TECHNOLOGY, TRADE AND GROWTH: SOME EMPIRICAL FINDINGS

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Abstract:

International patent data for 39 countries from 1970 to 1985 are used to create proxies for imitation and innovation. Domestic imitation and innovation both appear to depend positively on high technology imports from developed countries, intellectual property rights, and the size of the economy. Additionally, transportation and communication infrastructure and quality adjusted research effort are found to contribute positively to domestic innovation. Finally, growth in real per capita GDP is positively related to physical capital stock growth, foreign and domestic innovation, and negatively related to initial GDP levels, consistent with conditional convergence hypotheses. Interestingly, foreign technology from developed countries appears to play a greater role in per capita GDP growth than domestic innovation.

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I. Introduction

This paper empirically considers the role of trade in the international diffusion of technology. The endogenous growth model put forth in Connolly (1997) provides the starting point for this work. The model postulates that trade in intermediate capital 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 first the role of trade in the processes of imitation and innovation, and second the effect that these processes have on growth. Since I am particularly interested in the diffusion of technology from developed to less developed nations, all countries for which data are available are included. Specifically, there are data for 73 countries. However, only a subset of these countries is included in each regression depending upon which countries have all the data required for any particular regression. In particular, innovation regressions include 18, mostly developed, countries. Imitation regressions include 25 countries, and growth regressions include 32 countries. Hence, this paper provides empirical analysis inclusive of some developing countries not often considered in empirical papers on technological diffusion. Still, due to data limitations there remains an under representation of less developed nations relative to developed countries.

Other Empirical Work on Trade and Technological Diffusion

Several recent empirical papers have considered the role that trade may take in the international diffusion of technology. Eaton and Kortum (1995) consider geographical distance, human capital, and the level of a country's imports from a partner country relative to its own GNP as factors that could influence technological diffusion between the partner country and the home country. Using patent data from 19 OECD countries, they find that imports are significant in explaining technological diffusion, but that the elasticity for that variable is very small (approximately .1). They find however that geographical distance and human capital tend to play a much larger role in technological diffusion. So while they conclude that ideas are very mobile internationally and that this drives much of the world's productivity growth, they do not find that this is strongly linked to international trade. However, since they are only considering technological diffusion between developed nations these results may underestimate the role that trade may play between developed and less developed countries.

Coe and Helpman (1993) consider the importance of the role played by domestic R&D capital stocks as well as the import weighted sum of R&D stocks of a country's trade partners in domestic total factor productivity growth. They use the accumulated R&D stocks as proxies for the stock of knowledge in any given country. Using a sample of 22 developed countries, Coe and Helpman find that both the domestic and the foreign R&D capital stocks have significant effects on a country's total factor productivity, and that the effect of the foreign R&D stocks is greater the more open the economy. However, the work of Keller (1996) casts serious doubts as to the interpretation of Coe and Helpman's results, since Keller is also able to estimate large international R&D spillover effects using random bilateral trade shares instead of actual bilateral trade shares. Again, this may be, at least in part, the result of the fact that in these papers only developed and relatively highly interactive countries are being considered. These results may be interpreted as suggesting that we should not focus narrowly on bilateral trade shares if the group of countries has a great deal of interaction amongst themselves. For example, suppose one country, say France, interacts a great deal with a second country, say Germany, thus allowing technology transfers between France and Germany to occur easily through mechanisms other than goods trade. Then France would benefit not only from the technology embodied in its own imports from the rest of the world, but also from any technology that Germany gains from its imports from the rest of the world. Hence, France could benefit from R&D efforts in third countries without particularly having to trade directly with those countries so long as Germany (or other countries with which France is highly integrated) is trading with these other countries.

Coe, Helpman, and Hoffmaister (1995) extend the Coe and Helpman type of analysis to 77 developing countries although only foreign stocks of accumulated R&D expenditures are considered. They find that the total factor productivity of developing nations increases with a greater import weighted foreign (DC) R&D capital stock, with increased openness to trade with developed nations, and with greater secondary school enrollment.

Relative to the existing literature on trade and technological diffusion, this paper attempts to see specifically what direct effect trade has on domestic innovation and imitation, and in turn, what effect domestic innovation has on real per capita GDP growth. The paper is organized as follows. Section II presents a brief overview of the model guiding the empirical analysis. Section III describes the data and defines the innovation and imitation proxies. Section IV presents the empirical results and section V concludes.

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 (1997). 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.[1] 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 is:

$$Y = A\,L^{\alpha}\sum_{j=1}^{J} \left[\, q^{k_j}\,(x_{k_j} + x^{*}_{k_j})\right]^{1-\alpha}, \qquad \text{where } 0<\alpha<1.$$

A is a productivity parameter dependent upon the country's institutions, such as tax laws, property rights, and government services, and L is the labor input used by the representative firms for final goods production. 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 at which the good is found in a quality ladder. Normalizing so that all goods begin at quality level 1, the quality level of an intermediate good in sector j will rise from 1 to q with the first innovation, to q^2 with the second innovation, and to with the k_j th innovation. Thus, $q^{k_j}\,(x_{k_j} + x^{*}_{k_j})$ is the quality adjusted amount of the intermediate good of type j (with the asterisk denoting imports) used in final goods production.

[1] Following convention, the North is considered a developed country and the South a less developed country.

