Working Paper

IMF Working Paper

Technological Adaptation, Trade, and Growth

Alberto Chong and Luisa Zanforlin

INTERNATIONAL MONETARY FUND

IMF Working Paper

African Department

Technological Adaptation, Trade, and Growth

Prepared by Alberto Chong and Luisa Zanforlin[1]

Authorized for distribution by Sérgio Pereira Leite

October 2000

Abstract

The views expressed in this Working Paper are those of the author(s) and do not necessarily represent those of the IMF or IMF policy. Working Papers describe research in progress by the author(s) and are published to elicit comments and to further debate.

This paper extends Grossman and Helpman's seminal work (1991), and presents an endogenous growth model where innovations created in a high-tech sector may be assimilated or adapted by a low-tech sector. Applying a simple Heckscher-Ohlin framework, the effects of technological diffusion are found to allow a country relatively scarce in human capital to benefit from nondecreasing rates of growth through its low-tech sector. The model is tested by using a dynamic panel data approach (Arellano and Bover, 1995). Results are consistent with the predictions of the model and robust to a broad range of definitions of technological intensity.

<p style="text-align: center;">Contents   Page</p>

I. INTRODUCTION

This paper takes a fresh look at the relationship between trade flows and economic growth. In fact, the bulk of the existing literature on the subject was developed between the late eighties and the mid-nineties, the debate on some key issues are far from being settled. On the one hand, there are still lingering empirical issues related with the existing evidence supporting a positive relationship between trade flows and economic growth. Endogeneity is still a problem (Rodrik, 1999; Frankel and Razin, 1999). On the other hand, establishing a direct link between trade and economic growth has remained somewhat weak. While the development of the literature on endogenous growth has helped in this regard, a typical outcome of the existing models is that a countries relatively better endowed in human capital tend to enjoy positive long run rates of growth.[2] This occurs because, according to Heckscher-Ohlin theory, the technology sector, typically the one that drives growth, may be able to increase its share in total production in the country that is relatively more abundant in human capital. The other country may specialize in the production of its traditional good, which may cause its technological sector to shrink. Since the traditional sector is usually assumed not to enjoy endogenous increases in productivity, the overall rate of growth in this second country may be lower than in the country with more abundant human capital.

The theoretical prediction seems to be at odds with the conventional wisdom that countries with relatively small endowments in human capital that have been successful in achieving growth through export-led policies have done so, at least in part, by exporting goods based on assimilated foreign technologies. This, it is sometimes argued, has been one of the basic growth recipes followed by several East Asian economies in recent decades (World Bank, 1993).[3] Although some empirical evidence supports the idea that exports are positively linked with economic growth, the issue of endogeneity clearly lingers.[4] In fact, the current view that attaches great importance to the role of export orientation in growth performance has been criticized as "misleading" since it largely minimizes the possibility of reverse causality (Rodrik,

---

[2] Examples include Grossman and Helpman (1991), Rivera-Batiz and Romer (1991), Young (1991), Barro and Sala-i-Martin (1995), and Edwards (1995).

[3] Ventura (1997) gives a complementary explanation. He argues that in a small open economy, a country is able to grow by shifting to capital-intensive export goods, as the marginal product of capital is determined by the stock of capital of the world, which prevents returns from diminishing.

[4] For empirical studies of the link between trade and growth, see Michaely (1977), Feder (1983), Esfahani, (1991), Edwards (1991), Dollar (1992), Xu (1996), and Harrison (1996).

1993). In addition, the typical instruments employed in most empirical studies to reduce endogeneity are considered weak (Frankel and Romer, 1996).[5]

On the theoretical side, we extend the work of Grossman and Helpman (1991) to show that in an endogenous growth model a country that is relatively less endowed in human capital may also benefit from nondecreasing returns to production generated by the assimilation of the technology that was developed abroad, and continue on a path of long-run growth after trade is opened. This supports the conventional wisdom related with countries that have achieved long-run growth through export-led policies We consider an economy that consists of three productive sectors. The first is a "high-tech" sector that uses research and development (R&D) and highly skilled individuals to produce a high-tech good (Y). Examples are aircraft and supercomputers. The second is a "low-tech" sector that uses know-how initially developed in the high-tech sector and is adapted to produce a good (W) which requires a lower level of embodied technology and is relatively easy to produce. Production of W also requires a relatively abundant factor, typically unskilled labor. Examples are light electronics goods, such as televisions and radios. Finally, the third sector produces a traditional good (Z) that employs a natural resource available in the country. It also requires unskilled labor. When trade takes place between two countries with similar production structure but different factor endowments, each country will tend to specialize in production of the good that uses intensively the factor with which it is relatively highly endowed. Under certain conditions, even countries less endowed in human capital may experience output growth through the development of sector W. Thus, a main prediction of the model is that, countries with a comparative advantage in "low-tech" W goods may experience long-run economic growth. The expansion of a low-tech sector is accompanied by nondeclining growth rates.

This main prediction is tested empirically by using a generalized method of moments (GMM) dynamic panel data approach, along the lines of Arellano and Bond (1991) and, particularly, Arellano and Bover (1995) for the period 1960-95. The advantage of this approach over previous methods is that the problem of endogeneity of exports is explicitly accounted for; this allows us to argue in terms of (limited) causality and not simply association between variables (Loayza, Schmidt-Hebbel, and Serven, forthcoming ; and Easterly, Loayza, and Montiel, 1997). Another advantage of our model is that we employ Sargan and serial correlation tests to check for the validity of the "internal" instruments in the model. We test our hypothesis with a wide array of definitions of what constitutes low-tech exports and find that the broader the definition, the smaller the coefficient of exports on growth. Our results seem to suggest that exports of low-tech W goods contribute to long-run economic growth.

---

[5] Instead of using typical trade policies as instruments, Frankel and Romer (1996) use geographic characteristics as an alternative instrument but acknowledge that even with this approach "the effects of trade are not estimated with great precision (for) the hypothesis that the impact of trade is zero is typically rejected (...) but the rejections are not overwhelming" (p. 31). For East Asia, Frankel, Romer, and Cyrus (1996) use a variation of this approach (gravity model), which alleviate this problem somewhat.

The paper is organized as follows. The next section presents the model in a closed economy context. Here we introduce our low-tech sector and explain how it interacts with the standard Grossman and Helpman (1991) model. The third section opens the economy to trade and discusses possible patterns of trade in a simple Heckscher-Ohlin framework. The fourth section describes the Arellano and Bover (1995) empirical methodology and develops the basic conditions required for estimation. The fifth section describes the data. Section VI presents the results. Finally, section VII summarizes our main findings and concludes.

II. THEORETICAL MOTIVATION

The model deals with two sectors: a high tech sector and a traditional sector.[6] Unlike in Grossman and Helpman's model, there are in this economy three factors of production: highly skilled labor (H), unskilled labor (L), and a natural resource (T). There are also three final goods, a high-tech good (Y) that requires pure innovation, a low-tech good (W) that adapts high-tech technologies, and a traditional good (Z) that employs a standard production function.

A. Consumption

We assume that the representative consumer maximizes a standard intertemporal utility function of the form:[7]

$$U_t = \int_0^\infty e^{-\rho(\tau-t)} \log [\, C_Y(\tau)^{1/3} \, C_W(\tau)^{1/3} \, C_Z^{1/3}(\tau)\,]d\,\tau \,, \tag{1}$$

with C_Y, C_W, C_Z consumption of three goods, Y (high tech), W (low tech), Z (traditional); ρ is the subjective discount rate and r the real return on riskless assets. Intertemporal optimization yields:

$$E = (C_Y C_W C_Z)^{1/3} \,, \tag{2}$$

and

$$\frac{\dot{E}}{E} = r - \rho \,, \tag{3}$$

---

[6] For specific details of the model see Grossman and Helpman (1991). We use their notation.

