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*The Dual Nature of Trade: Measuring its Impact on Imitation and Growth**

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Abstract:

Imports of goods that embody foreign technology can raise a country's output directly as inputs into production and indirectly through reverse engineering of these goods, contributing to domestic imitation and innovation. This paper quantifies spillovers from high technology imports to domestic imitation and innovation in both developed and developing countries. It then considers the contribution of foreign and domestic innovation to real per capita GDP growth.

International patent data for 75 countries from 1965 to 1990 are used to create proxies for imitation and innovation. In conjunction with transportation and communication infrastructure, quality-adjusted R&D, and foreign direct investment, high technology imports positively affect both domestic imitation and innovation. Moreover their role is greater for developing nations than for developed nations. Transportation and communication infrastructure plays the largest role in domestic R&D processes. Finally, use of foreign technology embodied in high technology imports from developed countries plays a far greater role in growth than domestic technology.

Key Words: Embodied Technology, Technological Diffusion, Learning-to-Learn, Imitation, Innovation

JEL: F1, F43, O30, O31, O34, O40, O14

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I. Introduction

Imports of goods that embody foreign technology can raise a country's output in two ways. Firstly, use of more advanced foreign technology directly increases domestic output. Secondly, reverse engineering of these goods should positively affect domestic imitation and innovation. This paper attempts to quantify spillovers from imports of high technology goods from developed countries to domestic imitation and innovation in both developed and developing countries. It then considers the importance of foreign and domestic innovation to growth in real GDP per capita.

By its very nature, imitative activity is difficult to measure. Hence, this is one of the first studies that attempts to quantify both imitative and innovative activity across developed countries (DCs) and less developed countries (LDCs).[1] Additionally, in assessing the importance of trade to the international diffusion of technology, this paper looks at imports within certain specific Standard International Trade Classification (SITC) classes so as to distinguish the effects of imports of goods that embody technology, from general openness effects.

Several empirical studies consider the possible link between general imports and technological diffusion (Coe and Helpman 1995; Coe and Hoffmaister 1999; Eaton and Kortum 1996a and 1996b; Keller 1998 and 2001). Some empirical studies have also considered capital good imports either in terms of technological spillovers they create (Coe, Helpman, and Hoffmaister 1997[2]; Wang and Xu 2000[3]) or in terms of their use in production, thereby allowing countries access to foreign technology embodied within the imports (Lee 1995[4]; Romer 1993[5]). Finally, trade-based convergence clubs also provide

[1]Through surveys, Mansfield, Swartz, and Wagner (1981) quantify the cost (on average 65% of the cost of innovation) and speed (on average 70% of time required for innovation) of imitation for 48 product innovations within the U.S. chemical, drug, electronics, and machinery industries.

[2]Coe, Helpman, and Hoffmaister (1997) consider R&D spillovers to LDCs through machine and equipment imports.

[3]Wang and Xie (2000) consider R&D spillovers through capital goods trade and foreign direct investment, but consider only industrialized countries.

[4]Lee (1995) estimates the effect of the ratio of imported to domestically produced capital goods in investment on per capita income growth in a cross-section of countries from 1960 to 1985.

[5] Romer (1993) considers the effect of machinery and equipment imports both alone and interacted with the 1960 secondary school enrollment rate on per capita income growth in a cross-section of 76 developing countries, excluding Singapore. With the inclusion of total investment as a share of GDP as an additional

evidence that trade is likely an important channel for technological diffusion (Ben-David 1996; Ben-David and Rahman 1996).

This paper attempts to make four contributions to this literature. First, the paper looks at high technology imports (rather than general imports) and their direct effects on imitation and innovation using patent data. Moreover, it does so while controlling for other possible channels of technological diffusion such as transportation and communication infrastructure and foreign direct investment (FDI). Second, the paper attempts to distinguish between imitative and innovative activity, both in terms of how factors affecting R&D may affect these processes to differing extents and within differing time frames. Third, I consider the importance of domestic innovation, relative to foreign innovation, to per capita income growth. Fourth, the data analyzed include both LDCs and DCs, thereby allowing a comparison of a) the importance of high technology imports to their R&D processes, b) how the timing of their R&D processes might differ, c) how the direct use of foreign technology via capital goods in production may differ, and d) how the role of domestic innovation in income growth may differ in developing countries relative to developed countries.

Section II presents an endogenous growth model, which guides the empirical analysis. The model postulates that trade in intermediate goods and the quality of transportation and communication infrastructure play significant roles in the international diffusion of technology. The model is loosely used to empirically consider the role of trade in the processes of imitation and innovation, and the effect these processes have on growth. Section III describes the data and defines the innovation and imitation proxies. Section IV presents the empirical results and section V concludes.

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explanatory variable, the estimated coefficient on the interacted imports-education term is positive and significant, but equipment imports as a share of GDP are not.

II. Theoretical Considerations

For brevity, I present only the more salient features of the model of technological diffusion through trade and imitation developed in Connolly (2000). The model is a quality-ladder model with North-South trade, which incorporates the concept of learning-to-learn in both innovative and imitative processes.[6] The idea of learning-to-learn is that research allows firms to gain insights not only into the particular activity they are engaged in at the time, but also into the process of research itself. As a firm successfully imitates higher and higher quality levels of a particular type of good, it gains insights into how goods are engineered and improved upon. So imitation not only makes the firm better at future imitation, but also improves the firm's chances of successfully inventing the next quality level on its own.[7] Hence, learning-to-learn differs from learning-by-doing in that the skills gained are general and thus applicable to different types of research, rather than being limited to the exact task in which the learning occurs.

Domestic technological progress occurs via innovation or imitation, while growth is driven by technological advances in the quality of domestically available inputs, regardless of country of origin. Hence aggregate final goods production in each country, *i*, is

$$(1) \qquad Y_i = A_i L_i^{\alpha} \sum_{j=1}^{J} [q^{k_j} (x_{k_{ij}} + x^*_{k_{ij}})]^{1-\alpha} \ , \quad 0 < \alpha < 1, \text{ and } i = \begin{cases} 1 \text{ in the North} \\ 2 \text{ in the South} \end{cases} .$$

A_i is a productivity parameter dependent upon the country's institutions, such as tax laws, property rights and government services, and L_i is the labor input used in final goods production, which is a perfectly competitive industry. Following conventional notation for rising product quality models (Grossman and Helpman 1991a and 1991b; Aghion and Howitt 1992; Barro and Sala-i-Martin 1995 and 1997), there are a fixed number, *J*, of intermediate goods, whose quality levels are improved upon through innovation (or imitation). *q* reflects the size of quality improvements with each innovation, while *k* reflects the rung upon which the good is located on a quality ladder. Normalizing so all

[6] Following convention, the North is considered a DC and the South an LDC.

goods begin at quality level *1*, the quality level of an intermediate good in sector *j* rises from *1* to *q* with the first innovation, to q^2 with the second innovation, and to q^{k_j} with the k_jth innovation. Thus, $q^{k_j}(x_{k_{ij}} + x^*_{k_{ij}})$ is the quality-adjusted amount of the intermediate good of type *j* (with the asterisk denoting imports) used in final goods production.

Within each intermediate goods sector, limit pricing, along with a constant marginal cost of production, η_i, across domestic firms, allows the Northern firm with the leading technology to capture the world market. However, a Southern firm can take the world market from the lead firm by imitating the lead Northern good because of lower marginal costs of production.[8] Firms in both countries decide how many resources to devote to innovative or imitative research based on the expected present value of profits for successful research, which depends on the probabilities of innovation and imitation.