Within each intermediate goods sector, limit pricing (along with constant marginal costs of production across domestic firms) allows the Northern firm with the leading technology to capture the world market. However, a Southern firm will take the world market from the lead firm if it successfully imitates the lead Northern good, since it is able to underprice the Northern firm because of lower marginal costs of production. Firms in both countries decide how many resources to devote to innovative or imitative research based on expected present value of profits for successful research. For an intermediate goods sector presently at quality level k, p_k, is the probability per unit of time of successful innovative or imitative research. Specifically, p_k follows a Poisson process which depends positively on resources devoted to research, z_k, and past domestic learning-to-learn, ϑ_k, within that domestic industry, and negatively on the complexity, $\phi(k)$, of the good upon which firms are attempting to improve/imitate:

$$p_k = z_k \, \phi(k) \, \vartheta_k, \qquad \text{where}$$

$$\vartheta_k = \max \left(\beta_C \, q_C^{k_j}, \beta_I \, q_I^{k_j} \right), \qquad \beta_I > \beta_C > 0.$$

Subscripts C and I denote copying and innovation, respectively. ϑ_{k_j} reflects the positive spillover effects of past learning-to-learn through imitation or innovation. For a particular domestic intermediate goods sector, $q_C^{k_j}$ is the highest quality level attained through imitation and $q_I^{k_j}$ is the highest quality level attained through innovation. If a domestic industry has no imitative experience, then $q_C^{k_j} = 0$, and if it has no innovative experience, then $q_I^{k_j} = 0$.[2] 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, $\phi(k_j)$ reflects the increased difficulty of innovation/ imitation when higher quality levels are being invented/imitated, implying a lower probability of success, all else equal. This term differs for innovative and imitative processes. For innovative research the difficulty term includes a country specific fixed

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

cost of innovation, ζ_I, as well as a measure of the quality level upon which the firms is attempting to improve:

$$\phi_I(k) = (1/\zeta_I)q^{-k/\alpha}.$$

For imitative research this terms further includes an interaction term, ω, reflecting lower costs of imitation when firms are exposed to higher levels imports of capital goods from the developed country, as well as higher transportation and communication infrastructure quality. Finally, the difficulty of imitation term also depends on the ratio, $\hat{q}$, of the technology levels between the imitating and innovating country (denoted with subscripts S and N respectively):

$$\phi_C(k_j - 1) = (1/\zeta_C \hat{q}^{\sigma}(e^{-\omega}+1))\, q^{1-(k_j/\alpha)}, \quad \sigma > 0, \quad \text{and} \quad \hat{q}_j = \frac{q^{k_{Sj}}}{q^{k_{Nj}}}.$$

Given this setup and assuming balanced trade where all Southern intermediate goods sectors are undertaking imitative research, the equilibrium rates of innovation and imitation are as follows:

$$p_{IN} = [\frac{\beta_C}{\zeta_{CS}(e^{-\omega}+1)} \Omega_S (MC_N - MC_S)] - r_S,$$

$$p_{CS} = \frac{\frac{\beta_I}{\zeta_{IN}}(MC_S - \frac{MC_N}{q})\Omega_N - \frac{\beta_C}{\zeta_{CS}(e^{-\omega}+1)}(MC_N - MC_S)\Omega_S}{1 + r - \frac{\beta_C}{\zeta_{CS}(e^{-\omega}+1)}(MC_N - MC_S)\Omega_S}, \qquad \text{where}$$

$$\Omega_N = [L_N A_N^{1/\alpha}(\frac{MC_N}{MC_S})^{1/\alpha} + L_S A_S^{1/\alpha}]\,(1-\alpha)^{1/\alpha},$$

$$\Omega_S = [L_N A_N^{1/\alpha} + L_S A_S^{1/\alpha}(\frac{MC_S}{MC_N})^{1/\alpha}]\,(1-\alpha)^{1/\alpha}, \qquad \text{and} \quad MC_N = 1.$$

Both countries grow at the same rate, driven by Northern technological progress:

$$\gamma^* = [\frac{\beta_C}{\zeta_{CS}(e^{-\omega}+1)}\Omega_S\ (MC_N - MC_S) - \rho]/(\frac{1}{q^{(1-\alpha)/\alpha}-1}+\theta).$$

Imitation Regression

Based strictly on the model, imitation in a given country is a positive function of expenditures on research, real import levels of capital goods from developed countries, the country's transportation and communication infrastructure level, and past experience in imitative and innovative processes. Additionally, factors affecting the profitability of imitation, such as the size of the market, also contribute positively to imitative activities.[3]

The issue of human capital is not considered in the above model. However, the human capital level of researchers should also contribute positively to imitation. This concept is similar to a model by Nelson and Phelps (1966) where the rate of increase in the application of theoretical technology is an increasing function of educational attainment and the gap between the applied and the theoretical level of technology. The main conceptual difference from Nelson and Phelp's theory is that I am considering imitation of foreign technology rather than domestic application of theoretical technology.