[7] We assume a nondecreasing, strictly quasi-concave function, homogeneous of degree one in its arguments.

where E is an index of spending. Therefore,

$$r - i - (\frac{\dot{P}_Y}{P_Y} + \frac{\dot{P}_W}{P_Y} + \frac{\dot{P}_Z}{P_Z}) / 3 \qquad (4)$$

where i is the nominal interest rate, and P_j is the price of good j, $j = y,w,z$.

B. Production

The production of goods Z and Y follows Grossman and Helpman (1991). The production function of the traditional good is $Z = L_Z^{1-\mu} T_Z^{\mu}$, where L_Z is unskilled labor and T_Z is a natural resource. Y, the high tech good, is specified as $Y - H_Y^{1-\lambda} D_Y^{\lambda}$, where H_y is human capital and D_Y is a good assembled from a set of intermediate inputs, such that $D_Y = [\int_0^N x_i^{\gamma} di \,]^{1/\gamma}$, $i \in [1,N]$, and N is the total number of differentiated varieties of intermediate inputs available at t.[8] These varieties are developed in R&D labs by highly skilled workers. The price of a new variety is [9]

$$P_x = \frac{1}{\alpha} \delta_{Hx} w_H , \qquad (5)$$

where δ_{Hx} is the input-output coefficient of human capital in the production of intermediate goods in the high-tech sector. N depends on the human capital employed and on the stock of knowledge embodied in the varieties.[10] Grossman and Helpman show that, in equilibrium, sector Y displays a positive and constant long-run rate of growth, ω, so that:

$$\frac{\dot{N}}{N} - \frac{\pi_n}{v_n} - \rho = \omega > 0 , \qquad (6)$$

where ω is the long run rate of development of new varieties, π_n is the profits accruing to the producer of a new variety, v_n is the present value of discounted profits, and ρ is the discount rate.[11]

---

[8] Thus, the productivity of every stock of resources increases with N. (Ethier, 1982).

[9] Similar to Grossman and Helpman, a newly developed variety is covered by a patent and gives rise to a monopoly on its production. Thus, each variety is sold at a markup.

[10] The existing varieties influence the rate of inventions, such that $\frac{\dot{N}}{N} = \frac{H_x}{\delta_{Hx}}$.

[11] Provided that there is full factor employment and complete factor mobility. Wages cannot differ across sectors, and factor markets must clear.

Unlike in the two sector Grossman and Helpman model, our economy also manufactures a low-tech good, W. The production process is similar to that of Y in that we use a Cobb-Douglas function with a differentiated set of intermediate inputs D_w. That is, $W = L_W^{1-\lambda} D_W^{\lambda}$, where D_W, is defined analogously to D_Y through a set of varieties of intermediate inputs $D_W = [\int_0^M x_j^{\gamma} \, dj \,]^{1/\gamma}$, M are the varieties, and $j \in [1,M]$. In the case of W, the varieties x' which enter D_w are different from those entering D_Y. These x' are the result of an activity of *assimilation or adaptation* of technology, which is originally developed and embodied in each variety x developed in sector Y, but is then modified and adapted to fit the production of good W. The varieties x' are good imitations or adaptations of the original technological design, but they are not substitutes for the original designs used in good Y. Their technological features are not good enough as to enter in the production of the high-tech good Y. These varieties are clones, spin-offs, or particular adaptations of existing technology. Each intermediate input in the low-tech sector is produced by employing human capital to adapt the technology developed in the high-tech sector. The price of an imitation is[12]

$$p_x = \frac{1}{\beta}(\delta_{Hx} w_H),\qquad(7)$$

where δ_{Hx} is the input-output coefficient for human capital employed in the low-tech sector, and β the monopolistic markup.[13] There is no direct competition between makers of varieties x and x' as they supply to different sectors.[14] The technological feature of a final good is defined by the technological features of its intermediate inputs. That is, low-tech inputs produce a low-tech final good, and high-tech inputs produce a high-tech final good. Since all other conditions in sector W are equivalent to those of sector Y, the equilibrium in the imitated varieties market requires free entry and no divergence in profits at any time. The dynamic equilibrium in the

---

[12] Similar to Y, varieties are covered by patents and are sold in a monopolistic market with a markup price.

[13] We assume that if a_{HW}, a_{HY} are the input-output coefficients in logarithmic form of the production of the final goods Y and W, respectively (not the intermediate varieties) then, $a_{HW} < a_{HY}$. Also, more unskilled labor is employed in the production of W than in the production of T, so that $a_{LW} > a_{LZ}$. We ensure that the three final goods are ranked uniquely in terms of their factors. The fulfillment of this condition will be necessary to analyze the pattern of specialization after allowing the economy to trade.

[14] Producers of original and imitated varieties may compete in supplying the producers of technological goods; a dual pricing structure in the intermediate inputs market would result. Producers of not yet adapted innovations would behave as monopolists, and producers of adapted varieties would behave as oligopolists. These complications would not change the results.

low-tech sector is analogous to that in the high-tech one, shown above, and is characterized by a long-run positive and constant rate of adaptation. However, in this case the rate of adaptation also depends on the rate of innovation in the high-tech sector. Workers in the low-tech sector take some time to assimilate and adapt designs first developed in the high-tech sector. The amount of time depends on the technical features of the innovation. Thus, it is reasonable to assume that, for a given set of N innovations, a fraction ξ of recently produced ones cannot be quickly imitated or adapted in the low-tech sector. The remaining $N\text{-}\xi \equiv N^*$ can be adapted to fit production of W. Adaptation depends on the human capital employed in R&D in the low-tech sector, and on the difference in number between the existing innovations that can be adapted and those that have already been imitated.[15] In particular, we assume that the imitation process takes the following form:

$$\frac{\dot{M}}{M} = \sigma p(\frac{N^* - M}{M})$$

(8)

where σ is a function of the original varieties, $p = p(H_m)$, and H_m is the human capital employed in the low-tech sector. Also, $p(0) = 0$, and the limit of p when H_m tends to infinity is one. Finally, $(N^* - M)/M$ is the technological gap.[16] In the short run the rate of adaptation of new varieties is a function of this gap, the human capital, and the technical characteristics of the innovations. Equation (8) is increasing in M and will have a steady state for $M = N^*$. This is a stable equilibrium since the second derivative with respect to time is negative for M when $0 < M < N^*$, the relevant interval. Also, N^* increases at rate ω given that the set of varieties that has not yet been imitated is constant for every t. In the long-run, the rate of adaptation is:

$$\frac{\dot{M}}{M} = \frac{\dot{N}^*}{N^*} = \frac{\dot{N}}{N} = \omega$$

(9)

Equation (9) represents the rate of growth of productivity, which is a function of the rate of introduction of new varieties in production. There are two activities, Y and W, in which the introduction of varieties is productivity increasing. Thus, the total rate of change of productivity, g, in the economy is:

$$g = \frac{\dot{N} + \dot{M}}{N + M}$$

(10)

---

[15] Among others, Gomulka (1990) and, in particular, Edwards (1992, 1998) hypothesize on similar processes.

[16] By integrating equation (8) it can be shown that the number of imitations follows a path which has the shape of a logistic function (Chong and Zanforlin, 1999)

Since $\lim_{t \to \infty} g = \omega$, the long-run rate of productivity growth of the economy will be equal to the rate of introduction of new varieties in the two sectors.[17] In summary, by extending Grossman and Helpman's (1991) two sector model to allow for a third sector to adapt or assimilate innovative technology, we have shown that this low-tech sector will achieve long run rates of growth greater than zero. This sector, along with the high-tech sector, will function as the engine of growth of the closed economy.