For a Northern intermediate goods sector presently at quality level k_{1j}, $p_{Ik_{1j}}$ is the probability per unit of time that the $(k_{1j}+1)$th innovation occurs. Specifically, $p_{Ik_{1j}}$ follows a Poisson process, which depends positively on resources devoted to research, $z_{Ik_{1j}}$, and past domestic learning-to-learn, $\vartheta_{k_{1j}}$, in industry *j*, and negatively on the complexity, $\phi_I(k_{1j})$, of the good upon which firms are attempting to improve:

$$(2) \qquad p_{Ik_{1j}} = z_{Ik_{1j}}\phi_I(k_{1j})\vartheta_{k_{1j}}, \qquad \text{where}$$

$$\vartheta_{k_{1j}} = max\,(\beta_C q_C^{k_{1j}}, \beta_I q_I^{k_{1j}}), \qquad \beta_I > \beta_C > 0, \qquad \text{and}$$

$$\phi_I(k_{1j}) = \frac{q^{-k_{1j}/\alpha}}{\zeta_{I1}}.$$

Subscripts *C* and *I* denote copying and innovation, respectively. $\vartheta_{k_{1j}}$ reflects the positive spillover effects of past learning-to-learn through imitation or innovation. For a particular Northern intermediate goods sector *j*, $q_C^{k_{1j}}$ is the highest quality level attained through imitation and $q_I^{k_{1j}}$ is the highest quality level attained through innovation. If the

[7] This is much like graduate studies, where the first years in graduate school are spent reverse-engineering the pre-existing stock of academic knowledge. During that time, students attain the skills and detailed understanding of the subject matter necessary to innovate on their own.
[8] Hence, there is a Vernon-type product cycle.

country has no imitative experience, $q_C^{k_{1j}} = 0$, and if it has no innovative experience, $q_I^{k_{1j}} = 0$.[9] β_C and β_I are positive coefficients on past imitative and innovative experience, respectively. $\beta_I > \beta_C$ since there should be greater learning-to-learn effects in innovation than in imitation. Finally, $\phi_I(k_{1j})$ reflects the increased difficulty of inventing higher quality goods, implying a lower probability of success, all else equal. This difficulty term further includes a country specific fixed cost of innovation, ζ_{I1}.

Within a Southern intermediate goods sector j, presently at quality level k_{2j}, $p_{Ck_{1j}}$ is the probability per unit of time that a Northern intermediate good of quality rung k_{1j} is copied. Similarly to the probability of innovation, the probability of imitation depends positively on resources spent by firms in terms of output devoted to reverse engineering, $z_{Ck_{1j}}$, negatively on the complexity, $\phi_C(k_{1j})$, of the good being copied, and positively on past learning-to-learn in that domestic industry:

(3) $$p_{Ck_{1j}} = z_{Ck_{1j}} \phi_C(k_{1j}) \vartheta_{k_{2j}} \qquad \phi_C'(k_{1j}) < 0, \text{ where}$$

$$\vartheta_{k_{2j}} = max\,(\beta_C q_C^{k_{2j}}, \beta_I q_I^{k_{2j}}), \qquad \beta_I > \beta_C > 0 \; ,$$

$$\phi_C(k_{1j}) = \frac{q^{-k_{1j}/\alpha}}{\zeta_{C2} \hat{q}_j^{\sigma} (e^{-\omega} + 1)}, \qquad \sigma > 0, \text{ and } \hat{q}_j = \frac{q^{k_{2j}}}{q^{k_{1j}}}.$$ [10]

Relative to the cost of innovation, two new factors enter into the cost of imitation, $\zeta_{C2} \hat{q}_j^{\sigma} (e^{-\omega} + 1)$. The first term, ζ_{C2}, parallels the fixed cost in innovative research, ζ_{I1}. The second term, $\hat{q}_j^{\sigma}$, depends on the South/North technology ratio in sector j and reflects the increasing cost of imitation as Southern technology approaches that of the North. Hence, there are decreasing returns to imitation as the pool of goods that can be targeted for imitation decreases. Finally, the third term, $(e^{-\omega}+1)$, reflects lower costs of gathering information about foreign goods with greater interaction, ω, between the two countries,

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[9] I assume that each country has experience in at least one type of research. If not, then $\vartheta = 1$.

[10] Note that if the South has only been imitating, $\vartheta_{k_{2j}} = \beta_c q_C^{k_{2j}} = \beta_c q^{k_{1j} + k_{2j} - k_{1j}} = \beta_c q^{k_{1j}} \hat{q}_j$.

as measured by capital goods imports, M, and communications and transportation infrastructure, F: $\omega = M^{\lambda_1} F^{\lambda_2}$.

Assuming balanced trade, and focusing on the average intermediate goods industry in each country, we can write the steady-state rates of innovation and imitation as functions of the aggregate South /North quality ratio, $\hat{Q}$:

$$(4) \qquad p_I^* = [\hat{Q}*^{1-\sigma} \frac{\beta_C}{\zeta_{C2}(e^{-\omega^*}+1)}(\eta_1 - \eta_2)\Omega_2] - r^*,$$

$$p_C^* = \frac{\frac{\beta_I}{\zeta_{II}} q^{-1/\alpha}[(1-\hat{Q}*)(q-1)\eta_1\Omega_2 + \hat{Q}*(q\eta_2 - \eta_1)\Omega_1] - \hat{Q}*^{1-\sigma} \frac{\beta_C}{\zeta_{C2}(e^{-\omega^*}+1)}(\eta_1 - \eta_2)\Omega_2}{1 + r^* - \hat{Q}*^{1-\sigma} \frac{\beta_C}{\zeta_{C2}(e^{-\omega^*}+1)}(\eta_1 - \eta_2)\Omega_2}$$

where $\hat{Q} = \frac{Q_2}{Q_1} = \sum_{j=1}^{J} \left(\frac{q^{k_{2j}}}{q^{k_{1j}}} \right)^{(1-\alpha)/\alpha}$

$$\Omega_1 = [L_1 A_1^{1/\alpha} (\frac{\eta_1}{\eta_2})^{1/\alpha} + L_2 A_2^{1/\alpha}](1-\alpha)^{1/\alpha}$$

$$\Omega_2 = [L_1 A_1^{1/\alpha} + L_2 A_2^{1/\alpha} (\frac{\eta_2}{\eta_1})^{1/\alpha}](1-\alpha)^{1/\alpha}$$, $\eta_1 = 1$, and

r^* is the steady-state rate of return in both countries. This steady-state interest rate equalization is a consequence of international technological diffusion. Both countries grow at the same rate, driven by Northern technological progress:

$$(5) \qquad \gamma_1^* = \gamma_2^* = \frac{\hat{Q}^{*^{1-\sigma}} \frac{\beta_C}{\zeta_{C2}(e^{-\omega^*}+1)}(\eta_1 - \eta_2)\Omega_2 - \rho}{\theta + (q^{(1-\alpha)/\alpha} - 1)^{-1}}.$$

Imitation in a given country is thus a positive function of expenditures on research, past experience in all types of research, real imports of capital goods from the North, and the country's transportation and communication infrastructure level. Additionally, factors affecting the profitability of imitation, such as the size of the market, also contribute positively to imitative activities. Similarly, innovation is a positive function of research expenditures, past research experience, and market size.

III. Data

Given these specifications one would like measures of innovation, imitation, research experience, research expenditures, capital goods imports from DCs, transportation and communications infrastructure, and market size. This section discusses each measure in turn, providing a general overview of the data. More detailed descriptions are in the appendix.

Innovation.