Hence, I estimate the following equation

$$(1)\qquad C_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 F_{it} + \beta_3 H_{it} + \beta_4 NH_{it} + \beta_5 GDP_{it} + \beta_6 P_i + \mu_{it},$$

where $\mu_{it} = \alpha_i + \varepsilon_{it}$. The variables are named as follows. C_i is the imitation proxy, and R_i is the quality adjusted research effort measure. F_i is the real per capita measure of the transportation and communication infrastructure level. H_i is the real import level of high technology goods from developed countries, and NH_i is the real import level of all goods other than high technology goods from developed nations. GDP_i is the real gross domestic product (not scaled by population), and P_i is the patent protection index for country *i*. All variables used in these regressions are in natural logarithms. α_i represents a latent individual effect which is assumed to be time-invariant and identically distributed

[3]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 it is the size of their domestic market which is relevant.

across individual countries with variance σ_α^2. The ε_{it} are assumed to be identically, independently distributed with zero mean and constant variance σ_ε^2, conditional on the explanatory variables.

Note that in the above equation there are four unscaled variables, C_i, H_i, NH_i, and GDP_i. The imitation proxy, C_i, is not scaled since it represents increased technology or knowledge available in the economy after imitation. Hence, a per capita version of this variable would not be appropriate. The other three variables are not scaled since theory suggests that both the scale of imports of high technology goods and the size of the market affect research. Specifically, there are three reasons to argue that the volume of capital good imports from developed nations matter. First, suppose that each person who is exposed to a new good has a given probability that they will copy it. For a country as a whole, the good need only be copied by one domestic resident in order for the technology embodied in the good to be acquired domestically. Hence, it matters how many individuals are exposed to the new good. Therefore, the greater the volume of imports of this particular good, the greater the likelihood that it will be imitated. Second, if a country imports a large volume of high technology capital goods, it will generally also be importing a large variety of capital goods. This will increase the number of goods that can be potentially targeted for imitation. Third, in the case where importing firms undertake imitative activity, the greater the volume of imported capital goods which they distribute and service, the lower their costs of imitation will be thus making them more likely to imitate the good, all else equal.

Non-high technology imports are also included, principally to determine whether imports in general, matter to imitation. If this variable is positive and statistically significant, while the high technology imports is not, this would imply that there might simply be an openness effect, versus imports of capital goods from developed nations in particular, which matters to imitation. Hence, this variable is used in the same form as the high technology imports term.

Finally, the country's GDP level is also included. This serves two purposes. Firstly, it provides a measure of the size of the domestic market, which theoretically matters to both innovative and imitative research. Secondly, the GDP level provides a second scale variable in the regression. Hence, if the real level of high technology imports turns out to be significant when the GDP level is also included in the regression, we will know that most scale effects should be captured by the GDP level.[4]

Innovation Regression

Similarly to imitation, innovation should also depend positively on the quality adjusted research effort. Further, high technology imports and the transportation and communication infrastructure level positively affect equilibrium rates of innovation. Intuitively, high technology imports and the infrastructure level increase knowledge of foreign innovations, thereby positively affecting domestic innovation (perhaps through initial imitation). Hence, I consider a regression for innovation which is similar to that for imitation:

$$(2) \qquad I_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 F_{it} + \beta_3 H_{it} + \beta_4 NH_{it} + \beta_5 GDP_{it} + \beta_6 P_i + \mu_{it},$$

$$\mu_{it} = \alpha_i + \varepsilon_{it},$$

where I_i is the innovation rate in country i and all other variables are defined as before.

GDP Growth Regression

Theoretically, growth in output per worker is a positive function of growth in both the aggregate quality level and the intermediate goods stock. If a country allows free trade in intermediate goods then the quality level of the 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, either in imitation or innovation, depending on their relative costs. I therefore wish to consider domestic innovation and imitation, as well as foreign innovation in the GDP growth regressions. Growth of capital good imports from developed countries is used as a proxy for the effect of foreign technology on domestic growth.

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[4]Please note that these regressions are also performed using scaled versions of high technology imports yielding generally similar results.

Average annual data for three separate subperiods, 1970-74, 1975-79, and 1980-84 is used in the analysis that follows. For each subperiod, I consider the growth of real per capita GDP, Y_i, (in ln differences) as a function of the growth in the per capita physical capital stock, K_i, the innovation rate, I_i, the imitation rate, C_i, and the growth of real import levels of high technology goods, H_i. In addition, the average 1965-69 real per capita GDP level, $Y_{i,t-1}$, is included as an independent variable, to test for convergence:

(3) $$\gamma_{Y_{it}} = \beta_0 + \beta_1 Y_{i,\,t-1} + \beta_2 \gamma_{K_{it}} + \beta_3 I_{it} + \beta_4 C_{it} + \beta_5 \gamma_{H_{it}} + \mu_{it},$$

$$\mu_{it} = \alpha_i + \varepsilon_{it}.$$

III. Data

Innovation Proxy

The proxy for innovation is defined as the number of U.S. patents granted to residents of a given country each year as reported by the U.S. Patent and Trademark Office. This assumes that if an innovation is truly novel, its inventor will apply for and be granted a U.S. patent. Of course, there are 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. and is not worried about having American firms copy their good, then they will not bother applying for a U.S. patent. Furthermore, while the U.S. has very high levels of patent enforcement, there are industries in which it is easy to invent around a patent. Thus within these industries, firms will generally avoid applying for patents since this might divulge information which increases the chances that they will lose their market to another competitor. Hence, there are many reasons for which an innovation might not be patented in the United States, implying that this proxy will generally underestimate innovative activity.