The next step of our analysis is to open the economy to trade, in order to analyze whether the resulting pattern of trade is consistent with the conventional wisdom, according to which countries with relatively abundant labor end up exporting goods based on the low-tech sector.

C. Open Economy

To analyze the impact of trade on output growth, we use the Heckscher-Ohlin framework where two countries, A and B, are endowed with three production factors each, H, L, T, and three consumption goods $Y, W,$ and Z.[18] In country A, $H_A > L_A > T_A$. In country B, $L_B > T_B > H_B$. The world's total endowment is the sum of the endowments in each country. Thus, A is relatively abundant in human capital and B is relatively abundant in unskilled labor. Using a standard methodology (Leamer, 1982), we compute a trade vector T for each country, such that $T = A^{-1} [\, V\text{-}sV \,]$, where A is the input-output coefficient matrix for country A or B, and $[\, V\text{-}sV \,]$ is the excess factor supply vector of each country (V is the vector of the world's total factor endowments, and s is the vector of the country's endowment shares with respect to each factor). The signs on the elements of the trade vector T determine the direction of the trade flow, (+) export or (-) import, for each good of the global economy. Given the assumptions above (also, see footnote 10), the elements in A^{-1} yield the following signs:

$$A^{-1} = \begin{bmatrix} + & 0 & 0 \\ 0 & + & 0 \\ 0 & + & + \end{bmatrix} \tag{11}$$

---

[17] The rate of growth of total output will depend on the rate of growth of productivity of each of the two productivity-increasing sectors and on the relative share of each sector in the total output (Grossman and Helpman, 1991). The rate of growth of productivity in T is zero, given the assumption of decreasing returns to scale.

The excess factor supply vector has positive elements corresponding to the factors that one country has in relative abundance. Thus, for country B the elements in the vector of excess factor supply have the signs $V' = [\ -,\ +,\ +]$. Solving the above system for T, we obtain the elements in the trade vector, which have the signs $T = [\ -,\ +,\ +\ ]$.

In this framework, country B, which is more abundant in unskilled labor, will be a net exporter of goods W and Z and a net importer of good Y.[19] Factor price equalization will also hold. In country B, the traditional sector tends to expand as the price of the traditional good rises after trade, while the high-tech sector will tend to contract as wages for human capital drop, since these are the sectors of absolute comparative advantage and disadvantage. The opposite will occur in country A, which is relatively more abundant in skilled labor. An important result is that, even though the high-tech sector is contracting, country B ends up exporting its low-tech good and will thus still have an expanding sector that increases its long-run growth rate. Resources are shifted from the high-tech sector to the low-tech sector and to the traditional sector. Human capital crowded out of the high-tech sector has a declining wage and thus increases the returns to producers of assimilated varieties. The share of the low-tech sector, which also enjoys non decreasing returns in production will increase with respect to total output.[20] The productivity growth rate is thus positive, and the labor-abundant country may be able to enjoy sustained rates of output growth. However, as seen above, the impact on total output depends on the relative share of each production activity in the whole economy.[21]

---

[18] Trade in endogenous growth models is usually thought to have three main effects: integration, spillover, and factor reallocation. For the purposes of our paper, we focus on the latter effect.

[19] This result still holds for a more general specification of A in which we assume each of the goods to be manufactured using three factors, if $a_{YH} > a_{YL}$, $a_{WL} > a_{WH}$, and $a_{ZL} > a_{ZT}$, where a_{ij} are input-output coefficients.

[20] In the two-sector model of Grossman and Helpman (1991), resources will shift from the high-tech to the traditional sector, and, as the former's share of total output is reduced, the long-run growth rate of the economy approaches zero.

[21] The implicit assumption in this section is that trade in intermediate inputs is not allowed. However, allowing so does not affect the results. Monopolists in the assimilating sector compete with monopolists in the same sector abroad. In all cases, human capital has a declining wage, while returns to human capital abroad increase. Monopolists in the small economy enjoy cost advantages that enable them to drive foreign competitors out of the market and end up exporting low-tech intermediate inputs. However, the cost of human capital still remains too high to be competitive in the low-tech intermediate inputs. Thus, the intermediate inputs have to be purchased from abroad, together with the high-tech goods Whether trade in intermediate inputs is allowed or not, the development of the technology assimilating sector will depend crucially on the price at which the intermediate inputs are available inside the economy with respect to the foreign competitors in the same sector.

III. EMPIRICAL ESTIMATION

A. Econometric methodology

We have theoretically shown that a country relatively abundant in unskilled labor may specialize in exports of low-tech goods and enjoy long-run economic growth. That is, exports in the low-tech sector may be associated with nondecreasing growth rates. Unlike other empirical studies that have tried to link exports and growth, we employ a dynamic panel data methodology in order to address not only possible bias, but also inconsistency of the estimators that may arise, as a result of both unobserved time and country-specific effects, and of endogeneity in the regressors. Recently developed dynamic panel data techniques allow us to address potential endogeneity problems as well as possible unobserved time and country-specific effects that may produce biased and inconsistent estimates.[22] This methodology formulates a set of moment conditions that can be estimated using GMM techniques in order to generate consistent and efficient estimates (technical details are explained in Appendix II).

B. Data

The data cover the period 1960-95 for 79 countries (see appendix I) at five year intervals. We estimate a standard log-linear growth regression and analyze the impact of low-tech exports in the spirit of our theoretical model. Our dependent variable is real GDP per capita, and was constructed as the differences of the log values of per capita GDP averaged over each period. We control for the productivity gap, which is the natural logarithm of the ratio of a country's per capita GDP to the per capita GDP of the United States. This coefficient represents the process of catching up to the technology frontier (De Long and Summers, 1991). Schooling is constructed using averages, and investment is calculated as a share of GDP and introduced at beginning-of-period values[23]. The GDP growth and investment data are obtained from the Penn World Tables Mark 5.6 (Summers and Heston, 1991) and the World Bank (1997). Data on schooling and labor force are taken from the World Bank (1997) and various issues of the *U.N. International Trade Statistics Yearbook.*

---

[22] For instance, Holtz-Eakin, et.al., 1988, Arellano and Bond (1991), Kiviet (1995), Alonso-Borrego and Arellano (1999), Arellano and Bover (1995), Blundell and Bond (1997), and Ziliak (1997). As is known, these two issues, and in particular the first one, have dominated the discussion on trade and growth in recent years. Frankel and Romer (1996), Frankel, et.al. (1996), and Harrison (1996) provide literature reviews.

[23] Averages were also tested. Results do not change.