Patents, which reflect a positive fraction of output from R&D, are a commonly used measure of innovation. Hence, I define the proxy for the rate of innovation as U.S. patents granted to residents of a given country each year, by date of application, as reported by the U.S. Patent and Trademark Office.[11] This assumes that if an innovation is novel, its inventor will apply for and be granted a U.S. patent. There are of course many reasons why an inventor of a truly novel product or process might not apply for a patent in the United States. If the inventor has no plans to sell in the U.S., they will not bother applying for a U.S. patent. Furthermore, in industries in which it is easy to invent around a patent, firms will generally avoid applying for patents since this might divulge information that increases the chances of losing their market to a competitor. For these reasons, this proxy underestimates innovative activity.

Imitation.

The imitation proxy is defined as the number of applications for domestic patents by home residents, as reported by the World Intellectual Property Organization, minus U.S. patent applications by residents of that same country. The situation hopefully captured by this proxy is one where a firm has imitated say a German invention, but believes it will be able to get a patent in its home country. This could either be because of more lax novelty requirements at home, or simply because the German firm has not patented its invention in that particular country.[12] However, the imitating firm would not

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[11] The date of application rather than the date of granting is used in order to abstract from variations in the amount of time taken by the patent office to process applications.

[12] The Paris Convention allows a firm up to one year after its initial patent application in a member country to apply for a patent in any other member country. During that time the inventor has the right of priority

apply for a patent in the U.S. since the novelty requirements are more stringent and the German firm will likely have patented in the U.S. This assumes that non-U.S. residents will attempt to patent imitative goods in their home countries, but will only seek a U.S. patent if they consider their goods to be truly novel.

There are clear drawbacks to this proxy for imitation. As previously mentioned, there are economic reasons why a firm with a new invention might try to patent in its home country but not in the U.S. For example, the firm's invention might be tailored to domestic demand in its home country, but might not be in demand in the U.S. The firm would therefore seek a domestic patent but would not apply for a U.S. patent. In such a case the imitation proxy overestimates imitative activity. Additionally, the proxy depends on enforcement of patent laws in the home country and in the U.S. For example, in a country with strict novelty requirements, imitators might not be granted a domestic patent. In those types of countries, this measure underestimates the amount of imitation taking place. Similarly, if domestic patents are not enforced, as is often the case in LDCs, then imitation might be taking place, but again no firms would bother seeking domestic patent protection. Hence, this proxy will likely underestimate imitative activity in LDCs.[13]

For the above-mentioned reasons, the imitation proxy is far from ideal, and to some extent may simply capture domestic R&D activity.[14] Still, much of the technology literature presents innovation and imitation, not as completely different processes, but rather as different extremes of the same R&D process. I.e. innovation that is simply more adaptive than novel can alternatively be considered imitation. Thus, it may be reasonable for the imitation proxy to simply reflect domestic R&D, so long as it is capturing R&D

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over other applications for the same invention. If the inventor does not apply for a patent in certain countries within that year, then other firms can legally patent the exact same invention in those countries.

[13]A final consideration for the imitation proxy is that the Japanese patent system leads to far higher domestic patent counts than other countries, for the same amount of innovative activity. Eaton and Kortum (1994) translate 4.9 Japanese domestic patent applications as equivalent to 1 application elsewhere. This number is based on a study by Okada (1992) which finds that Japanese patents granted to foreigners on average contained 4.9 times more inventive claims as Japanese patents granted to domestic residents. This makes Japan artificially appear to imitate far more than other countries since domestic patent applications enter positively in the imitation proxy. Since this peculiarity of the Japanese patent system makes Japan an outlier in the sample, a dummy variable is used for Japan in the imitation regressions.

that is at the more adaptive, rather than the more novel, end of the R&D scale. Since this proxy distinguishes between attempts at patenting in the home market versus successful patenting in the US market, it is likely to capture R&D activity that is more adaptive than novel. From that perspective, the imitation proxy used here is reasonable, at least as a first attempt to distinguish between these two extremes of the research process.

Quality-Adjusted Research.

Measures of research experience are difficult to find. However, one might think of the experience from research as accumulated in researchers' human capital. While data on human capital accumulated through research are not readily available, measures of human capital accumulated through formal education are available. I therefore create a proxy for quality-adjusted research based on the number of R&D personnel per capita employed in research (UNESCO), multiplied by the average years of higher education for the population over the age of 25 (Barro and Lee, 1993). This proxy is intended to reflect both research expenditures and research experience.

High Technology Imports.

In the model, technology is embodied only in intermediate goods. However empirically, the relevant measure is imports of all goods that embody technology, not just intermediate goods. Hence, I consider imports of goods from DCs in Standard International Trade Classes 7, 86, and 89 (SITC, Rev. 1) from the *Commodity Trade Statistics*. These classes include machinery and transport equipment, instruments (optical, medical and photographic), watches, clocks, and miscellaneous manufactured goods (such as office equipment, which in later years include computers). These commodity classes were chosen since they contain goods that are likely to embody technology and belong to what are often considered to be high technology industries.[15]

Communication and Transportation Infrastructure.

Estimates for the stock of communication and transportation infrastructure are derived according to the perpetual inventory method using government expenditures on

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[14] Litigation might provide an alternative measure of IPR infringement. However, a majority of the IPR infringement cases are settled out of court, often prior to official filing. Hence, only a small fraction of imitative activity would be reflected by the small number of cases that actually are filed in courts of law.

[15] The OECD classifies drugs and medicines, office machinery and computers, electrical machinery, electronic components, aerospace, and scientific instruments as high technology industries (Abbott 1991).

roads, and other transportation and communication infrastructure from *Government Financial Statistics*. Finally, domestic population is used to reflect market size.[16]

This completes the list of variables that come from the model. However, three additional variables must be considered in order to control for other factors that could potentially lead to spurious correlation between the independent variables and the research proxies. For example, a finding that high technology imports contribute positively to imitation could simply reflect an openness effect, rather than spillovers from the technology embodied in high technology imports. For this reason, an openness measure is also included in the research regressions. Similarly, since imports of high technology goods from DCs include capital goods, this measure might capture the effects of foreign direct investment (FDI) on technological diffusion. Hence, FDI inflows are added. Finally, since domestic patent data are used to create the imitation proxy and the enforcement of intellectual property rights (IPRs) affects the domestic research environment, an IPRs index is included in the research regressions.

Hence, I estimate the following equation for imitative research

$$\text{(6)}\quad C_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 F_{it} + \beta_3 M_{it} + \beta_4 OPEN_{it} + \beta_5 POP_{it} + \beta_6 IPR_{it} + \beta_7 FDI_{it} + \mu_{it}\ .$$

C_i is the imitation proxy, and R_i is quality-adjusted research per capita.[17] F_i is the per capita measure of transportation and communication infrastructure and M_i represents imports of high technology goods from DCs as a share of GDP. $OPEN_{it}$ is a general openness measure, defined as imports of all goods (other than high technology goods from DCs) as a share of GDP. Market size is proxied by domestic population, POP_{it}.[18] IPR_{it} is Park and Ginarte's (1997) time varying IPRs protection index, and FDI_{it} measures

[16]The size of the world market is the relevant measure if a firm is imitating to sell on the world market and there are relatively low transportation costs. However, if a firm plans to only sell domestically, then the size of their domestic market is the relevant measure.

[17] The imitation proxy is not scaled since technology is a non-rival good freely available domestically.