Imitation Proxy

The proxy for imitation is defined as the number of applications for domestic patents by home residents (as reported by the World Intellectual Property Organization

(WIPO) in annual issues) 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 an American invention, but believes it will be able to be granted a patent in its home country. This could either be because of more lax novelty requirements at home as compared to the U.S., or simply because the American firm has not bothered to patent its invention in that particular country. However, the imitating firm would not bother to apply for a patent in the U.S. since the novelty requirements are more stringent and the U.S. firm will have patented in the United States. This assumes that residents of countries other than the U.S. will attempt to patent imitative goods in their home countries, but will only seek patenting in the U.S. if they consider their goods to be truly novel. There are several drawbacks to this proxy for imitation. As previously discussed, there may be very good reasons for which a firm with an new invention may try to patent in their home country, but not in the United States. For example, a firm may invent a good that is particularly tailored to the domestic demand of its home country, but might not be in demand in the United States. The firm would therefore seek a domestic patent but would not try to patent the good in the U.S. where it does not foresee selling its good. This will cause the imitation proxy to overestimate imitative activity. On the other hand, the imitation proxy also depends on enforcement of patent laws in the home country and in the U.S., as well as expected profits from sales at home versus in the United States. For example, suppose patents are not enforced in a given country. Then imitative activity might be taking place, but no firms would bother seeking domestic patent protection. Similarly, if a country has strict novelty requirements, imitators would not be granted a domestic patent. Hence, for those types of countries, this measure of imitation underestimates the true quantity of imitation taking place. Overall however, this proxy will underestimate imitative activity in less developed nations. With these caveats in mind, I use this proxy as a first attempt to quantify imitative activity.[5]

For brevity the remainder of the data series are described in the appendix.

[5] Litigation might provide an alternative measure of intellectual property right infringement. However, in a majority of the cases of intellectual property right infringement, the cases are settled out of court, often prior to officially filing the case. 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.

IV. Empirical Results

The empirical analysis which follows uses a panel data set consisting of three separate five year periods, 1970-74, 1975-79 and 1980-84, for a cross-section of up to 32 countries. All variables are in natural logarithms and are expressed in real terms.

Section II described the basic regression equations tested. Instrumental Variable Estimation (*IVE*) is used throughout. Both cross sectional results using the time average over all three time periods (i.e. the time average from 1970 to 1984) and results from random effects estimation over the three time periods are presented. It should also be noted that there is evidence of multicollinearity problems in all the regressions that follow. The regressions nonetheless yield robust results.

Imitation and Innovation

Due to endogeneity problems, instruments are used for high technology imports, non-high technology imports, the GDP level, and intellectual property rights. Earlier import values, the exchange rate, terms of trade shocks, a black market premium, a measure of free trade openness, and measures of tariff and non-tariff restrictions on imports of intermediate inputs and capital goods are all used as instruments for imports. The average GDP level from 1965-69 is used as an instrument for GDP levels in the regressions. Finally, instruments suggested by Maskus and Penubarti (1995) are used for the level of intellectual property right protection. These include alternative measures of intellectual property right protection such as dummy variables for former British and French colonies and for membership in the Paris Convention, and earlier indicators of development such as secondary school enrollment ratios, infant mortality rates and fertility rates, all in 1965.

Since the quality adjusted measure of research effort and transportation and communication infrastructure are both predetermined stock measures, they enter as their own instruments. The same regressions are run for both the imitation and innovation proxies and are therefore described together. For illustrative purposes, I first present straightforward pooled *2SLS* regression results. I then present cross sectional and random effects *2SLS* regression results.

Table 1. Innovation and Imitation Regressions
(using White's Heteroskedasticity Correction)

Dependent Variable	**Imitation** Eq. 1			**Innovation** Eq. 2		
	(1) **Pooled** ***2SLS***	(2) **Cross – Section (Between)** ***2SLS***	(3) **Random Effects** ***2SLS***	(4) **Pooled** ***2SLS***	(5) **Cross - Section (Between)** ***2SLS***	(6) **Random Effects** ***2SLS***
Constant	-11.6* (-4.21)	-8.75** (-2.29)	-2.09** (-2.01)	-18.3* (-7.44)	-17.7* (-3.22)	-18.3* (-7.44)
Quality Adj. Research Effort (R)	.178 (1.19)	.341 (1.46)	-.525* (-2.73)	.154** (1.74)	.323** (2.71)	.154** (1.74)
Transp. & Communic. Infrastructure (*F*)	.432** (2.11)	.329 (1.48)	.080 (.132)	.943* (6.44)	1.06** (2.71)	.943* (6.44)
High Tech. Imports (*H*)	.983** (2.09)	1.22*** (2.04)	1.76* (3.05)	2.13* (6.87)	2.0* (4.74)	2.13* (6.87)
Non-High Tech. Imports (NH)	-.992* (-3.48)	-1.02* (-2.99)	-.988 (-1.14)	-1.26* (-6.78)	-1.33* (-4.40)	-1.26* (-6.78)
Real GDP (GDP)	.995* (3.78)	.712** (2.05)	.956*** (1.56)	.578* (3.14)	.559 (1.49)	.578* (3.14)
Intellectual Property Rights (P)	.606* (2.58)	.521**** (1.53)	.465 (1.56)	.835* (3.84)	.930* (3.53)	.835* (3.84)
Observations	81	25	75	55	18	55
R^2	.80	.85	.	.89	.95	.89
F-Statistic	57	32	6	88	185	88

*Significant at the 1% confidence level. **5% conf. level. ***10% conf. level. ****15% conf. level.
All variables are in natural logarithms. t-statistics are in parentheses.