Our variable of interest is exports of "easily imitable" goods, or what in the spirit of our model are called "low-tech" exports. In general, identifying appropriate export categories to represent such a variable is not trivial. Using the *U.N. International Trade Statistics Yearbook*, we tried to identify sectors that embody a relatively high degree of technology, and have low fixed capital costs and minimum requirement for skilled labor in the production process We also use ratios of overseas production to total production and parent exports to total production for a sample of multinational enterprises by sector of production. It is reasonable to assume that activities with the highest overseas production ratio use more easily imitable or transferable technology (Gomulka, 1990). By these two criteria, the activities in the Standard International Trade Classification (SITC) classification that best match our data requirements are those in category 7, as well as a few in category 8.[24] Since there may be some controversy as to what constitutes "low-tech" exports, we use a wide array of proxies, each defined as total exports of the chosen SITC categories as a percentage of GDP.[25] In particular, according to the model, we expect that the narrower the definition employed, the larger the coefficient of the proxy. Narrow definitions of "low-tech exports are expected to bear a higher coefficient on growth than broader definitions because the latter tends to pick up additional effects less related to the development of the low-tech sector. Also, if it is true that low-tech exports have played a role in the catching up process observed in a number of developing economies in the last decades, we would expect to find the respective coefficients for the sample of developing countries to be larger than the ones for the full sample. Finally, we also consider an interactive term, defined as schooling times the technology proxy. Consistent with the prediction of the theoretical model, countries with relatively scarce human capital that export low-tech goods may achieve long-run economic growth, and, thus, the expected sign of the interactive term is negative.[26]

C. Results

Tables 1-4 present our main results, using the Arellano-Bover (GMM) "system estimator" technique. Tables 1 and 2 show our results when using corresponding beginning-of-period values per interval of our technology proxy, while Tables 3 and 4 use the average values of the five-year interval. We run regressions for both the full sample and for

---

[24] Appendix II details the different SITC categories employed and provides the precise definition of the different technology export variables used.

[25] These variables were also calculated as a share of exports. However, we found that they were 95 percent correlated with the proxies calculated as a share of gross domestic product. Variables calculated as a share of GDP are believed to be better proxies since they exclude factors which might affect both general exports and exports within certain categories at the same time. Results are very similar (not reported).

[26] In the theoretical model, workers may be shifting to the high-tech sector.

developing countries only.[27] In all cases, we find strong evidence that low-tech exports are positively associated with long-term growth, for a broad range of definitions of low-tech exports (see Appendix II). Indeed, regardless of the definition, the coefficient of the proxy is statistically significant at 1 percent when using either beginning-of-period values, or averages. In fact, since we are paying particular attention to simultaneity and country heterogeneity issues, these results allow us to "make some progress towards drawing inferences on (limited) causation, rather than mere association" between low-tech exports and economic growth (Loayza, Schmitt-Hebbel, and Serven, forthcoming). Our results are consistent with our theoretical model. In addition, as expected, coefficients of narrower definitions of low-tech exports tend to be larger than the coefficients of proxies constructed with broader SITC categories. For instance, in Table 1 the coefficient of $TECHX1$ ($\beta = 1.79$) is significantly larger than that of $TECHX5$ ($\beta = 0.34$) the most broadly defined "low-tech" variable, when using beginning-of-period values. The same results are obtained when using period averages, as shown in Table 3 ($\beta = 1.33$ and $\beta = 0.29$, respectively). Also, and consistent with the predictions of the theoretical section, the sign of the interactive term between schooling and the technology proxy is always negative and statistically significant at the 1 percent level or higher. Our generalized method of moments estimates pass both the second-and-third order serial correlation tests, as well as the Sargan test, indicating that the lagged values of the explanatory variables are valid instruments to account for endogeneity and unobserved country and time effects.

Tables 2 and 4 repeat the same exercise as before but focus on our subsample of developing countries (see Appendix I). The results are consistent with those obtained in Tables 1 and 3 for the full sample. Again, the proxies for low-tech exports, both in averages and beginning-of-period values, are statistically significant at the 1 percent level, regardless of the definition of the proxy. Similarly, the more narrow the definition of the proxy, the larger the coefficient of the associated variable, in particular when using averages (Table 4). For example, while the coefficient of $TECHX1$ is 2.01, the coefficient of $TECHX5$ in the same table is 0.72. These differences in coefficients are, for the most part, statistically significant. Additionally, if comparing the coefficients of the low-tech export proxies of Table 1 with the ones in Table 2 (and those in Table 3 with those in Table 4), in all cases but one the technology coefficients for the set of developing countries is larger than those for the full sample. This is consistent with the theoretical model that predicts that acquiring a

---

[27] Conventional ordinary least squares (OLS) and instrumental variables were also used. The results are remarkably similar. In fact, although the coefficients of the low-tech exports proxies are always significant at the 5 percent level, these regressions do not pass either the second-order serial correlation tests or the Sargan tests. Because, as explained above, in panel estimations bias in the coefficients may occur, the OLS and two stage least squares (TSLS) results may be considered weak.

comparative advantage in low tech goods is a key engine of growth in developing countries.[28]

IV. SUMMARY AND CONCLUSIONS

In the two-sector model of Grossman and Helpman (1991), the development of a technological sector that enjoys increasing returns enables the economy to achieve long-run sustained growth. Once the economy opens to trade, comparative advantage dictates that high-tech goods will be produced in countries relatively abundant in human capital. However, by adding a third, low-tech sector that imitates the goods produced in the high-tech sector, we show that the effects of opening to trade for countries relatively scarce in human capital are less stringent than in the two-sector model. In our model, output growth may increase if the country is labor-abundant. This is mainly because the crowding out of human capital from the high-tech sector may be absorbed by the low-tech sector. In the low-tech sector, the increase in productivity, although lower than in the high-tech sector, nevertheless enables the country to achieve an overall positive rate of growth. This is a consequence of the labor-intensive characteristic of the low-tech sector, as cheaper labor constitutes a comparative advantage.

Based on the theoretical results, in the second part of the paper, we test the hypothesis that countries with less human capital that export low-tech goods are associated with long-run economic growth. To do this, we tackle two main issues that have plagued most empirical studies that have tested such a link. First, we use recently developed dynamic panel econometric techniques, both to eliminate endogeneity and to take into account unobserved country-specific effects. We apply Sargan tests and serial correlation tests in order to verify the validity of the internal instruments used. Second, we use different definitions of low-tech exports to check for consistency of the results. Our results are in line with the conventional wisdom, namely, that indicates that countries that have emphasized exports of easily imitable, low-tech goods have been able to achieve long-run economic growth. In fact, the coefficient of the technological exports in our standard empirical specification are positive and statistically significant, regardless of the definition of proxy employed. Moreover, the coefficient is typically larger for the developing country case. These findings may give some basic clues to explain the long-run pattern of some developing countries, particularly in East Asia, as our theoretical prediction is consistent with the idea that countries with relatively small endowments in human capital have been successful in achieving long-run growth through export-led policies have done so, at least in part, by means of exporting goods based on assimilated foreign technologies.

---

[28] For both the full sample and the developing countries sample we performed basic outlier analysis. We checked the consistency of our results when excluding (i) Latin America, (ii) Africa; (iii) Latin America and Africa; (iv) all countries but East Asia; and (v) The United States. The results are similar.

References

Aghion, Philippe, and Peter Howitt, 1998, *Endogenous Growth Theory* (Cambridge, Massachussets: MIT Press).

Alonso-Borrego, Cesar, and Manuel Arellano, 1999, "Symetrically Normalized Instrumental-Variable Estimation Using Panel Data," *Journal of Business and Economic Statistics*, Vol. 17 (January 1999), pp.36-49.

Anderson, Roy and Cheng Hsiao 1991 "Estimation of Dynamic Models with Error Components" *Journal of the American Statistical Association* 76, 598-606

Arellano, Manuel and Steven Bond, 1991, "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations." *Review of Economic Studies*, Vol. 58 (April), pp. 277-97.

Arellano, Manuel and Olympia Bover, 1995, "Another Look at the Instrumental Variable Estimation of Error-Component Models," *Journal of Econometrics*, Vol. 68 (July), pp. 29-51.

Baltagi, Badi, 1995, *Econometric Analysis of Panel Data* (New York: Wiley).

Barro, Robert, and Xavier Sala-i-Martin, 1995, *Economic Growth* (NewYork: McGraw-Hill).

