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ECONOMIC GROWTH AND TECHNOLOGY DIFFUSION IN DEVELOPING COUNTRIES

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This paper aims to use the system-GMM estimation to fit an augmented Solow growth model with international technology diffusion variables. We also investigate whether the parameters of the model differ appreciably across subsamples of countries. The paper finds that foreign direct investment is a more important channel for technology transfer to developing countries than openness to international trade. Furthermore, the estimates indicate that the more rapidly technology transfer is made, the greater is the stock of human capital accumulated.

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I. INTRODUCTION

International technology diffusion is the subject of many recent empirical studies. International trade and foreign direct investment (FDI) are considered to be two major channels for embodied knowledge spillovers.[1] The speed of technology diffusion will also depend on the

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[1] As a consequence of technological spillovers, FDI and openness increase the productivity not only on the firms, which receive these investments, but potentially also on all host-country firms. Rappaport (2000), Javorcik (2004), and Alfaro and Rodriguez-Clare (2004) show that these spillover effects result from both intra-industry and inter-industry externalities stemming, reflecting forward and/or backward linkages.

absorptive capacity of developing countries. One of the main determinants of absorptive capacity is the level of a country's human capital. A higher level of human capital allows a country to close the gap between the current level of productivity and that of the leading technology country faster, and enables a country to achieve a higher rate of expansion of technology frontier. The other determinant of absorptive capacity is its own R&D efforts and on foreign R&D that spills over into the world economy by means of international trade and FDI.

Human capital and domestic R&D are related to the ability of developing countries to benefit from international technology transfer, to catch up technologically, and contribute to their technological progress. Nelson and Phelps (1966), Coe and Helpman (1995), Benhabib and Spiegel (1994, 2002), Engelbrecht (2002), and Salinas-Jiménez (2003) among others have studied how absorptive capacity facilitates technological catch-up. Sachs and Warner (1997) estimate a neoclassical model that incorporates measures of openness to international trade as well as a number of geographical variables.

Recent studies assess whether there is an independent impact of FDI on economic growth and especially whether the impact of FDI on growth depends importantly on the stock of human capital. Borensztein et al. (1998) find that the direct effect of FDI on growth is negative and the higher productivity of FDI holds only when the host country has a minimum threshold of human capital. Carkovic and Levine (2002) include the term, FDI∗School, which equals the product of FDI and the average years of schooling of the working-age population in those simple growth regression models. They find that the impact of FDI on growth does not robustly vary with level of educational attainment. Wu and Hsu (2008) find that FDI alone plays an ambiguous role in contributing to economic growth and that human capital is an important factor in explaining FDI from a threshold-regression analysis.[2]

This paper considers how absorptive capacity and technological spillovers from international trade and FDI affect the diffusion of technology. We therefore incorporate variables measuring international

[2] Recent research in this area recommends using system Generalized Methods of Moments (GMM) versus first-difference GMM, especially when estimating growth models.

technology diffusion variables into the augmented Solow model, focusing on technological catch-up as resulting in income convergence.[3] Furthermore, we investigate a subsample of the countries in order to allow for some limited heterogeneity and to gauge its importance. In dynamic panel-data models, it is necessary to control for the endogeneity of the regressors and to allow for limited heterogeneity. Our method is the system Generalized Methods of Moments (GMM) panel estimator designed by Blundell and Bond (1998). Bond et al. (2001) discuss a potentially serious problem with first-difference GMM in the context of the empirical growth model. This estimator combines the standard set of equations in the first differences with suitably lagged levels as instruments and an additional set of equations in levels with suitably lagged first-differences as instruments.

The rest of the paper is organized as follows: Section II discusses the model and how we test it, Section III is devoted to our empirical findings, and Section IV concludes.

II. THE MODEL AND ITS ESTIMATION

We start from the assumption that levels and growth rates of technology can vary across countries and that production is governed by the linear homogenous Cobb-Douglas technology,

$$Y_{it} = K_{it}^{\alpha} H_{it}^{\beta} (A_{it} L_{it})^{1-\alpha-\beta}, \; 0<\alpha<1, \; 0<\beta<1, \; i=1,\cdots,N, \; t=1,\cdots,T, \qquad (1)$$

where Y is output, L is labor, K is the stock of physical capital, H is the stock of human capital, and A is the level of labor efficiency in country i during period t. Let the growth rate of labor- augmenting technology be γ. Mankiw, Romer, and Weil (1992) show that this production function together with the assumptions that constitute Solow's model of economic growth imply that to the first approximation,