[18] Theory also suggests that the scale of high technology imports affects research for two reasons. First, suppose each person exposed to a new good has a given probability that they will copy it. For a country as a whole, a good need be copied only once for its technology to be acquired domestically. Hence, the number of individuals exposed to the new good matters, implying the greater the volume of imports of a particular good, the greater the likelihood it will be imitated. Second, for importing firms, the greater the volume of goods they distribute and service, the lower their costs of imitation. Regressions using high technology import levels, rather than their share in GDP, yield results consistent with those reported here.

inflows of FDI as a share of GDP. All variables used in these regressions are in natural logarithms.

It is likely that this equation neglects certain unobservable country specific effects. Hence, the regressions to follow will test equation (6) with a one-factor error term, μ_{it}, where $\mu_{it} = \alpha_i + \varepsilon_{it}$. Following Hausman and Taylor (1981), α_i represents an unobservable latent individual country effect. The α_i are assumed to be time-invariant, and independently distributed across individual countries with variance, σ^2_α. The ε_{it} are assumed to be identically, independently distributed with zero mean and constant variance, σ^2_ε, conditional on the explanatory variables. While the ε_{it} are assumed to be uncorrelated with the explanatory variables, there may be correlation between the latent individual effects, α_i, and the explanatory variables. For example, high technology imports of a country are likely to vary according to the type of industries present in the country, in addition to depending on whether the country is primarily agricultural or industrial. Similarly, a country's culture and policy environment will greatly affect funding and administrative decisions for public infrastructure. Since such country specific characteristics are not included as independent variables, their effects will be captured in the latent individual effects, α_i, and are likely to be correlated with the independent variables included in the regression. Hence, there is an a priori reason to think that fixed effects (*FE*) estimation is the appropriate specification.

Similarly to imitation, innovation theoretically depends positively on quality-adjusted research and market size. Further, high technology imports, the infrastructure level, and FDI inflows increase knowledge of foreign innovations, thereby possibly affecting domestic innovation (perhaps through initial imitation). Hence, I consider an innovation regression similar to that for imitation:

$$\text{(7)} \qquad I_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 F_{it} + \beta_3 M_{it} + \beta_4 OPEN_{it} + \beta_5 POP_{it} + \beta_6 IPR_{it} + \beta_7 FDI_{it} + \mu_{it},$$

where I_{it} is the innovation rate in country *i* and all other variables are defined as before.

From equation (1) we see that growth in output per worker is a positive function of growth in both the aggregate quality level and the intermediate goods/physical capital stock. If a country allows free trade in intermediate goods then the quality level of intermediate goods is determined by the technology of lead innovators, whether domestic or foreign. If the country is cut off from trade, then the quality level is determined by domestic research. I therefore consider foreign innovation embodied in high technology imports, as well as domestic innovation and imitation, in the GDP growth regressions.

Growth of real per capita GDP, y_i, (in ln differences) is therefore a function of growth in the physical capital stock per capita, k_i, the innovation rate, I_i, the imitation rate, C_i, and growth of real imports of high technology goods per capita, m_i. m_i proxies for the direct effect of foreign technology embodied in imported inputs used in domestic production. Finally, initial per capita income in 1969, y_{i,t_0-1}, is included as an independent variable to test for conditional convergence:

$$(8) \qquad \gamma_{y_{it}} = \beta_0 + \beta_1 y_{i,t_0-1} + \beta_2 \gamma_{k_{it}} + \beta_3 I_{it} + \beta_4 C_{it} + \beta_4 \gamma_{m_{it}} + \mu_{it} \,.$$

IV. Empirical Results

The empirical analysis that follows uses a panel data set consisting of annual data from all countries and all dates between 1965 and 1995 for which data are available. There are limited data for 86 countries. A subset of these countries (the list is provided in the Appendix) is included in each regression depending upon availability of data. Innovation regressions include twenty-six, mostly DCs, imitation regressions include fifty-one countries, and growth regressions include thirty-five countries.

All variables other than dummies are in natural logarithms and are expressed in real terms. Both fixed effects (*FE*) and random effects (*RE*) regressions are performed.[19] *RE* estimation is *BLUE* if there is no correlation between the latent individual effect and the explanatory variables. However, if such correlation exists, then *FE* estimation is the most appropriate technique since its estimates are consistent and unbiased regardless of such correlation.

Imitation and Innovation

[19] Fixed effects estimation treats latent individual effects as fixed and focuses on deviations of states over time from their individual means. In other words, fixed effects estimation considers within-group variations over time. Random effects estimation on the other hand, allows for random latent effects and represents a weighted average of both cross-sectional and within-group variance.

Since annual patent data are used to create the imitation and innovation proxies, we must consider the timing of patent applications relative to the time when research is first initiated. For example, a firm is unlikely to be in a position to apply for a patent within less than a year of beginning a research project. Still, if a firm is planning on patenting, they are likely to do so fairly early in the R&D process. In pharmaceuticals for example, firms will patent a compound before undertaking the clinical trials that will ultimately determine the value of the compound. This is done on the chance that the compound will prove useful, in order to prevent other firms from patenting the compound during the many years that clinical trials may require. Hence, patenting in that instance occurs years before the R&D process is completed. Based on these observations, I consider how factors influencing R&D affect the imitation and innovation proxies one, two, and three years in the future.[20] This time lag also means that the independent variables can be considered exogenous and therefore do not require instrumentation.

Table 1 presents fixed effects estimation results for both imitation and innovation regressions, while the random effects results are presented in the appendix. I focus on the *FE* results since there is an *a priori* reason to believe that *FE* estimation is the more appropriate estimation technique, and because the Hausman (1978) specfication test rejects the null hypothesis of no correlation between the independent variables and the latent individual effects in all six R&D regressions.[21]

Columns 1 to 3 present the one, two, and three-year patent application lags for the imitation regressions. Similarly columns 4 to 6 present the three time lags for the innovation regressions. The coefficients are of the expected sign with one exception, quality-adjusted research effort, which enters negatively in the imitation regressions. It is worth noting that while the R^2 of .65 to .69 for the innovation regressions are good, the explanatory power of the *FE* imitation regressions is low, with R^2 values of .1 to .2. Still,

[20] This approach imposes that all factors have the same time lag in influencing R&D output. However, given the fact that a time lag is theoretically relevant, this is a clearer and less ad-hoc approach than allowing the lag time to vary with each independent variable.

[21] Since *FE* estimation looks at deviations from time means, it cannot estimate the coefficient for any constants. Hence, the Japan dummy for the imitation regressions is not listed in Table 1. Still, in the *RE* regressions (Table A1), the Japan dummy is always positive (with coefficient estimates between 4.5 and 4.9) and significant, as expected due to the Japanese patent system.

the equivalent R^2 of the *RE* imitation regressions in the appendix are good with values of .74 to .78.

Infrastructure and Scale.

Transportation and communications infrastructure plays the largest positive role in both R&D processes with statistically significant coefficient (or elasticity) estimates ranging from .6 to .8 for imitation, and from .8 to .9 for innovation. The size of the economy, as measured by population, is the next most important determinant with coefficient estimates ranging from .4 to .7 in the imitation regressions, and from .7 to .9 in the innovation regressions. The population coefficients are significant in five of the six regressions.

High Technology Imports.

High technology imports enter positively and significantly in all the imitation regressions with estimated coefficients of .13, .30, and .26 in the one-, two-, and three-year lag regressions, respectively. In the innovation regressions, high technology imports are positive in all three regressions, but are only statistically significant in the one-year lag regression with a coefficient estimate of .14. If it is the exposure of researchers to these imports that matters, then we should interact the quality-adjusted research term with high technology imports. Doing so yields highly significant coefficients of .27, .27, and .16 on this interacted term for the one-, two-, and three-year lag innovation regressions, while leaving the remainder of the results much as presented in Tables 1 and A1.[22] It is also interesting to note that differences in R&D timing between DCs and LDCs appear to play an important role in the innovation regressions. This will be elaborated upon later.

