2000	Indonesia	1	1	3	2000	Mozambique	1	1	2	2000	Senegal	1	1	2	2000	United Kingdom	2	3	4
1980	Chile	1	1	3	1980	Iran	1	1	1	1980	Nepal	1	1	1	1980	Sierra	1	1	1	1980	United States	2	3	4
1985	Chile	1	1	3	1985	Iran	1	1	3	1985	Nepal	1	1	1	1985	Sierra	1	1	1	1985	United States	2	2	3
1990	Chile	1	1	3	1990	Iran	1	1	3	1990	Nepal	1	1	1	1990	Sierra	1	1	1	1990	United States	2	3	4
1995	Chile	1	1	3	1995	Iran	1	1	1	1995	Nepal	1	1	1	1995	Sierra	1	1	1	1995	United States	2	3	4
2000	Chile	1	1	3	2000	Iran	1	1	3	2000	Nepal	1	1	2	2000	Sierra	1	1	2	2000	United States	2	3	4
1980	China	2	2	3	1980	Ireland	1	1	3	1980	Netherlands	2	3	4	1980	Singapore	1	1	3	1980	Uruguay	1	1	3
1985	China	1	1	3	1985	Ireland	2	2	3	1985	Netherlands	2	3	4	1985	Singapore	1	1	3	1985	Uruguay	1	1	3
1990	China	1	1	3	1990	Ireland	2	3	4	1990	Netherlands	2	3	4	1990	Singapore	1	1	3	1990	Uruguay	1	1	3
1995	China	1	1	3	1995	Ireland	2	2	3	1995	Netherlands	2	3	4	1995	Singapore	1	1	3	1995	Uruguay	1	1	3
2000	China	1	1	3	2000	Ireland	2	2	3	2000	Netherlands	2	3	4	2000	Singapore	1	1	3	2000	Uruguay	1	1	3
1980	Colombia	1	1	3	1980	Israel	1	1	3	1980	New Zealand	1	1	3	1980	South	1	1	3	1980	Venezuela	1	1	3
1985	Colombia	1	1	1	1985	Israel	1	1	3	1985	New Zealand	1	1	3	1985	South	1	1	3	1985	Venezuela	2	1	3
1990	Colombia	1	1	1	1990	Israel	1	1	3	1990	New Zealand	1	1	3	1990	South	1	1	3	1990	Venezuela	1	1	3
1995	Colombia	1	1	3	1995	Israel	1	1	3	1995	New Zealand	1	1	3	1995	South	1	1	1	1995	Venezuela	1	1	3
2000	Colombia	1	1	3	2000	Israel	1	1	3	2000	New Zealand	1	1	3	2000	South	1	1	3	2000	Venezuela	1	1	3
1985	Costa Rica	1	1	3	1985	Italy	2	3	4	1985	Nicaragua	1	1	1	1985	Spain	2	3	4	1985	Zimbabwe	1	1	1
1990	Costa Rica	1	1	3	1990	Italy	2	2	3	1990	Nicaragua	1	1	1	1990	Spain	2	2	3	1990	Zimbabwe	1	1	1
1995	Costa Rica	1	1	3	1995	Italy	2	2	3	1995	Nicaragua	1	1	3	1995	Spain	2	2	3	1995	Zimbabwe	1	1	1
2000	Costa Rica	1	1	2	2000	Italy	2	2	3	2000	Nicaragua	1	1	2	2000	Spain	2	2	3	2000	Zimbabwe	1	1	2
1980	Costa Rica	1	1	3	1980	Italy	2	3	4	1980	Nicaragua	1	1	1	1980	Spain	1	1	3	1980	Zimbabwe	1	1	1
1980	Denmark	2	3	4	1980	Jamaica	2	2	3	1980	Niger	1	1	1	1980	Sri Lanka	1	1	3					
1985	Denmark	2	2	3	1985	Jamaica	1	1	3	1985	Niger	1	1	1	1985	Sri Lanka	1	1	1					
1990	Denmark	2	3	4	1990	Jamaica	1	1	3	1990	Niger	1	1	1	1990	Sri Lanka	1	1	1					
1995	Denmark	2	3	4	1995	Jamaica	1	1	3	1995	Niger	1	1	1	1995	Sri Lanka	1	1	1					
2000	Denmark	2	3	4	2000	Jamaica	1	1	2	2000	Niger	1	1	2	2000	Sri Lanka	1	1	2					
1980	Dominican Rep.	1	1	3	1980	Japan	2	2	3	1980	Norway	2	1	3	1980	Sudan	1	1	1					
1985	Dominican Rep.	1	1	3	1985	Japan	1	1	3	1985	Norway	2	3	4	1985	Sudan	1	1	1					
1990	Dominican Rep.	1	1	3	1990	Japan	1	1	3	1990	Norway	2	1	3	1990	Sudan	1	1	1					
1995	Dominican Rep.	1	1	3	1995	Japan	2	3	4	1995	Norway	2	2	3	1995	Sudan	1	1	1					
2000	Dominican Rep.	1	1	2	2000	Japan	2	2	3	2000	Norway	2	2	3	2000	Sudan	1	1	2					

Note: This table reports the technological group to which each observation belongs according to the estimation outputs for the 2-regimes, 3-regimes, and 4-regimes models.