Pooled *2SLS* Innovation and Imitation Regressions

The first and fourth columns of Table 1 present the pooled *2SLS* estimates for the imitation and innovation regressions, respectively. The coefficient estimates generally have the expected signs and are all statistically significant with the exception of research effort in the imitation regression. For the imitation regression, the variables with the largest magnitudes are high technology imports from developed countries and the scale of the economy which both have coefficients of approximately 1. Transportation and communication infrastructure, with a coefficient of .4 also contributes positively to domestic imitation. The only result which might seem surprising is that patent protection (with a coefficient of .6) is also found to positively affect the imitation proxy. However, given that firms only bother patenting domestically if intellectual property rights are enforced, this result is consistent with the imitation proxy as defined. Imports of non-high technology goods, on the other hand, enter negatively with a coefficient of –1, demonstrating that misplaced openness effects are not driving the results for high technology goods.

In the innovation regression, all of the independent variables are significantly different from zero. Innovation is found to depend positively on the quality adjusted research effort, infrastructure, high technology imports, the scale of the economy, and intellectual property rights. Still the quality adjusted research effort has a coefficient of only about .2, while infrastructure and intellectual property rights have coefficients of .9 and .8 respectively. Interestingly, in the innovation regression the coefficient on high technology imports from developed countries, 2, is now larger than the coefficient on the scale of the economy, .6. This elasticity of domestic innovation with respect to high technology imports implies that a 1 percent increase in level of high technology imports from developed countries would contribute to a 2 percent increase in domestic innovative activity. For example, if the domestic innovation rate had been 1 percent initially, a 1% increase in high technology imports would raise the domestic innovation rate to 1.2%. Again imports of all other goods other than high technology goods from developed countries enter negatively with a coefficient of –1.3.

Cross Sectional *2SLS* Innovation and Imitation Regressions

Columns 2 and 5 of Table 1 present the results from the cross-sectional *2SLS* regressions for imitation and innovation respectively, using the time averages for each country from 1970 to 1984.[6] In the imitation regression the estimated coefficients for quality adjusted research and transportation and communication infrastructure are not significantly different from zero. The coefficient on intellectual property rights is positive but significant only at the 15% confidence level. Still, some results mirror those in the previous pooled regression. For example, while the size of the economy is statistically significant with a coefficient of .7, imports of high technology goods from developed countries, whose coefficient is 1.2, is also statistically significant and of far greater magnitude than GDP. Thus, the significance of high technology imports is again not solely due to a scale effect. Additionally, imports of all other goods enter negatively, showing that the positive coefficient for high technology imports is also not simply due to openness effects.

The innovation regression is once again more successful than the imitation regression. With the cross-sectional *2SLS* innovation regression, the coefficient estimates for the explanatory variables are all statistically significant except for real GDP. Note however that the coefficient on GDP, .6, is the same as in the previous pooled *2SLS* regression. Only the standard errors have changed. This may be due to problems of multicollinearity between GDP and several other independent variables in the regression such as imports, infrastructure, and quality-adjusted research. As expected, quality adjusted research effort, transportation and communication infrastructure, and intellectual property rights are all found to positively contribute to domestic innovation with coefficients of .3, 1, and 1, respectively. High technology imports from developed nations

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[6]This yields consistent and unbiased (although inefficient) estimates provided there is no correlation between the latent individual effect and the explanatory variable. Random effects estimation, which follows, is more efficient than between groups estimation and is in fact *BLUE* so long as there is no correlation between the latent individual effect and the explanatory variables. However, if there is correlation between the latent individual effect and the explanatory variables, then fixed effects estimation, which considers deviation from time averages, is the most appropriate estimation technique. This is because its estimates will be consistent and unbiased regardless of such correlation. However, given the nature of the data being used, i.e. three different subperiods of five-year averages, and the nature of the relationships we are attempting to observe, fixed-effects estimation is not really applicable. Specifically, it is unrealistic to assume that high technology imports will have an instantaneous effect on domestic innovation and imitation. With such aggregate data it is not possible to accurately capture the timing issues involved. Furthermore, since fixed-effects estimation considers deviations over time from individual country averages and there are only three time periods (themselves five-year averages) under consideration, not much information is left after the fixed effects transformations are completed. For these reasons, fixed effects estimates do not yield any worthwhile results.

also positively contribute to innovation with a coefficient of 2, while imports of all other goods enter negatively with a coefficient of −1.3.