Openness.

The openness measure enters negatively and significantly in all six regressions. Its coefficient estimate ranges from –0.21 to –0.54, with higher coefficients in the innovation regressions than in the imitation regressions.[23] This suggests that the result for high technology imports is not simply reflecting openness per se.

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[22] This concept is similar to that proposed in Nelson and Phelps' (1966) model where the rate of increase in the application of theoretical technology is an increasing function of educational attainment. This interaction term however is not significant in the imitation regressions.

[23] When alternative measures of openness are considered, results vary. Sachs and Warner's dummy for openness is not statistically significantly different from zero in any of the six regressions. Similarly to my

Foreign Direct Investment.

Foreign direct investment from DAC (OECD) countries to developing countries is positive and significant in all six fixed effects regressions, which is consistent with the findings of Borensztein, De Gregorio and Lee (1998). Its coefficient estimates are greater in the innovation regressions (.11-.15) than in the imitation regressions (.04-.05). From the perspective of the theoretical motivation of this paper, the FDI variable is included to control for the possibility that high technology imports include capital imports that might more appropriately be considered FDI. Hence, various measures of FDI investment are considered, none of which cause high technology imports to lose significance in the four regressions in which it is significant in Table 1. [24]

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measure of openness, exports plus imports as a share of nominal GDP generally enter negatively and significantly in all of the innovation regressions and one of the imitation regressions. On the other hand, Lee's (1993) free trade openness measure (based negatively on the average distance to the capitals of the 20 major world exporters and the size of the land surface in the home country) enters positively and significantly in all the *RE* estimates but cannot be estimated in the *FE* regressions (favored by the Hausman test) since it is a constant.

[24] It should be mentioned that the two other measures of FDI (net inflows of FDI from the world, both based on IMF data), as reported by the World Bank's *World Development Indicators*, and the IMF's *International Financial Statistics*, yield widely varying coefficient estimates for FDI in these regressions. Still the overall regression results remain regardless of which FDI measure is used, and within the *FE* regressions, the FDI estimates are always positive, although not always statistically significant. The results using the OECD FDI data are presented since these allow for the greatest number of observations.

Intellectual Property Rights.

Intellectual property rights enter positively in all the regressions although they are statistically significantly different from zero only in the two- and three-year lagged innovation regressions.[25]

Timing.

It is worth considering what information these regressions contain regarding the time frame of R&D processes. Firstly, we can look at the overall regression results presented in Table 1. In the imitation regressions, the general relationships between the factors affecting research and imitation appear to be rather consistent, although the magnitudes of the coefficients suggest that the links peak at the two-year interval. This is the case for infrastructure, high technology imports, non-high technology imports, and foreign direct investment. In the innovation regressions, the relationship appears to be strongest at around two-years, at least for infrastructure, non-high technology imports, foreign direct investment, and intellectual property rights.

When DCs and LDCs are considered separately, interesting patterns emerge. Among both LDCs and DCs, the lag for imitation appears to peak at around two to three years. Still, the coefficient estimates for high technology imports in LDCs are generally greater than those for DCs. When tested by interacting an LDC dummy with high technology imports in the general imitation regressions, we find that the high technology imports coefficient estimate of .42 for LDCs is statistically significantly different from that of the DC's (.13) in the two-year lagged imitation regression.

We also gain interesting insights into possible differences in the time frame of LDC and DC R&D processes by doing similar comparisons in the innovation regressions. Firstly, in the general results of Table 1, high technology imports are not found to be significant in the two- and three-year lag innovation regressions. However, when looking at DCs separately from LDCs, we see very different timing patterns between the two groups. Firstly, for DCs the lag between high technology imports and patenting appear to be shorter. Specifically, high technology imports are statistically significant in the one- and two-year innovation lag for the DCs with a coefficient of .21 in the one-year lag

[25] IPRs are highly significant in all of the *RE* regressions presented in Table A1.

versus .13 in the two-year lag. Conversely, for the LDCs, high technology imports are only statistically significant in the three-year lag, with an estimated coefficient of .35. Further, when high technology imports are interacted with an LDC dummy in the three-year lag, the marginal contribution to the high technology import term is positive, and statistically significant. This demonstrates that in the three-year time lag, the spillover from high technology imports to domestic innovation is statistically different for LDCs than for DCs. These results suggest that for innovative activity, the time frame is longer for developing countries than for developed countries. Moreover, this strong difference in the timing of the effects of high technology imports between DCs and LDCs may explain the lack of significance in the two- and three-year lagged innovation regressions that include all countries.

A consistent finding of these regressions is that regardless of the estimation technique, high technology imports from DCs generally contribute positively to both domestic innovation and imitation.[26] The coefficient estimate on high technology imports ranges between 0.13 and .26 for the imitation regressions, and is around .14 for the 1-year lagged innovation regression. When considering only LDCs, these estimates go as high as .42 for imitation (2-year lag), and as high as .35 for innovation (3-year lag). This suggests that the importance of high technology imports as a channel for technological diffusion is greater for developing countries than for developed countries.

The average level of high technology imports as a share of GDP is only .029 for LDCs, compared to .064 for DCs. The world average is .038. Suppose the LDCs were able to increase high technology imports to the world average of .038. The results suggest that this (almost 31% increase in their high technology import share) would lead to an 11% increase in LDC innovation within 3 years, and to a 13% increase LDC imitation within 2 years. Such increases imply that the average number of U.S. patents granted to LDC residents would increase from a yearly average of 29 to 32, while imitative patents would increase from 49 to 56. If LDCs increased their high technology

[26]These results complement Ben-David's (1996) findings that trade-based country groupings are more likely to converge than randomly selected country groupings and Ben-David and Rahman's (1996) findings that trade-based country groupings are more likely to have total factor productivity convergence than randomly selected country groupings. Their findings, as well as the findings in this paper, suggest that trade plays an important role in technological diffusion and, in turn, conditional convergence.

import share to the DC average, their innovative patents would rise to 42 per year, and their imitative patents would rise to 75.

Per Capita GDP Growth

We now turn to the question of how foreign and domestic technologies affect growth.[27] As is standard within the empirical growth literature, average annual data for four five year periods, 1970-74, 1975-79, 1980-84, and 1985-89 are used. This greatly decreases the sample size, but helps avoid business cycle issues. Due to endogeneity problems with high technology imports and the innovation and imitation proxies, instrumental variables estimation is used throughout. Instruments used for high technology imports include lagged import values, the exchange rate, the black market premium, the inflation rate, world GDP, the international price of oil, absolute temperature deviations from means, a measure of tariff restrictions on imports of intermediate inputs and capital goods, official development assistance and a lagged measure of openness to trade. Exogenous variables from the previous innovation and imitation regressions are used as instruments for domestic innovation and imitation. These include transportation and communications infrastructure per capita, quality adjusted research effort per capita, lagged population, lagged intellectual property rights, and for imitation, the Japan dummy. Lagged innovation and imitation proxies are the final instruments.