Table 5. Testing the Equivalence of Rybczynski Coefficients across Technological Groups

	2-Regimes	3-Regimes	4-Regimes
Test Rabund(K)[Reg 1]=Rabund(K)[Reg 2]	**0.000*****	**0.000*****	0.5303
Test Rabund(K)[Reg 1]=Rabund(K)[Reg 3]		**0.001*****	0.158
Test Rabund(K)[Reg 1]=Rabund(K)[Reg 4]			0.118
Test Rabund(K)[Reg 2]=Rabund(K)[Reg 3]		**0.000*****	**0.000*****
Test Rabund(K)[Reg 2]=Rabund(K)[Reg 4]			**0.001*****
Test Rabund(K)[Reg 3]=Rabund(K)[Reg 4]			**0.000*****
Test Rabund(sk-L)[Reg 1]=Rabund(sk-L)[Reg 2]	**0.0308****	**0.0933***	**0.087***
Test Rabund(sk-L)[Reg 1]=Rabund(sk-L)[Reg 3]		**0.002****	**0.004*****
Test Rabund(sk-L)[Reg 1]=Rabund(sk-L)[Reg 4]			**0.000*****
Test Rabund(sk-L)[Reg 2]=Rabund(sk-L)[Reg 3]		**0.011*****	**0.026****
Test Rabund(sk-L)[Reg 2]=Rabund(sk-L)[Reg 4]			**0.001*****
Test Rabund(sk-L)[Reg 3]=Rabund(sk-L)[Reg 4]			**0.002*****
Test Rabund(unsk-L)[Reg 1]=Rabund(unsk-L)[Reg 2]	**0.0678***	**0.0241****	**0.000*****
Test Rabund(unsk-L)[Reg 1]=Rabund(unsk-L)[Reg 3]		0.253	**0.064***
Test Rabund(unsk-L)[Reg 1]=Rabund(unsk-L)[Reg 4]			0.439
Test Rabund(unsk-L)[Reg 2]=Rabund(unsk-L)[Reg 3]		0.179	0.239
Test Rabund(unsk-L)[Reg 2]=Rabund(unsk-L)[Reg 4]			0.419
Test Rabund(unsk-L)[Reg 3]=Rabund(unsk-L)[Reg 4]			0.388
Test Rabund(Land)[Reg 1]=Rabund(Land)[Reg 2]	0.235	**0.051****	**0.006***
Test Rabund(Land)[Reg 1]=Rabund(Land)[Reg 3]		**0.043****	0.557
Test Rabund(Land)[Reg 1]=Rabund(Land)[Reg 4]			**0.015****
Test Rabund(Land)[Reg 2]=Rabund(Land)[Reg 3]		**0.010*****	0.283
Test Rabund(Land)[Reg 2]=Rabund(Land)[Reg 4]			**0.011*****
Test Rabund(Land)[Reg 3]=Rabund(Land)[Reg 4]			**0.021****

Note: This table reports the p-values corresponding to the null hypothesis of equivalence between the estimated Rybczynski coefficients of the mentioned technological groups. *, **, and *** means we reject the null hypothesis at 10, 5 and 1% level.

Appendix

List of countries

Algeria
Argentina
Australia
Austria
Benin
Bolivia
Brazil
Cameroon
Canada
Chile
China
Colombia
Costa Rica
Denmark
Dominican Rep.
Ecuador
Egypt
El Salvador
Finland
France
Greece
Iceland
India
Indonesia
Iran
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kenya
Korea Rep.
Malawi
Malaysia
Mali
Mauritius
Mexico
Mozambique
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Norway
Pakistan
Panama
Paraguay
Peru
Philippines
Portugal
Romania
Rwanda
Senegal
Sierra Leone
Singapore
South Africa
Spain
Sri Lanka
Sudan
Sweden
Switzerland
Syria
Togo
Trinidad and Tobago
Tunisia
Turkey
United Kingdom
United States
Uganda
Uruguay
Venezuela
Zimbabwe

Appendix

Standard deviation of each variable according to the four-regimes model

Variables	Regime 1	Regime 2	Regime 3	Regime 4
NX	67906.95	8325.721	2254826	5866697
Rabund(K)	1.81E+11	2.22E+10	1.64E+12	4.58E+12
Rabund(sk-L)	2411.862	740.962	32882.94	30837.84
Rabund(unsk-L)	7208.96	2487.769	69618.21	5505.05
Rabund(Land)	5024774	4049225	3.52E+07	5.32E+07

Note: This table reports the standard deviation of each variable per regime.