[3] Bond et al. (2001) estimate the Solow growth model without international technology transfer by system GMM, finding evidence of a lower rate of convergence than many other authors. Dowrick and Rogers (2002) use dynamic panel estimation to estimate the separate contributions of diminishing returns and technology transfer to the rate of conditional convergence.

$$y_t - y_{t-1} = \gamma_i + (1-e^{\lambda})\log A_{i0} + (1-e^{\lambda})\left(\frac{\alpha}{1-\alpha-\beta}\right)\log s_{ki}$$
$$+(1-e^{\lambda})\left(\frac{\alpha}{1-\alpha-\beta}\right)\log s_{hi} - (1-e^{\lambda})\left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\log(n_{it}+\delta_i+\gamma_i)$$
$$-(1-e^{\lambda})y_{i,t-1},\quad 0<\alpha<1,\ 0<\beta<1,\ i=1,\cdots,N,$$
$$t=1,\cdots,T, \tag{2}$$

where y_{it} is the logarithm of output per worker in country *i* during period *t*, s_{ki} is the investment rate of country *i* during period *t*, s_{hi} is the measure of the investment rate in human capital, n_{it} is the population growth rate of country *i* in period *t*, γ_i is the growth rate of technology in country *i*, δ_i is the depreciation rate of both physical and human capital in country *i*, and $\lambda = (n_{it}+\delta_i+\gamma_i)(\alpha-\beta-1)$,[4] assumed to be constant both across countries and over time.

For purposes of estimation, we employ the following regression equation:

$$y_{it} = \eta y_{i,t-1} + BX_{it} + \varphi_i + \phi_t + e_{it}, \tag{3}$$

where X is a vector of explanatory variables other than $y_{i,t-1}$, B is a vector of parameters, φ_i is the country-specific component of countries i, ϕ_t is a time-specific component shared by all countries, η is a parameter lying on (0,1), and e_{it} is an independently and identically distributed error term with a zero mean and finite variance. Arellano and Bond (1991) suggest that equation (3) be differenced to eliminate the country-specific effects:

$$\Delta y_{it} = \eta\Delta y_{i,t-1} + B\Delta X_{it} + \Delta\phi_t + e_{it} - e_{it-1}. \tag{4}$$

One can then estimate equation (4) consistently using instrumental variables to deal with the endogeneity of the explanatory variables and the fact that $\Delta y_{i,t-1}$ is correlated with ($e_{i,t}$–$e_{i,t-1}$). Assuming that e is serially

[4] In the empirical application of Solow growth model, we assume an exogenous growth rate of technical change to be 0.02 per year and a common depreciation rate to be 0.03 per year.

uncorrelated and that X is weakly exogenous, Arellano and Bond derive the following moment conditions:

$$\begin{aligned} &E[y_{i,t-s}(e_{it}-e_{i,t-1})]=0 \\ &E[X_{i,t-s}(e_{it}-e_{i,t-1})]=0 \end{aligned} \quad \text{for all} \quad s>1, t=3,\cdots,T. \tag{5}$$

Blundell and Bond (1998) show that when the explanatory variables are persistent over time, lagged levels of these variables are weak instruments and as a result the asymptotic and finite-sample performance of the difference estimator can deteriorate appreciably. They suggest that one should use a new estimator that combines a regression in levels with the regression in differences described above. The instruments for the regression in levels consist of differences in the variables, which are appropriate under the additional assumption that these differences are uncorrelated with the country-specific effects. In the levels regression, only the most recent difference is used, thereby imposing the additional moment condition[5]

$$\begin{aligned} &E[\Delta y_{i,t-1}(\varphi_i+e_{it})]=0 \\ &E[\Delta X_{i,t-1}(\varphi_i+e_{it})]=0 \end{aligned} \quad \text{for} \quad t=3,\cdots,T. \tag{6}$$

We need more discussion to set up the Solow growth model to be estimated by the system-GMM. In equation (3), the unobserved country-effects (φ_i) reflect differences in the initial level of efficiency, whilst the period-specific intercepts (ϕ_t) capture productivity changes that are common to all countries. To eliminate the country effect, we difference the equation (3) to get equation (4). The inclusion of time dummies allows for common long-run growth in GDP per worker, consistent with common technical progress without violating the validity of additional moment restrictions used by the system GMM estimator. In equation (5), given that $E(\varphi_i \Delta X_{it})=0$ for all *t*, $E(\varphi_i \Delta y_{it})=0$ is required. However,

[5] In the first step, the error terms are assumed to be independent, homoskedastic across countries, and over time. In the second step, the residuals obtained in the first step are used to consistently estimate the covariance matrix of the error term, enabling the assumptions of independence and homoskedasticity to be relaxed.

if these first-differences were correlated with country-specific effects, this would have implausible long-run implications. This means that assumption $E(\varphi_i \Delta y_{it}) = 0$ does not imply that the country-specific effects play no role in GDP determination.[6] Our research estimates the augmented Solow model considering the effect of technology diffusion on economic growth and income convergence after controlling for initial output per worker and while accounting for endogeneity and country-specific effects.