Blundell, Richard, and Stephen Bond, 1997, "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models," Discussion Papers in Economics, No. 97-07 (London: Department of Economics, University College).

Chong, Alberto, and Luisa Zanforlin, 1999, "Technology and Epidemics," IMF Working Paper 99/125 (Washington: International Monetary Fund).

De Long, J. Bradford, and Lawrence H. Summers, 1991, "Equipment Investment and Economic Growth," *Quarterly Journal of Economics*, Vol.106 (May), pp: 445-502.

Dixit, Avinash, and Victor Norman, 1980, *Theory of International Trade: A Dual, General, Equilibrium Approach*, Cambridge Economic Handbooks (Walewyn, England: J. Nisbet).

Dollar, David, 1992, "Outward-Oriented Developing Economies Really Do Grow More Rapidly: Evidence From 95 LDCs, 1976-1985," *Economic Development and Cultural Change*, Vol. 40 (April), pp. 523-44.

Easterly, William, Norman Loayza and Peter Montiel, 1997, "Has Latin America's Post-Reform Growth Been Disappointing?" *Journal of International Economics*, Vol. 43 (November), pp: 287-311.

Edwards, Sebastian, 1988, "Terms of Trade, Tariffs, and Labor Market Adjustment in Developing Countries," *World Bank Economic Review*, Vol. 2 (May), pp. 165-85.

_____, 1992, "Trade Orientation, Distortions and Growth in Developing Countries," *Journal of Development Economics*, Vol. 39 (July), pp. 31-57.

_____, 1993, "Openness, Trade Liberalization, and Growth in Developing Countries," *Journal of Economic Literature*, Vol. 31 (September), pp. 1358-93.

_____, 1995, *Crisis and Reform in Latin America: From Despair to Hope*, (New York: Oxford University Press for the World Bank).

_____, 1998, "Openness, Productivity and Growth: What Do We Really Know?" *Economic Journal*, Vol. 108 (March), pp. 383-98.

Esfahani, Hadi, 1991, "Exports, Imports, and Economic Growth in Semi-Industrialized Countries," *Journal of Development Economics*, Vol. 35 (January), pp. 93-116.

Ethier, Wilfred, 1982, "National and International Returns to Scale in the Modern Theory of International Trade," *American Economic Review*, Vol. 72 (June), pp. 389-405.

Feder, Gershon, 1983, "On Exports and Economic Growth," *Journal of Development Economics*, Vol. 12 (February-April), pp. 59-73.

Frankel, Jeffrey and David Romer, 1996, "Trade and Growth: An Empirical Investigation," NBER Working Paper No. 5476 (Cambridge: Massachusetts: National Bureau of Economic Research).

_____, 1999, "Does Trade Cause Growth ?" *American Economic Review*, Vol. 89 (June), pp. 379-99.

_____, and Teresa Cyrus, 1996, "Trade and Growth in East Asian Countries: Cause and Effect," NBER Working Paper No. 5732 (Cambridge, Massachusetts: National Bureau of Economic Research).

Gomulka, Stanislaw, 1990, *The Theory of Technological Change and Economic Growth*, (London: Routledge).

Grossman, Gene, and Elhanan Helpman, 1991, *Innovation and Growth in the Global Economy* (Cambridge, Massachusetts: MIT Press).

_____, 1996, "Technology and Trade," in *Handbook of International Economics*, Vol III, ed. by Gene Grossman and Kenneth Rogoff, (Amsterdam: North Holland), pp. 1279-1377.

Harrison, Ann (1996) "Openness and Growth: A Time-Series, Cross-Country Analysis for Developing Countries," *Journal of Development Economics*, Vol. 48 (March), pp. 419-47.

Helpman, Elhanan and Paul Krugman, 1985, *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competitors, and the International Economy*, (Cambridge, Massachusetts: MIT Press).

Helpman, Elhanan, 1993, "Innovation, Imitation, and Intellectual Property Rights," *Econometrica*, Vol. 61 (November), pp. 1247-80.

Holtz-Eakin, Douglas, Whitney Dewey, and Harvey S. Rosen, "Estimating Vector Autoregressions with Panel Data," *Econometrica*, Vol. 56 (November), pp. 1371-95.

Jung, Woo, and Peyton Marshall, 1985, "Exports, Growth and Causality in Developing Countries," *Journal of Development Economics*, Vol. 18 (May-June), pp. 1-12.

Klodt, Henning, 1990, "Technology-Based Trade and Multinationals' Investment in Europe: Structural Change and Competition in Schumpeterian Goods," paper presented at Conference of Multinationals in Europe and Global Trade in the 1990s, Washington.

Krueger, Anne, 1993, "East Asian Experience and Endogenous Growth Theory," paper presented at the East Asian Seminar on Economics, National Bureau of Economic Research, Cambridge, Massachusetts, June.

Krugman, Paul, 1979, "A Model of Innovation, Technology Transfer, and the World Distribution of Income," *Journal of Political Economy*, Vol. 87 (April), pp. 253-66.

Leamer, Edward, 1982, *Sources of International Comparative Advantage* (Cambridge, Massachusetts: MIT Press).

Lin, Ching-Yuan, 1988, "East Asia and Latin America as Contrasting Models" *Economic Development and Cultural Change*, Vol. 36 (April), pp S153-97.

Loayza, Norman, Klaus Schmidt-Hebbel, and Luis Serven, forthcoming, "What Drives Saving Across the World?" *Review of Economics and Statistics.*

Lucas, Robert and E. Ju, 1988, "On the Mechanics of Economic Development," *Journal of Monetary Economics*, Vol. 22 (July), pp. 3-42.

Michaely, Michael, 1977, "Exports and Growth: An Empirical Investigation," *Journal of Development Economics*, Vol. 4 (March), pp. 49-53

Pack, Howard, and John Page, 1994, "Accumulation, Exports, and Growth in the High-Performing Asian Economies," *Carnegie-Rochester Conference Series on Public Policy*, Vol. 40 (June), pp. 199-235.

Parente, Stephen, and Edward Prescott, 1994, "Barriers to Technological Adoption and Development", *Journal of Political Economy*, Vol. 102 (April), pp. 298-321.

Pritchett, Lant, 1996, "Measuring Outward Orientation in LDCs: Can It Be Done?" *Journal of Development Economics*, Vol. 49 (May), pp. 307-35

Reinganum, Jennifer, 1989, "The Timing of Innovation: Research, Development, and Diffusion," in *Handbook of Industrial Organization*, Vol. 1, ed. by Richard Schmalensee and Robert Willig (New York: North Holland), pp. 849-908.

Rivera-Batiz, Luis, and Paul Romer, 1991, "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, Vol. 106 (May), pp. 531-554.

_____, 1991, "International Trade with Endogenous Technological Change," *European Economic Review, Journal of Political Economy*, Vol. 35 (May), pp. 971-1004.

Rivera-Batiz, Luis and Danyang Xie, 1992, "Endogenous Growth in Open Economies," *American Economic Review, Papers and Proceedings*, Vol 82 (May), pp. 422-7.

Rodrik, Dani, 1993, "Trade and Industrial Policy Reform in Developing Countries: A Review of Recent Theory and Evidence," NBER Working Paper No. 4417 (Cambridge, Massachusetts: National Bureau of Economic Research).

Romer, Paul, 1990, "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98, (October), pp. S71-S102.

Segerstrom, Paul (1991) "Innovation, Imitation, and Economic Growth," *Journal of Political Economy*, Vol. 99 (August), pp. 807-27.