Table 2 presents both *FE* and *RE* Two-Stage Least Squares Panel regressions for equation 8. The Hausman (1978) specification test rejects the null hypothesis of no correlation between the independent variables and the latent individual effect, suggesting that *FE* is the more appropriate estimation technique. Initial 1969 GDP per capita cannot be estimated using *FE* estimation, but in the *RE* results it enters negatively, supporting the notion of conditional convergence.[28] Growth of physical capital, with an estimated

[27] To include more countries in the growth regressions, the proxy for domestic innovation is redefined as U.S. patents granted to residents of a given country plus one. Then the natural log of the innovation proxy is zero for countries with no U.S. patents, rather than being undefined.
[28] This is similar to Barro and Sala-i-Martin's (1991) findings of convergence between states of the U.S.

coefficient of 0.21, has by far the greatest effect on real per capita GDP growth.[29, 30, 31] Growth of high technology imports per capita from DCs contributes positively to GDP growth per capita with an estimated coefficient of 0.14.[32] Domestic innovation and domestic imitation are not statistically significantly different from zero in the *FE* regression.[33] This suggests that technological progress from DCs embodied in high technology imports has a far greater effect on domestic growth than does domestic innovation.[34]

An alternative measure for the influence of foreign technology that may be more directly comparable to that of domestic innovation, is an imported weighted measure of foreign innovation. Specifically, interacting growth of high technology imports per capita from DCs with a measure of world innovation, based on U.S. patents granted to residents of DCs by date of application, yields a term more readily comparable to domestic innovation. When this term is used in lieu of the growth of high technology imports per capita, the regression results remain generally the same. In the *FE* regressions, the high technology import weighted foreign innovation term has an estimated coefficient of .07

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[29] Physical capital stock growth may be endogenous. For example, Lee (1995) points out that previous studies find that initial human capital levels positively affect investment rates (Barro 1991, Romer 1990). If lagged values are used to instrument for capital stock growth, the results remain, with a significant coefficient estimate of .33 for capital stock growth. The only real difference when capital stock growth is instrumented is that the Hausman test then marginally favors the *RE* results.

[30] Since high technology imports include some capital goods, one might worry about positive collinearity between growth of physical capital per capita and growth of high technology imports per capita. However, the correlation between these variables is negative and not alarmingly large (-0.22).

[31] Transportation and communications infrastructure may also matter to production. In that case, the growth of infrastructure per capita should also be included in the growth regression. However, given that the growth of physical capital per capita is already included in the regression, this yields a collinearity problem between the two variables. When both are included together, the results are generally as presented in Table 2, with the exception of domestic innovation and imitation which are no longer significant in the *RE* regressions. However, infrastructure growth is at best marginally significant. Alternatively, if infrastructure growth is considered without including physical capital growth, then it is highly statistically significant in all of the regressions, with large coefficient estimates ranging from 2.5 to 3.5.

[32] These results are robust to the inclusion of growth of human capital (the average number of schooling years in the total population over age 25 (Barro and Lee 1993) and other measures of openness: Sachs and Warner's (1995) index, or exports plus imports as a share of GDP (the open variable from Summers and Heston 1991). The Sachs and Warner index enters positively and significantly. The Summers-Heston open measure on the other hand is not statististically significantly different from zero. In both cases human capital growth contributes positively and significantly to per capita GDP growth. Inclusion of these variables does not greatly affect the coefficient estimates for the other variables, with the exception of domestic innovation, which is no longer significantly different from zero in the *RE* results.

[33] In the *RE* regression, both are significant although innovation is positive and imitation is negative.

and is significant at the 1% confidence level. Domestic innovation is not statistically significant. Still, the Hausman test cannot reject the null hypothesis of no correlation between the independent variables and the latent effects, suggesting that *RE* estimation is the most appropriate technique. In the *RE* regression, both the import weighted foreign innovation term and domestic innovation are statistically significant, with coefficient estimates of .06 and .003 respectively.

If the regression from equation (8) is run on DCs and LDCs separately, domestic innovation is statistically significant in explaining LDC growth but not DC growth. Two factors may support this. First, frontier technology may be less appropriate to production in LDCs. Second, LDCs are relatively less integrated with lead innovating countries. Still, the demonstrated importance of high technology import growth to per capita income growth suggests that the relative lack of integration is the more dominant explanation.

To verify if imports of high technology goods are actually more important to LDCs than to DCs, columns 3 and 4 of Table 2 present results that include a dummy for LDCs, as well as an interaction term between the LDC dummy and growth of high technology imports. As expected, these results show that LDCs tend to grow more slowly than DCs. More interestingly, when growth of high technology imports is separated into a general component and the marginal change when considering a LDC, we find that the coefficient estimate for LDCs of .16 is statistically different from that of DCs of .076. In other word, the marginal contribution to this elasticity when a country is an LDC is .085 and highly significant. Hence, the positive link between foreign technology embodied in high technology imports and growth holds for both DCs and LDC, but is significantly stronger for LDCs.[35]

V. Conclusion

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[34]This finding is broadly consistent with the Eaton and Kortum (1996) finding that with the exception of the United States, *OECD* countries derive almost all of their productivity growth from abroad.

[35]These findings complement Lee's (1995) empirical finding that the ratio of imported to domestically produced capital goods in investment positively affects growth of income per capita in a cross-section of countries from 1960-85. Moreover, by repeating the analysis separately for OECD and non-OECD countries he finds that this effect is more important for developing countries.

The four main findings of this paper provide general support for the role of imports of high technology goods from developed countries in the international diffusion of technology: 1. Domestic imitation and innovation both consistently depend positively on high technology imports from developed countries. 2. The importance of imports in the diffusion of technology is greater for developing countries than for developed countries. This suggests that less developed countries rely more on trade in goods for access to foreign technology. 3. Foreign technology from developed countries contributes more to per capita GDP growth than domestic innovation. This demonstrates that new foreign technology is applied directly to production, in addition to leading to increased domestic innovation and imitation. 4. The importance of high technology imports in domestic production is greater for LDCs than DCs, as is the importance of domestic innovation. Both results suggest that LDCs rely more heavily than DCs on trade and domestic R&D as sources of productivity growth.

These findings are consistent with the idea that trade with developed countries benefits less developed countries via both static effects and dynamic externalities. High technology good imports from developed countries not only positively affect domestic innovation, but also lead to increased GDP growth as higher quality capital goods are used in domestic production. Thus, trade is a mechanism by which more advanced foreign technology can be used to the advantage of a less developed country, not only to boost domestic innovation, but also as a means of benefiting from continued foreign innovation.

Table 1. Imitation and Innovation: Fixed Effects Regressions

Dependent Variable	Imitation Eq. 6			Innovation Eq. 7		
	(1) 1 Year Lag	(2) 2 Year Lag	(3) 3 Year Lag	(4) 1 Year Lag	(5) 2 Year Lag	(6) 3 Year Lag
Constant	-5.00	-8.75*	-12.1**	-11.12**	-11.14**	-9.26*
	(-0.93)	(-1.71)	(-2.18)	(-2.22)	(-2.12)	(-1.73)
Quality Adj. Research Effort Per Capita(*R*)	-0.107	-0.137**	-0.143**	0.250**	0.268**	0.364**
	(-1.51)	(-2.07)	(-2.04)	(4.43)	(4.50)	(6.01)
Transp. & Communic. Infrastructure Per Capita (*F*)	0.621**	0.790**	0.782**	0.829**	0.907**	0.885**
	(4.66)	(6.21)	(5.74)	(9.56)	(10.04)	(9.73)
High Tech. Imports as Share of GDP (*M*)	0.128*	0.295**	0.256**	0.135**	0.071	0.004
	(1.69)	(4.09)	(3.30)	(2.70)	(1.33)	(0.07)
Non-High Tech. Imports as Share of GDP (*OPEN*)	-0.206**	-0.354**	-0.346**	-0.504**	-0.538**	-0.451**
	(-2.43)	(-4.41)	(-4.17)	(-9.41)	(-9.46)	(-7.81)
Foreign Direct Invest. as Share of GDP (*FDI*) *(OECD to LDCs)*	0.051**	0.047**	0.041**	0.132**	0.145**	0.112**
	(2.39)	(2.34)	(1.99)	(5.22)	(5.51)	(4.19)
Population (*POP*)	0.398	0.552*	0.738**	0.863**	0.834**	0.730**
	(1.23)	(1.80)	(2.21)	(3.03)	(2.79)	(2.40)
Intellectual Property Rights (*IPR*)	0.220	0.234	0.385	0.295	0.381*	0.361*
	(0.69)	(0.77)	(1.22)	(1.56)	(1.90)	(1.77)
Observations	645	643	617	444	447	449
Number of Countries	51	51	51	26	26	26
R^2	0.09	0.17	0.16	0.65	0.66	0.69
F-Statistic	8.7	17.0	15.2	109	117	130
Hausman Test (Prob.>χ^2)	0.00	0.00	0.00	0.00	0.00	0.00
H_o: no correl. betw. the indep. vars and the latent indiv. effect	Reject H_o	Reject H_o	Reject H_o	Reject H_o	Reject H_o	Reject H_o