Random Effects *2SLS* Innovation and Imitation Regressions

The results in columns 3 and 6 of Table 1 are from random effects *2SLS* estimation using the following transformation of equation (1)

$$(1\text{ R.E.})\; C_{it} - \theta\overline{C}_i = (1-\theta)\beta_0 + \beta_1(R_{it} - \theta\overline{R}_i) + \beta_2(F_{it} - \theta\overline{F}_i) + \beta_3(H_{it} - \theta\overline{H}_i) + \beta_4(NH_{it} - \theta\overline{NH}_i) + \beta_5(GDP_{it} - \theta\overline{GDP}_i) + [(1-\theta)\alpha_i + (\varepsilon_{it} - \theta\overline{\varepsilon}_i)],$$

where variables with bars represent time averages from 1970 to 1984. The weight, θ, used in the above transformation depends on σ_α and σ_ε.[7] Note that if θ equals 1, then random effects estimation is equivalent to fixed effects estimation. On the other hand, if θ equals 0, then random effects estimation is equivalent to *OLS* estimation. A similar transformation of equation (2) is used for the innovation regression.

The random effects imitation regression performs quite poorly. The oddest result is the negative (and statistically significant) coefficient on quality adjusted research. The remaining variables enter with the same signs as in the previous regressions, although only high technology imports and the scale of the economy continue to be significant with coefficients of 1.8 and 1 respectively.

Conversely, the random effects *2SLS* innovation regression performs well. Still, note that the estimated θ for this regression is 0, so the random effects *2SLS* results presented in column 6 are identical to the previous pooled *2SLS* results in column 4. Hence, all the variables have the expected sign and are significantly different from zero. Again imports of high technology goods, whose coefficient is 2, contributes the most to domestic innovation. By order of importance they are followed by infrastructure (.9), intellectual property rights (.8), real GDP (.6), and quality adjusted research effort (.2).

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[7] Specifically, $\theta = 1 - \frac{\sigma_\varepsilon}{(T\sigma_\alpha^2 + \sigma_\varepsilon^2)^{1/2}}$, where T = number of time periods.

Again non-high technology imports contribute negatively to domestic innovation with a coefficient of –1.3. Hence, despite multicollinearity problems, the data show that quality adjusted research effort, transportation and communication infrastructure, imports of high technology goods from developed nations, the scale of the domestic economy, and domestic intellectual property rights all positively influence domestic innovation.

The most consistent finding of these regressions is that regardless of the estimation technique, high technology imports from developed countries are always found to contribute positively both to domestic innovation and imitation. Furthermore, the coefficient estimate on high technology imports is consistently 2 for all innovation regressions and ranges between 1 and 1.7 for the imitation regressions. Since all variables are in natural logarithms, these coefficient estimates represent the elasticities of domestic innovation and imitation with respect to high technology imports. Assuming that the initial rate of domestic innovation and imitation were both 1%, this implies that a sustained 1% increase in imports of high technology capital goods would have raised the domestic innovation and the imitation rates to 1.2% and 1.1% respectively during that same period, all else equal.

Per Capita GDP Growth

Now that we have considered factors which contribute to domestic innovation, we can turn to the question of how foreign and domestic technology affect growth.[8] To analyze the contributing factors to real per capita GDP growth, theory suggests considering the following relationship

$$(3) \qquad \gamma_{Y_{it}} = \beta_0 + \beta_1 Y_{i,\,t-1} + \beta_2 \gamma_{K_{it}} + \beta_3 I_{it} + \beta_4 C_{it} + \beta_5 \gamma_{H_{it}} + \mu_{it},$$

[8] In order to consider a larger number of countries in the growth regressions, the proxy for domestic innovation is changed slightly. For these regressions it is defined as the number of U.S. patents granted to residents of a given country plus one. Then the natural log of the innovation proxy will be zero for countries that have not patented in the U.S. rather than being undefined and dropped from the regression.

where $\mu_{it} = \alpha_i + \varepsilon_{it}$. However, due to collinearity between the innovation and imitation proxies, the imitation proxy is not included in the regressions that follow.[9]

Table 2. Growth Regressions
Eq. (3') (using White's Heteroskedasticity Correction)

Dependent Variable: Growth of Real GDP Per Capita (*Y*)

	(1) Pooled *2SLS*	(2) Cross -Section (Between) *2SLS*	(3) Random Effects *2SLS*
Constant	.071* (2.50)	.071*** (1.53)	.082** (2.19)
1965-69 GDP per capita (Y_{t-1})	-.009** (-2.27)	-.009*** (-1.47)	-.012** (-1.98)
Growth of per capita Capital Stock (K)	.327* (3.70)	.424* (2.87)	.231** (1.98)
Growth of High Tech. Imports (*H*)	.088* (3.59)	.134** (1.72)	.108* (3.91)
Domestic Innovation (I)	.002*** (1.87)	.002 (.961)	.003**** (1.55)
Observations	107	32	96
R^2	.51	.63	.49

*Significant at the 1% confidence level. **5% conf. level. ***10% conf. level. ****15% conf. level.
All variables are in natural logarithms. t-statistics are in parentheses.

For illustrative purposes, first column of Table 2 shows the results of the pooled *2SLS* regression on equation (3) without the imitation proxy. Instruments are used for both the imports of high technology goods and domestic innovation. The exogenous variables from the previous innovation regressions are employed to instrument for domestic innovation. In particular, average innovation from 1965 to 1969, the per capita transportation and communication stock, and quality-adjusted research are all used as

[9]Inclusion of the imitation proxy does not significantly affect the coefficient estimates of the other explanatory variables, although its own coefficient estimate is generally negative and significantly different from zero. Interestingly, the magnitude of its coefficient tends to be close (although of the opposite sign) to

instruments for domestic innovation. All independent variables are significantly different from zero and have the expected signs. Initial (1965-1969) per capita GDP levels enter negatively, supporting the notion of conditional convergence. This finding is similar to the Barro and Sala-i-Martin (1991) findings of conditional convergence between states of the United States. Growth of the physical capital stock, growth of high technology imports from developed countries, and domestic innovation all contribute positively to domestic per capita GDP growth with coefficients of approximately .3, .1, and .002, respectively.