Therefore, we incorporate variables to measure the international transfer of technology into the augmented Solow model discussed above. We test whether technology is transmitted either by openness to international trade or by FDI and whether the transmission is sped up by an increased level of educational attainment (h_{it}). We do so by using the system GMM to estimate

$$\Delta y_{it} = \eta \Delta y_{it-1} + \beta_1 \Delta i_{it} + \beta_2 \Delta(n_{it} + \delta + \gamma) + \beta_3 \Delta h_{it} + \beta_4 \Delta(openness_{it} \times h_{it}) + \beta_5 \Delta(FDI_{it} \times h_{it}) + \Delta\phi_t + e_{it} - e_{it-1}. \quad (7)$$

We interpret positive and statistically significant estimates of β_4 and/or β_5 as evidence that absorptive capacity is well measured by human capital per worker and that technology diffuses by means of international trade and/or FDI.

The serial correlation test as well as the Sargan test and the Wald tests of the joint significance of variables confirm that the GMM estimator is appropriate.[7]

III. DATA AND EMPIRICAL RESULTS

1. Data

We obtained data on real GDP per worker, the investment ratio, nominal exports, nominal imports, and nominal GDP from the *Penn*

[6] Bond, et al. (2001).

[7] A Wald test of joint significance for all variables entered in x_{it} shows a test of the null hypothesis that their estimated coefficients are all zero.

World Tables 6.1. Our variable *openness* is the ratio of the sum of nominal exports and imports to nominal GDP.[8] Our measure of human capital per worker comes from Barro and Lee (2001) and is the percent of the population at least 15 years of age attaining a secondary education. Finally, our variable *FDI* comes from the IMF's *Balance of Payments Statistics* and is the gross FDI inflow as a share of GDP. Our data are averaged over non-overlapping five-year periods between 1970 and 2000, leading to six observations for each of 50 developing countries of which 17 are in Africa, 13 are in Asia, 10 in the Caribbean, and 10 in South America.[9]

2. Estimates

Table 1 reports the difference-GMM and system-GMM estimates of equation (7). We assume that initial GDP and education are predetermined, investment is endogenous, and population growth is exogenous.[10] We test whether technology is transmitted by means of

[8] Some literature considers not openness per se but general imports or high-technology imports as a channel for technology diffusion. Data limitations were the key determinant of the sample used in the paper (for example, R&D data).

[9] The sample consist of: 17 African countries (Benin, Botswana, Republic of Congo, Gambia, Ghana, Kenya, Malawi, Mauritius, Mozambique, Niger, Senegal, South Africa, Togo, Tunisia, Uganda, Zambia, and Zimbabwe), 13 Asian countries (Bangladesh, China, Hong Kong, Indonesia, India, Korea, Malaysia, Pakistan, the Philippines, Singapore, Sri Lanka, Taiwan, and Thailand), 10 Caribbean (Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, and Trinidad & Tobago), and 10 South American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela).

[10] If x_{it} variables were predetermined with respect to error terms e_{is} (which rules out contemporaneous correlation but not feedbacks from past shock) or strictly exogenous with respect to e_{is} (which rules out correlation between x_{it} and e_{is} at any dates), additional instruments would be available for equation in first-differences. If x_{it} variables were endogenous, lagged values of endogenous x_{it} variables dated t–2 and earlier could be used as instruments for the equations in the first-differences, and also lagged first-differences of endogenous x_{it} variables could then be used as instruments for the level equations from the moment conditions. See Arellano and Bond (1991) and Bond, Hoeffler, and Temple (2001) for further discussion. Initial investment would be endogenous if expectations of subsequent growth in GDP affect it. The standard theory of investment has that implication. If education were measured as educational attainment, its initial value would be predetermined. If it were measured as the enrollment rate in, say, secondary schooling, it would not necessarily be predetermined. On the one hand, if the initial enrollment rate depended only on initial per capital income and other predetermined variables, it would behave like a predetermined variable. On the other hand, the enrollment rate might be like the investment rate in physical capital. In that case, it would depend on expectations of future growth and would be endogenous like the investment rate.