Summers, Robert, and Alan Heston, 1991, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988," *Quarterly Journal of Economics*, Vol.106 (May), pp. 327-68.

United Nations, various years, *International Trade Statistics Yearbook* (New York: United Nations).

Ventura, Jaume, 1997, "Growth and Interdependence," *Quarterly Journal of Economics*, Vol. 112 (February), pp. 57-84.

World Bank, 1993, *The East Asian Miracle: Economic Growth and Public Policy* (New York: Oxford University Press for the World Bank).

World Bank, 1997, *World Development Indicators,* 1997 (Washington: World Bank). Available on CD-Rom.

Xu, Zhenhui, 1996, "On the Causality Between Export Growth and GDP Growth: An Empirical Reinvestigation," *Review of International Economics,* Vol. 4 (June), pp. 172-84.

Young, Alwyn, 1991, "Learning by Doing and the Dynamic Effects of International Trade," *Quarterly Journal of Economics,* Vol. 106 (May), pp. 369-406.

Table 1.
All countries. Arellano-Bover GMM System Estimator,
Beginning of Period Values of *TECHX* Indices, 1960-95
Dependent Variable: Per-Capita GDP Growth

	TECHX1	*TECHX2*	*TECHX3*	*TECHX4*	*TECHX5*
Constant	0.013	0.009	0.010	0.013	0.017
	(3.56)	(3.13)	(3.96)	(3.98)	(6.86)
Gap in GDP	-0.007	-0.007	-0.007	-0.008	-0.009
	(-6.95)	(-7.88)	(-8.83)	(-8.37)	(-11.63)
Investment	0.138	0.145	0.140	0.137	0.135
	(17.35)	(17.92)	(24.85)	(31.85)	(28.03)
Schooling	0.001	0.001	0.001	0.001	0.001
	(13.57)	(14.16)	(10.72)	(12.14)	(13.04)
TECHX	1.795	0.326	0.247	0.301	0.340
	(29.24)	(16.20)	(9.84)	(9.68)	(12.43)
Schooling**TECHX*	-0.084	-0.012	-0.011	-0.012	-0.014
	(-24.92)	(-14.28)	(-8.95)	(-11.54)	(-12.48)
Specification tests					
Sargan test:	0.309	0.204	0.238	0.183	0.295
Serial correlation tests:					
First order	0.000	0.000	0.000	0.000	0.000
Second order	0.880	0.985	0.999	0.977	0.908
Third order	0.859	0.987	0.965	0.986	0.952

Notes: Generalized method of moments (GMM) system estimator approach of Arellano-Bover (1995) followed. See Appendix II for definitions of *TECHX* indices. Panel Data in five year periods for 70 countries (264 observations). Time and country dummies not reported, t-statistics in parenthesis. To ensure time-series properties, countries with four observations or less have been excluded.

Table 2.
Developing Countries: Arellano-Bover GMM System Estimator
Beginning of period values of *TECHX* indices, 1960-1995
Dependent Variable: Per-Capita GDP Growth.

	TECHX1	*TECHX2*	*TECHX3*	*TECHX4*	*TECHX5*
Constant	0.011	0.012	0.013	0.012	0.016
	(2.272)	(2.918)	(3.117)	(2.806)	(3.758)
Gap in GDP	-0.009	-0.008	-0.010	-0.008	-0.008
	(-5.200)	(-6.595)	(-7.154)	(-7.196)	(-6.324)
Investment	0.218	0.171	0.195	0.169	0.149
	(15.471)	(15.729)	(14.051)	(13.000)	(11.582)
Schooling	0.001	0.001	0.001	0.001	0.001
	(3.213)	(7.458)	(5.506)	(7.492)	(7.579)
TECHX	1.029	1.232	1.272	1.124	0.924
	(3.137)	(10.476)	(7.597)	(9.110)	(15.280)
Schooling**TECHX*	-0.045	-0.064	-0.072	-0.067	-0.051
	(-1.886)	(-7.564)	(-5.072)	(-7.402)	(-11.340)
Specification tests					
Sargan test:	0.369	0.381	0.386	0.376	0.348
Serial correlation tests:					
First order	0.002	0.002	0.002	0.002	0.002
Second order	0.905	0.895	0.868	0.895	0.798
Third order	0.972	0.834	0.834	0.883	0.769

Notes: Generalized method of moments (GMM) system estimator approach of Arellano-Bover (1995) followed. See Appendix II for definitions of TECHX indices. Panel data in five year periods for 49 countries (180 observations). Time and country dummies not reported. *t*-statistics in parenthesis. To ensure time-series properties countries with four observations or less have been excluded.

Table 3.
All Countries. Arellano-Bover GMM System Estimator,
Average Values of *TECHX* indices 1960-1995
Dependent Variable: Per-Capita GDP Growth.

	TECHX1	*TECHX2*	*TECHX3*	*TECHX4*	*TECHX5*
Constant	0.016	0.014	0.013	0.014	0.017
	(6.07)	(5.97)	(4.69)	(4.59)	(5.39)
Gap in GDP	-0.008	-0.009	-0.008	-0.008	-0.009
	(-8.12)	(-8.71)	(-11.62)	(-11.59)	(-13.44)
Investment	0.127	0.141	0.139	0.131	0.128
	(10.79)	(13.65)	(36.52)	(32.60)	(28.01)
Schooling	0.001	0.001	0.001	0.001	0.001
	(15.81)	(10.35)	(10.19)	(10.63)	(11.07)
TECHX	1.332	0.396	0.279	0.289	0.292
	(18.51)	(33.60)	(18.45)	(18.10)	(15.63)
Schooling**TECHX*	-0.059	-0.014	-0.010	-0.011	-0.011
	(-15.05)	(-13.59)	(-11.23)	(-10.62)	(-10.34)
Specification tests					
Sargan test:	0.209	0.201	0.181	0.184	0.233
Serial correlation tests:					
First order	0.000	0.000	0.000	0.000	0.000
Second order	0.882	0.986	0.990	0.985	0.951
Third order	0.734	0.860	0.903	0.870	0.862

Notes. Generalized method of moments (GMM) system estimator approach of Arellano-Bover (1995) followed. See Appendix II for definitions of TECHX indices. Panel data in five year periods for 72 countries (273 observations) Time and country dummies not reported. *t*-statistics in parenthesis. To ensure time-series properties countries with four observations or less have been excluded.

Table 4.
Developing Countries. Arellano-Bover GMM System Estimator
Average Values of *TECHX* indices 1960-1995
Dependent Variable: Per-Capita Economic Growth.

	TECHX1	*TECHX2*	*TECHX3*	*TECHX4*	*TECHX5*
Constant	0.018	0.017	0.020	0.016	0.020
	(4.91)	(5.09)	(5.15)	(4.09)	(4.89)
Gap in GDP	-0.010	-0.010	-0.011	-0.009	-0.009
	(-8.36)	(-9.81)	(-10.82)	(-9.08)	(-8.80)
Investment	0.180	0.185	0.182	0.160	0.146
	(14.25)	(13.98)	(14.74)	(13.35)	(13.51)
Schooling	0.001	0.001	0.001	0.001	0.001
	(7.37)	(8.30)	(9.80)	(14.19)	(12.00)
TECHX	2.012	1.151	0.976	0.792	0.718
	(12.08)	(10.25)	(9.08)	(9.48)	(10.57)
Schooling*TECHX	-0.120	-0.066	-0.054	-0.047	-0.042
	(-10.58)	(-8.80)	(-7.34)	(-8.29)	(-9.14)
Specification tests					
Sargan test:	0.235	0.264	0.267	0.304	0.368
Serial correlation tests:					
First order	0.001	0.001	0.001	0.001	0.001
Second order	0.896	0.935	0.908	0.949	0.891
Third order	0.894	0.975	0.980	0.970	0.928

Notes. Generalized Method of Moments (GMM) system estimator approach of Arellano-Bover (1995) followed. See Appendix II for definitions of TECHX indices. Panel data in five year periods for 50 countries (185 observations) Time and country dummies not reported. *t*-statistics in parenthesis. To ensure time-series properties countries with four observations or less have been excluded.