*Significant at the 10% confidence level. **Significant at the 5% confidence level or better.
t-statistics are in parentheses. All variables are in natural logarithms.

Table 2. Growth Regressions

Dependent Variable: Growth of Real GDP Per Capita (y) Eq. (8)

	(1) Fixed Effects *2SLS*	(2) Random Effects *2SLS*	(3) Fixed Effects *2SLS*	(4) Random Effects *2SLS*
Constant	0.098** (2.43)	0.069** (2.25)	0.086** (2.18)	0.111** (2.98)
1969 GDP per capita (y_{t-1})	◦	-0.008* (-1.86)	◦	-.011** (-2.45)
Growth of per capita Capital Stock (*k*)	0.208** (2.42)	0.305** (5.15)	0.263** (3.04)	0.317** (5.55)
Growth of per capita High Tech. Imports (*m*)	0.137** (8.56)	0.115** (7.64)	0.076** (2.57)	0.044 (1.61)
Domestic Innovation (*I*)	-0.007 (-0.70)	0.004** (2.62)	-0.002 (-0.21)	.003** (2.28)
Domestic Imitation (*C*)	-0.011 (-1.57)	-0.002* (-1.65)	-0.012* (-1.76)	-0.003** (-1.99)
LDC Dummy			◦	-0.016** (-2.08)
LDC · Growth of High Tech. Imports per capita (*LDCm*)			0.085** (2.62)	0.111** (3.68)
Observations	112	112	112	112
Countries	35	35	35	35
R^2	0.61	0.62	0.63	0.66
χ^2-Statistic	291	127	327	193
Hausman Test (Prob.>χ^2)	0.00		0.01	
H_o: no correl. betw. the indep. vars and the latent indiv. effect	Reject H_o		Reject H_o	

*Significant at the 10% confidence level.

**Significant at the 5% confidence level or better.

z-statistics are in parentheses.

All variables are in natural logarithms.

Appendix

Table A1. Imitation and Innovation: Random Effects Regressions

Dependent Variable	Imitation Eq. 6			Innovation Eq. 7		
	(1) 1 Year Lag	(2) 2 Year Lag	(3) 3 Year Lag	(4) 1 Year Lag	(5) 2 Year Lag	(6) 3 Year Lag
Constant	-15.26** (-6.15)	-16.79** (-6.99)	-17.39** (-7.25)	-13.25** (-6.44)	-13.69** (-6.57)	-12.62** (-6.26)
Quality Adj. Research Effort Per Capita(*R*)	-0.073 (-1.15)	-0.10* (-1.67)	-0.074 (-1.20)	0.307** (6.34)	0.333** (6.51)	0.422** (8.38)
Transp. & Communic. Infrastructure Per Capita (*F*)	0.552** (4.60)	0.717** (6.25)	0.724** (6.10)	0.669** (7.60)	0.732** (8.03)	0.698** (7.85)
High Tech. Imports as Share of GDP (*M*)	0.209** (2.74)	0.359** (4.93)	0.331** (4.28)	0.207** (3.77)	0.154** (2.64)	0.081 (1.40)
Non-High Tech. Imports as Share of GDP (*OPEN*)	-0.139 (-1.60)	-0.290** (-3.53)	-0.295** (-3.49)	-0.405** (-6.95)	-0.426** (-6.86)	-0.342** (-5.56)
Foreign Direct Invest. as Share of GDP (*FDI*) *(OECD to LDCs)*	-0.054** (-3.37)	-0.042** (-2.76)	-.048** (-3.11)	-0.047** (-3.32)	-0.041** (-2.88)	-.045** (-3.27)
Population (*POP*)	0.930** (7.29)	0.964** (7.69)	0.997** (8.05)	0.869** (8.21)	0.867** (8.14)	0.848** (8.27)
Intellectual Property Rights (*IPR*)	0.478* (1.69)	0.485* (1.80)	0.597** (2.20)	0.399** (2.05)	0.522** (2.52)	0.527** (2.57)
Japan Dummy	4.54** (3.10)	4.89** (3.36)	4.61** (3.27)	◦	◦	◦
Observations	645	643	617	444	447	449
Number of Countries	51	51	51	26	26	26
R^2	0.75	0.74	0.77	0.75	0.73	0.77
χ^2-Statistic	171	231	238	717	757	896
Hausman Test (Prob.>χ^2)	0.00	0.00	0.00	0.00	0.00	0.00
H_o: no correl. betw. the indep. vars and the latent indiv. effect	Reject H_o	Reject H_o	Reject H_o	Reject H_o	Reject H_o	Reject H_o

*Significant at the 10% confidence level. **Significant at the 5% confidence level or better.
z-statistics are in parentheses. All variables are in natural logarithms, except for the Japan dummy.

Countries Included in Regressions (parenthesis indicate # of time observations)

Imitation Regress. : 1 year lag	**Innovation Regress. : 1 year lag**	**Growth Regression**
ARGENTINA (12)	ARGENTINA (18)	ARGENTINA (3)
AUSTRALIA (19)	AUSTRALIA (19)	AUSTRIA (4)
AUSTRIA (19)	AUSTRIA (19)	BELGIUM-LUX. (4)
BELGIUM (19)	BELGIUM (19)	BOLIVIA (4)
BOLIVIA (11)	BRAZIL (19)	BRAZIL (4)
BRAZIL (19)	CANADA (19)	CHILE (4)
CANADA (1)	DENMARK (19)	COSTA RICA (3)
CHILE (14)	FINLAND (19)	DENMARK (4)
COSTA RICA (12)	FRANCE (15)	EGYPT (3)
CYPRUS (1)	GERMANY, WEST (19)	FINLAND (4)
DENMARK (19)	IRELAND (1)	FRANCE (3)
EGYPT (16)	ISRAEL (16)	GERMANY, WEST (4)
FINLAND (19)	ITALY (19)	GREECE (3)
FRANCE (15)	JAPAN (22)	GUATEMALA (4)
GERMANY, WEST (19)	KOREA, REP. (11)	INDONESIA (3)
GREECE (14)	MEXICO (15)	IRAN (2)
GUATEMALA (18)	NETHERLANDS (19)	ITALY (3)
HONDURAS (7)	NEW ZEALAND (19)	JAPAN (4)
ICELAND (18)	NORWAY (19)	JORDAN (1)
INDONESIA (8)	SINGAPORE (15)	KOREA, REP. (2)
IRAN (5)	SPAIN (19)	MALAWI (1)
IRELAND (1)	SWEDEN (19)	MEXICO (4)
ISRAEL (16)	SWITZERLAND (15)	NETHERLANDS (4)
ITALY (14)	U.K. (19)	NICARAGUA (1)
JAPAN (22)	U.S.A. (19)	NORWAY (4)
JORDAN (4)	VENEZUELA (12)	PAKISTAN (3)
KENYA (3)		PHILIPPINES (4)
KOREA, REP. (17)		SINGAPORE (2)
MALAWI (2)		SPAIN (4)
MALAYSIA (2)		SWEDEN (4)
MALTA (15)		SWITZERLAND (3)
MAURITIUS (7)		TUNISIA (2)
MEXICO (15)		TURKEY (4)
NETHERLANDS (19)		U.K. (4)
NEW ZEALAND (19)		VENEZUELA (2)
NORWAY (19)		
PAKISTAN (6)		
PERU (1)		
PHILIPPINES (17)		
SINGAPORE (17)		
SPAIN (19)		
SRI LANKA (1)		
SWEDEN (19)		
SWITZERLAND (15)		
TRINIDAD&TOBAGO (6)		
TUNISIA (17)		
TURKEY (16)		
U.K. (19)		
URUGUAY (15)		
VENEZUELA (13)		
ZAMBIA (6)		
51 countries	**26 Countries**	**35 countries**