Column 2 of Table 2 presents the results from the cross-sectional (between-groups) *2SLS* regression. While the coefficient estimate for domestic innovation is again .002, it is no longer significantly different from zero. Nonetheless, the remaining variables are all statistically significant. Initial income again enters negatively, as consistent with conditional convergence. Growth of the capital stock, with an estimated coefficient of .4, has by far the greatest effect on growth in real per capita GDP. Still the elasticity of per capita GDP growth with respect to growth in imports of high technology capital goods is estimated to be .1.[10]

Finally, column 3 presents results from random effects estimation of equation (3') with instrumental variables for imports and domestic innovation. This regression uses the following transformation of equation (3')

$$(3'\text{ R.E.})\quad \gamma_{Y_{it}} - \theta\bar{\gamma}_{Y_i} = (1-\theta)\beta_0 + (1-\theta)\beta_1 Y_{i,t-1} + \beta_2(\gamma_{K_{it}} - \theta\bar{\gamma}_{K_i}) + \beta_3(I_{it} - \theta\bar{I}_i) + \beta_4(\gamma_{H_{it}} - \theta\bar{\gamma}_{H_i}) + [(1-\theta)\alpha_i + (\varepsilon_{it} - \theta\bar{\varepsilon}_i)].$$

This regression yields similar results to the previous regressions. Initial income from 1965-69 enters negatively. Growth of the per capita physical capital stock contributes the most to per capita GDP growth with an estimated coefficient of approximately .2. The

that of the innovation proxy. Again, this is probably due to the construction of the imitation proxy where U.S. patent applications are subtracted from domestic patent applications.

10 This between-groups regression was also run, in one case using growth in the high technology imports per capita, and in another using growth in high technology imports as a share of GDP. Both regressions yield results that are remarkably similar to these.

elasticity of GDP growth with respect to growth of high technology imports is again about .1. The new finding in this regression is that while the magnitude of the coefficient on domestic innovation is still quite small (.003), it is again marginally significant at the 15% confidence level. If we consider the innovation proxy to be an accurate measure of domestic innovation and growth in imports of high technology goods from developed nations as a reasonable proxy for the influence of developed country innovations on the domestic economy, this suggests that the influence of innovations from developed countries tends to have a greater effect on domestic growth than domestic innovation.[11]

V. Conclusion

This paper finds general support for several of the hypotheses and implications of the Connolly (1997) model of technological diffusion through trade and imitation. Domestic imitation and innovation both appear to depend positively on high technology imports from developed countries, intellectual property rights, and the size of the economy. Additionally, transportation and communication infrastructure and quality adjusted research effort are found to contribute positively to domestic innovation. Finally, growth in real per capita GDP is positively related to physical capital stock growth, foreign innovation, and domestic innovation, and negatively related to initial GDP levels, as consistent with conditional convergence hypotheses. Interestingly, foreign technology from developed countries appears to play a greater role in per capita GDP growth than domestic innovation, suggesting that new foreign technology is applied directly to production as well as leading to increased domestic innovation and imitation.

Thus, the role of imports of high technology goods from developed countries in the international diffusion of technology is supported by the empirical results. These results are also consistent with the idea that trade with developed countries benefits less developed countries. This is due to evidence that capital goods imports from developed countries not only positively affect domestic innovation, but also that growth in their imports will lead to increased GDP growth as higher quality capital goods are used in

[11] Furthermore, since the measure of high technology imports is based on capital goods, it makes sense that growth in this term should positively affect GDP growth.

domestic production. Thus, the argument that trade is a mechanism by which more advanced foreign technology can be used to the advantage of a less developed country, as a means to boost domestic innovation, as well as a means of benefiting from continued foreign innovation, is supported empirically.

Appendix

High Technology Imports

A measure of imports of capital goods from developed nations is created using data from various issues of the *Commodity Trade Statistics* published by the United Nations.[12] The commodity groups used in this measurement include Standard International Trade Classes 7, 86, and 89 (SITC, Rev. 1). Class 7 includes machinery and transport equipment. Class 86 includes instruments (optical, medical, and photographic), watches and clocks. Finally, class 89 includes "miscellaneous manufactured goods" which include sound recorders, musical instruments, toys, and office supplies (which in later years include computers). These data are reported in current U.S. dollar terms. 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.