Countries in Sample

Africa	Middle East and South Asia	Industrialized countries
1 Algeria	28 India	57 Australia
2 Cameroon	29 Israel	58 Austria
3 Central African Republic	30 Jordan	59 Belgium
4 Congo	31 Myanmar	60 Cyprus
5 Egypt	32 Nepal	61 Canada
6 Ghana	33 Pakistan	62 Denmark
7 Kenya	34 Syria	63 Finland
8 Malawi	35 Sri Lanka	64 Germany
9 Mali	36 Thailand	65 Greece
10 Mauritius		66 Iceland
11 Rwanda	Latin America	67 Ireland
12 Senegal	37 Argentina	68 Italy
13 Sierra Leone	38 Barbados	69 Japan
14 South Africa	39 Bolivia	70 Netherlands
15 Togo	40 Brazil	71 New Zealand
16 Tunisia	41 Chile	72 Norway
17 Uganda	42 Colombia	73 Portugal
18 Zaire	43 Costa Rica	74 Spain
19 Zimbabwe	44 Dominican Republic	75 Sweden
	45 Ecuador	76 Switzerland
	46 El Salvador	77 Turkey
Asia and Pacific	47 Guatemala	78 United States
20 Fiji	48 Haiti	79 United Kingdom
21 Hong Kong SAR	49 Honduras	
22 Indonesia	50 Jamaica	
23 Korea	51 Mexico	
24 Malaysia	52 Paraguay	
25 Papua New Guinea	53 Peru	
26 Philippines	54 Trinidad and Tobago	
27 Singapore	55 Uruguay	
	55 Venezuela	

Definitions of Technology Variables:

Standard International Trade Classification (SITC) categories employed for the construction of the technology indices.

TECHX1	714, 723, 725, 726
TECHX2	712, 714, 715, 716, 717, 718, 719, 723, 724, 725, 726, 812, 861, 862, 864, 891
TECHX3	712, 714, 715, 716, 717, 718, 719, 723, 724, 725, 726, 731, 732, 733, 812, 861, 862, 864, 891
TECHX4	All 7, except 711, 712, 733, 734 and 734
TECHX5	All 7.

Description of SITC Indices

7	Machines, transport equipment
711	Power machinery nonelectrical
712	Agricultural machinery
714	Office machines
715	Metalworking machinery
716	Miscellaneous machinery
717	Textile, leather machinery
718	Machinery for special industries
719	Machines non electric
721	Electrical machinery and equipment
723	Electrical distributing machinery
724	Telecommunications equipment
725	Domestic electrical equipment
726	Electro-medical, X-ray equipment
731	Railway vehicles
732	Road motor vehicles
733	Road vehicles nonmotor
734	Aircraft
735	Ships and boats
812	Plumbing, heating, lighting equipment
861	Instruments apparatus
862	Photo, cinema supplies
864	Watches and clocks
891	Sound recorders, producers.

Mathematical Derivation of the Growth Model[29]

Differentiated goods in the production function

Total factor productivity increases with the number of intermediate inputs that enter D. When $x_i = x$ and $D = n^{1/\gamma} x$, the resource embodied in the final good is $X = nx$. Final output per unit of intermediate input is:

$$\frac{D}{X} = n^{\frac{(1-\gamma)}{\gamma}} \quad ; 0 < \gamma < 1 \tag{A1}$$

Equilibrium in the intermediate inputs market

The development of a new variety of intermediate inputs is covered by a patent and gives rise to a perpetual monopoly for the developer. If any producer is able to freely enter the market, the present value of future discounted profits must equal the cost of entry:

$$\int_0^\infty e^{(R_t - R_\tau)} \pi_n(\tau) d\tau = \frac{1}{N} (w_H a_{Hx}) = v_n . \tag{A2}$$

In addition, by a no-arbitrage condition, capital gains and relative profits in the production of intermediate inputs have to equal the return on riskless assets:

$$\frac{\pi_n}{v_n} + \frac{\dot{v}_n}{v_n} = r . \tag{A3}$$

Equilibrium requires that every innovative variety enter the production function with the same amount bearing the same price. Assumptions on the demand function ensure that producers' profits are a fraction $(1-\alpha)$ of their revenues such that the profits of the innovating manufacturer are:

$$\pi_n = \frac{1}{N} (p_x x - w_H H_x) = \frac{1}{N} \{ p_x [\frac{H_x}{\delta_{Hx}}] - w_H H_x \} = \frac{1}{N} w_H H_x (\frac{1-\alpha}{\alpha}) \tag{A4}$$

where H_x is the human capital in production of the innovative varieties. Differentiating over time gives rise to an equilibrium condition for n and N, when a and w are fixed. When r is constant or when increases in human capital productivity in research are perfectly balanced by increases in wages for human capital, there is a constant growth rate of N equal to:

---

[29] This appendix draws on Grossman and Helpman (1991).

$$-\frac{\dot{N}}{N} = \frac{\dot{v}_n}{v_n} \tag{A5}$$

Equilibrium in the market of adapted varieties (low-tech sector)

The free market entry equilibrium condition in the low-tech sector is:

$$\int_0^\infty e^{(R_t - R_\tau)} \pi_m(\tau) d\tau = (w_H \delta_{Hm})/M = v_m. \tag{A6}$$

by analogous conditions as for the high-tech good, the equilibrium rate of growth for assimilated varieties can be derived as:

$$\frac{\dot{M}}{M} = \frac{\pi_m}{v_m} - \rho. \tag{A7}$$

Econometric Methodology

Recently developed dynamic panel data techniques allow us to address potential endogeneity problems as well as possible unobserved time and country-specific effects that may produce biased and inconsistent estimates.[30] This methodology formulates a set of moment conditions that can be estimated using GMM techniques in order to generate consistent and efficient estimates. We assume that the error process $\{\varepsilon_{i,t}\}$ is serially uncorrelated and use a first-difference specification of N individual time series and T periods, so that

$$y_{i,t} - y_{i,t-1} = \alpha\,(y_{i,t-1} - y_{i,t-2}) + \beta\,(x_{i,t} - x_{i,t-1}) + \mu_i + (\varepsilon_{i,t} - \varepsilon_{i,t-1}) , \qquad (A7)$$

where y is the dependent variable and x a set of explanatory variables. By construction, in (A7) the error term and the lagged dependent variable are correlated. In order to achieve the desired parameters, we follow previous research and assume the presence of unobserved effects and weakly exogenous regressors. Our first assumption states that $\{\varepsilon_{i,t}\}$ is serially uncorrelated, that is, $E(\varepsilon_{i,t}\varepsilon_{i,s}) = 0$ for $t \neq s$ for $T \geq 3$. This assumption implies the following linear moment conditions:

$$E[\,(\varepsilon_{i,t} - \varepsilon_{i,t-1})y_{i,t-j}\,] = 0 \quad (j = 2,\ldots,\,t\text{-}1\,;\,t = 3,\ldots,T). \qquad (A8)$$