Data

***C*: Imitation.** Annual data on domestic patent applications by residents in each country comes from data collected from annual issues of *Industrial Property Statistics* and *One Hundred Years Protection of Industrial Property* (1983), both created by the World Intellectual Property Rights Organization. Annual data on U.S. patent applications by date of application and by the country of residence of the innovator come from the U.S. Patent and Trademark Office. These data are then used to create the imitation proxy, defined as the number of applications for domestic patents by home residents minus U.S. patent applications by residents of that same country.

***I*: Innovation.** Annual data on U.S. patents granted to residents of a given country each year (by date of application) come from the U.S. Patent and Trademark Office.

***M*: High Technology Imports.** A measure of high technology imports from DCs is created using data (in thousands of current U.S. dollars) from various issues of the United Nations' *Commodity Trade Statistics*.[36] To express the data in real terms (1985 $U.S.), I deflate by the U.S. Producer Price Index (PPI), for machinery and transport equipment, which are consolidated under the category of capital equipment in more recent years.

For the growth regressions, lagged import values, the exchange rate (*World Development Indicators* (WDI), World Bank), the black market premium (Wood 1988 and the World Bank 1991), CPI inflation (WDI), world GDP (Penn World Table (PWT), v. 5.6), the international price of oil defined as the U.S. Refiner Acquisition Cost of Imported Crude Oil (1985 US$ per barrel) (Energy Information Administration, Office of Energy Information Markets and End Use, U.S. Department of Energy, Washington, DC), annual average absolute temperature deviations from monthly means (derived from data provided by the Global Historical Climate Network, see Peterson and Vose, 1997), a measure of tariff restrictions on imports of intermediate inputs and capital goods (Lee 1993), gross official development assistance from DAC countries (*Geographical Distribution of Financial Flows to Aid Recipients*, OECD), and a lagged measure of openness to trade (PWT, v. 5.6) are all used as instruments for imports .

***OPEN*: Non-High Technology Imports.** Non-high technology imports are measured as total imports from the world, *excluding* high technology goods imported from DCs. The 1985 real value of high technology imports, is subtracted from 1985 real level of total imports from the *Commodity Trade Statistics*. Lagged values, along with the instruments for imports described above are used as instruments for this openness measure.

***R*: Quality Adjusted Research Effort.** A measure for quality-adjusted research is created by multiplying the number of R&D personnel per capita employed in research (UNESCO), by the average years of higher education for the population over the age of 25. The education data, which come from the updated Barro-Lee data set (Barro and Lee, 1993), provides annual observations, every five years, from 1960 to 1990. Interpolated values are therefore used in creating the annual quality-adjusted research measure. The measure is then put in per capita terms using population data from the PWT, v.5.6.

***IPR*: Intellectual Property Rights.** Park and Ginarte (1997) created this IPRs index for 110 countries over five-year periods from 1960 to 1990. The index is based on five categories of patent laws: extent of coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms, and the duration of protection. This index has two main advantages over other time-invariant indices of IPRs (Rapp and Rozek 1990; Mansfield 1994). Firstly, it covers more countries and a larger time period than the other indices. Secondly, the index considers broader categories of the patent system, consequently yielding greater variability in the measurement of *IPR*s across countries.

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[36] During this time period, the U.N. lists the following countries as DCs: Australia, Austria, Belgium-Luxembourg, Canada, Denmark, Finland, France, Germany (Fed. Rep.), Greece, Iceland, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, the South African Customs Union, Spain, Sweden, Switzerland, the United Kingdom, the United States, and Yugoslavia.

***K*: Capital Stock.** Using initial capital stock estimates from Benhabib and Spiegel (1994),[37] along with investment flows given in the PWT, v5.6, I derive capital stock estimates for subsequent years.

***F*: Transportation and Communication Infrastructure.** Estimates for the stock of communication and transportation infrastructure are derived according to the perpetual inventory method using government expenditures on roads, and other transportation and communication infrastructure as reported in annual issues of *Government Financial Statistics* (GFS). Initial 1965 stock estimates are based on Benhabib and Spiegel's (1994) 1965 capital stock estimates multiplied by the average fraction of total domestic investment made by the government in roads, other transport equipment and communication capital between 1972 and 1985. This yields an estimate of the 1965 stock of transportation and communication capital to which annual government investments in roads, other transport equipment and communication capital can be added according to the perpetual inventory method. Since GFS do not include the necessary Japanese data, I generated the Japanese infrastructure stock using data on government expenditures in annual issues of the *Japan Statistical Yearbook*.

***FDI*: Foreign Direct Investment.** Three different FDI series were considered in the regressions. The first two are both measures of net inflows of FDI from the world to the recipient country. One comes from the *World Development Indicators*, published by the World Bank, and the other comes from *International Financial Statistics*, IMF, line 78 *bed*. The data published by both these sources come originally from the IMF. Consequently there is overlap between the two series, and yet they are not identical. The third series measures net private inflows of FDI from DAC countries to countries that are aid recipients. That series comes from *Geographical Distribution of Financial Flows to Aid Recipients*, published by the OECD. Since the DCs are by definition not included as recipients in that series, the value of this inflow is by definition zero for DCs. In order to include DCs in the regressions that include this OECD measure of FDI, I take the natural log of one plus this measure.

***Y*: Real GDP.** Data on real GDP per capita in constant dollars (expressed in 1985 international prices) come from the PWT, v. 5.6 in SH (1991).[38]

***POP*: Population.** Population data are from the PWT, v.5.6.

[37] Using the SH (1991) data on investment flows and capital stocks for 29 countries in 1980 and 1985, Benhabib and Spiegel estimate the capital stock coefficient in a standard three factor aggregate production function with constant returns to scale. They then use this coefficient to estimate initial capital stocks in 1965 for the remaining countries in the data set.

[38] SH (1991) created this data set using a series of benchmark studies by the United Nations International Comparison Program (ICP). These studies attempt to report prices of identical goods and services in participating countries. From the reported prices, estimates of price parities were created to convert national currency expenditures into a common currency unit. These studies actually present cross-sectional data on prices for between 16 and 60 countries in 1970, 1975, 1980 and 1985. The Penn World Table estimates are therefore based on extrapolations of the cross-section comparisons, in order to include additional countries and dates.

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