Instrumental variables are used to control for endogeneity of imports in the regressions. Earlier import values, the exchange rate, terms of trade shocks, a black market premium, a measure of free trade openness, and measures of tariff and non-tariff restrictions on imports of intermediate inputs and capital goods are all used as instruments for imports. Exchange rate data come from Summers and Heston (1991) version 5.0. Terms of trade shocks are defined as the growth rate of export prices minus the growth rate of import prices and come from the World Bank's World Table and the United Nations' Handbook of International Trade and Development. The black market premium data are from Wood (1988) and the World Bank (1991), where the black market premium is defined as the black market exchange rate divided by the official exchange rate with one subtracted from the ratio. Lee (1993) provides measures of trade restrictions as well as openness. In particular, he derives a measure of what he calls free trade openness based negatively on the average distance to the capitals of the 20 major world exporters and the

[12] During this time period, the United Nations includes the following list of countries as developed nations: 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.

size of the land surface in the home country. Using UNCTAD data, Lee also creates measures of both tariff and non-tariff trade restrictions on imports of intermediate goods and capital goods.

Non-High Technology Imports

To distinguish between the effects of imports of capital goods from developed countries versus other types of imports, I consider total imports, *excluding* capital goods imported from developed countries. Specifically, the real 1985 value of high-technology imports, derived earlier, is subtracted from real 1985 level of total imports from Summers and Heston (v.5.0). Hence, this measure serves both as a measure of openness and as a means by which to determine if the types of goods imported truly matter to domestic innovation and imitation. This variable also suffers from endogeneity problems. Hence, earlier values of this variable, along with the instruments for imports described above are used as instruments for non-high technology imports.

Intellectual Property Rights

Since patent data is used to create innovation and imitation proxies, it is important to control for varying enforcement of intellectual property rights across countries. To this end, I use a time varying index of intellectual property rights enforcement developed by Park and Ginarte (1997) for 110 countries. This 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. The Park and Ginarte index has two main advantages over other time-invariant indices of intellectual property rights [Rapp and Rozek (1990) and Mansfield (1994)]. Firstly, it covers more countries and a larger time period than the other indices, since it follows these countries over five-year periods from 1960 to 1990. Secondly, the index considers broader categories of the patent system, consequently yielding greater variability in the measurement of intellectual property rights across countries.

Since the level of intellectual property right protection is endogenously related to the level of domestic development, instruments are used for this variable. This paper uses several instruments suggested by Maskus and Penubarti (1995) when considering the Rapp and Rozek (1990) index. These include alternative measures of intellectual property right protection such as dummy variables for former British and French colonies and for membership in the Paris Convention, and earlier indicators of development such as secondary school enrollment ratios, infant mortality rates and fertility rates, all in 1965. Data for the school enrollment ratios comes from UNESCO, and infant mortality rates and fertility rates are from the World Bank.

Quality Adjusted Research Effort

To reflect not only the research effort by scientists, but also the quality of their efforts, I create a measure called the quality adjusted research effort. It is defined as the number of R&D personnel employed in research multiplied by the average years of higher education for the population over the age of 25. Data on R&D personnel employed in research come from various annual UNESCO *Statistical Yearbooks*. The education data are from Barro and Lee (1993).[13]

Capital Stock

Initial capital stock data are taken from estimates made by Benhabib and Spiegel (1994). Using the Summers-Heston (1991) data on investment flows and capital stocks for a limited sample of 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. Using these initial capital stock estimates, along with investment flows given in Summers-Heston (v5.6), I derive capital stock estimates for subsequent years. The capital stock is then scaled using population data from Summers and Heston.

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[13] To create this educational data set Barro and Lee first used census and survey data and then estimated missing observations using a perpetual-inventory method with school-enrollment data.

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*. To estimate the initial 1965 stocks of government communication and transportation infrastructure, I use the 1965 capital stock estimates made by Benhabib and Spiegel (1994). I then multiply the initial capital stock estimate 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. The stock of transportation and communication infrastructure is then also scaled using population data from Summers and Heston (1991).

Real GDP

Data on real GDP per capita in constant dollars (expressed in 1985 international prices) come from the Penn World Table, version 5.6., compiled by Summers and Heston (1991).[14] Whenever GDP is used as an explanatory variable in either innovation or imitation regressions, the average GDP level from 1965-69 is used as its instrument.

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[14] Summers and Heston (1991) created this data set using a series of benchmark studies by the United Nations International Comparison Program (ICP). These studies attempted to report prices of identical goods and services in participating countries. From the reported prices, estimates of price parities were created and then used to convert national currency expenditures into a common currency unit. It is important to note that these studies actually presented cross-sectional data on prices for between 16 and 60 countries during four specific years, 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. Hence these estimates will undoubtedly be mismeasured. Nonetheless, this is the only data set which allows for real comparisons across countries.

Countries Included in Cross-Section Regressions

Imitation Regression
Egypt
Tunisia
Mexico
Argentina
Bolivia
Brazil
Chile
Venezuela
Korea, Rep.
Philippines
Austria
Belgium-Luxembourg
Denmark
Finland
France-Monaco
Germany
Greece
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
Turkey
United Kingdom

Innovation Regression
Canada
Mexico
U.S.A.
Argentina
Brazil
Austria
Belgium-Luxembourg
Denmark
Finland
France-Monaco
Germany
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
United Kingdom

Growth Regression
Egypt
Tunisia
Canada
El Salvador
Guatemala
Mexico
U.S.A.
Argentina
Bolivia
Brazil
Chile
Venezuela
Jordan
Pakistan
Philippines
Singapore
Thailand
Austria
Belgium-Luxembourg
Denmark
Finland
France-Monaco
Germany
Greece
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
Turkey
United Kingdom

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