The assumption of weakly exogenous regressors states that $E[x_{i,t}\varepsilon_{i,s}] = 0$ for $s > t$. Hence, for $T \geq 3$, this assumption implies the following the additional linear moment conditions:

$$E[\,(\varepsilon_{i,t} - \varepsilon_{i,t-1})x_{i,t-j}\,] = 0 \quad (j = 2,\ldots,\,t\text{-}1\,;\,t = 3,\ldots,T). \qquad (A9)$$

Our moment conditions, equations (A8) and (A9), can be written in the following vector form: $E[\,\mathbf{Z}_i'\,\zeta_i\,] = 0$, where the instrument matrix, $\mathbf{Z}_i$, is a matrix of the form $\mathbf{Z}_i = \mathrm{diag}(\,y_{i,1}\,\ldots\,y_{i,s},\,x_{i,1}\,\ldots\,x_{i,s}\,)$, $s=1,2,\ldots,T\text{-}2$, and the errors of the first-differenced equation are $\zeta_i = [\,(\varepsilon_{i,3} - \varepsilon_{i,2})\ldots(\varepsilon_{i,T} - \varepsilon_{i,T-1})]'$.[31] The estimator of the $k\times 1$ coefficient vector $\theta = (\alpha\ \beta')'$ is given by: $\hat{\theta} = (\overline{\mathbf{X}}'\mathbf{Z}\ ^{-1}\mathbf{Z}'\overline{\mathbf{X}})^{-1}\overline{\mathbf{X}}'\mathbf{Z}\ ^{-1}\mathbf{Z}'\overline{y}$, where $\overline{\mathbf{X}}$ is a stacked $(T\text{-}2)N \times k$ matrix of observations

---

[30] For instance, Holtz-Eakin, Neway, and Rosen, (1988), Arellano and Bond (1991), Kiviet (1995), Alonso-Borrego and Arellano (1999), Arellano and Bover (1995), Blundell and Bond (1997), and Ziliak (1997). As is known, these two issues, and in particular the first one, have dominated the discussion on trade and growth in recent years. Frankel and Romer (1996), Frankel, Romer, and Cyrus (1996), and Harrison (1996) provide literature reviews.

[31] The number of columns of $\mathbf{Z}_i$, for example, a matrix of rank column M, is equal to the number of available instruments.

$\bar{x}'_{i,t}$ on $\bar{y}'_{i,t-1}$, $\bar{y}$ is a stacked $(T\text{-}2)N$ x1 vector of $\bar{y}'_{i,t}$; $\mathbf{Z} = (\mathbf{Z}_i' \dots \mathbf{Z}_N')'$ is a $(T\text{-}2)N$ x M matrix; and Ω is any M x M, symmetric, positive definite matrix. A bar denotes that the variables are expressed in first differences. For an arbitrary Ω, a consistent estimate of the asymptotic variance-covariance matrix of $\hat{\theta}$ is given by:

$$Asy.Var(\hat{\theta}) = N(\overline{\mathbf{X}}'\mathbf{Z} \ ^{-1}\mathbf{Z}'\overline{\mathbf{X}})^{-1}\overline{\mathbf{X}}'\mathbf{Z} \ ^{-1}\left(\sum_{i=1}^{N}\mathbf{Z}_i'\hat{v}_i\hat{v}_i'\mathbf{Z}_i\right) \ ^{-1}\mathbf{Z}'\overline{\mathbf{X}}(\overline{\mathbf{X}}'\mathbf{Z} \ ^{-1}\mathbf{Z}'\overline{\mathbf{X}})^{-1} \quad (A10)$$

When Ω is chosen such that $V = E[\ \mathbf{Z}_i'v_iv_i'\mathbf{Z}_i\ ]$ we obtain the most efficient GMM estimator for θ. This covariance matrix may be consistently estimated using the residuals obtained from a preliminary, consistent estimation of θ. We first assumed that $\{\varepsilon_{i,t}\}$ is independent and homoskedastic both across units and over time. We relax such assumptions across units and use the residuals obtained in the first step to construct a consistent estimate of the variance-covariance matrix of the moment conditions. This matrix, denoted by Ω_2, becomes the optimal choice of Ω and is used to reestimate the coefficients of interest. Here, $\Omega_2 = (1/N)$ $\Sigma_{i=1}\mathbf{Z}_i'\hat{\eta}_i^1\hat{\eta}_i^{1'}\mathbf{Z}_i$, where $\hat{\eta}_i^1$ are the residuals estimated in the first step. Because the persistence of lagged dependent and explanatory variables over time might generate inconsistent estimates that might have adverse consequences on both the asymptotic and small-sample performance of the difference estimators, we use an estimator that complements the moment conditions applied above to the regression in differences with appropriate moment conditions applied to the regression in levels (Arellano and Bover, 1995). We obtain a system estimator that combines the regression in differences with the regression in levels. Here, the instruments for the regression in differences are the lagged levels of the corresponding variables, and the moment conditions in equations (A8) and (A9) apply to this first part of the system.

The instruments for the regression in levels are the lagged differences of the corresponding variables; these are the appropriate instruments under the two assumptions that (i) the error term ε is not serially correlated, and (ii) although there may be some correlation between the levels of the explanatory variables and the country-specific effects, there is no correlation between the differences of these variables and the country-specific effects. This yields the following stationary properties: E $[\ y_{i,t+p}\ \mu_i\ ] =$ E $[\ y_{i,t+q}\ \mu_i\ ]$, $\forall\ p,\ q$; and, E $[\ \mathbf{X}_{i,t+p}\ \mu_i\ ] =$ E $[\ \mathbf{X}_{i,t+q}\ \mu_i\ ]$; $\forall\ p,\ q$. The additional moment conditions for the second part of the system (the regression in levels) are given by E $[(y_{i,t-s} - y_{i,t-s-1})\ (\mu_i + \varepsilon_{i,t})] = 0$; for $s = 2$, E $[(\mathbf{X}_{i,t-s} - \mathbf{X}_{i,t-s-1})(\mu_i + \varepsilon_{i,t})] = 0$, for $s=1$. Finally, we use Sargan tests to verify the overall validity of the

instruments and serial correlation tests to examine the hypothesis that the error term in the difference regression $\varepsilon_{i,t}-\varepsilon_{i,t-1}$, is not second-order serially correlated, which implies that the error term in the level regression, $\varepsilon_{i,t}$, is not serially correlated.[32]

---

[32] If $v_{i,t}$ are the first differences of $\varepsilon_{i,t}$, the condition $E[v_{i,t}v_{i,t-1}] = 0$ must hold to obtain a consistent GMM estimator where it is required that $E[v_{i,t}v_{i,t-2}] = 0$. Consider $v^*(t)_i \equiv [\ v^*_{i,3},$ ..., $v^*_{i,T}\ ]'$, $v^*(t-2)_i \equiv [\ v^*_{i,1},\ ...,\ v^*_{i,T-2}\ ]'$, $v^*(t-2)_i \equiv [v^*(t-2)_1,\ ...,\ v^*(t-2)_N]'$. The serial correlation statistic

$$m_2 = \frac{v^*(t-2)'v^*(t)}{Q}$$

is standard normal (Q is a standardization factor) and may be used as a test of the null that $E[v_{i,t}v_{i,t-2}] = 0$. Also, in a Sargan test we test $E[Z_i'v_i] = 0$, based on the statistic

$$s = v^{*'}Z\left(\sum_{i=1}^{N}Z_i'v_i^*v_i^{*'}Z_i\right)^{-1}Z'v^*$$

where $v^* = [v_i^{*'},..., v_N^{*'}\ ]'$ are the residuals from the second stage. Under the null, the asymptotic distribution of the statistic s is χ^2, with M-k degrees of freedom (M are instruments and k are explanatory variables).