[Table 1] Estimation for a version of the augmented Solow model: whole sample

	Dif GMM (1)	System GMM (2)	Dif GMM (3)	System GMM (4)
$\Delta\log(GDP_{it-1})$	-0.284***	-0.171***	-0.294***	-0.186***
	(0.056)	(0.031)	(0.056)	(0.031)
$\Delta\log(investment_{it})$	0.137***	0.203***	0.130***	0.163***
	(0.045)	(0.027)	(0.045)	(0.029)
$\Delta\log(n_{it}+\delta+\gamma)$	-0.068	-0.473***	-0.059	-0.437***
	(0.099)	(0.107)	(0.100)	(0.097)
$\Delta\log(h_{it})$	0.014	0.045	-0.016	0.010
	(0.051)	(0.034)	(0.029)	(0.018)
$openness_{it}$*$\log(h_{it})$	0.010	0.006	-	-
	(0.040)	(0.021)		
FDI_{it}*$\log(h_{it})$	-	-	0.006	0.022***
			(0.007)	(0.006)
λ	0.0556	0.0312	0.0556	0.0343
m1	0.215	0.028	0.279	0.042
m2	0.180	0.590	0.142	0.334
Sargan test	0.555	0.503	0.414	0.660
Wald test	0.009	0.000	0.066	0.000

Notes: The dependent variable in each regression is the growth rate of output per worker. The figure in parentheses below each estimate is standard error. ***, **, and * indicate significance at 1, 5 and 10 percent, respectively. The reported figures for the tests for *m1* and *m2* tests (tests for first and second-order serial correlation) as well as Sargan test (test of over identifying restrictions) are *p-values* of the null hypothesis. The whole sample consists of 50 developing countries over six time periods consisting of five years each. The time span is 1970-2000. Arellano and Bond's GMM estimator is computed using DPD98 Gauss program. The estimated convergence rate (λ) is related to the estimate of η_1 by $-T^{-1}\ln(1+\hat{\eta}_1)$.

openness to international trade or FDI and whether it is sped up by an increased level of educational attainment. We first include $openness_{it}*h_{it}$ as a measure absorption ability of technology progress, obtaining the estimates in columns 1 and 2 of Table 1. We find that the coefficients on $openness_{it}*h_{it}$ are statistically insignificant in the two regressions. Turning to $FDI_{it}*h_{it}$ as our measure of absorptive capacity, we find that this variable is highly statistically significant in columns 3 and 4 of Table 1 when the system-GMM estimator is employed. The estimate of β_5 indicates that technology is indeed transmitted through FDI and that human capital is indeed an important element in generating a country's absorptive capacity. The system-GMM estimates of the other coefficients indicate that investment contributes positively to growth in per capita real GDP while population growth contributes negatively, which are two effects that were expected. Little evidence is found that investment in human capital directly contributes to growth in per capita real GDP. Its contribution is rather indirect, enhancing absorptive capacity. Finally, we note that our specification tests on no evidence of misspecification.

[Table 2] Estimation for a version of the augmented Solow model: the sub sample excluding 17 African countries

	System GMM (1)	System GMM (2)	System GMM (3)
$\Delta\log(GDP_{it-1})$	-0.240^{***}	-0.253^{***}	-0.257^{***}
	(0.037)	(0.037)	(0.039)
$\Delta\log(investment_{it})$	0.218^{***}	0.207^{***}	0.167^{***}
	(0.025)	(0.030)	(0.025)
$\Delta\log(n_{it}+\delta+\gamma)$	-0.265^{**}	-0.327^{**}	-0.225^{**}
	(0.118)	(0.127)	(0.111)
$\Delta\log(h_{it})$	0.045	-0.029	0.017
	(0.028)	(0.054)	(0.023)
$openness_{it}*\log(h_{it})$	-	0.019	-
		(0.030)	
$FDI_{it}*\log(h_{it})$	-	-	0.027^{***}
			(0.006)
λ	0.0457	0.0486	0.0421
m1	0.014	0.021	0.014
m2	0.776	0.644	0.892
Sargan test	0.215	0.139	0.202
Wald test	0.000	0.000	0.000

Notes: The dependent variable in each regression is the growth rate of output per worker. The figure in parentheses below each estimate is standard error. ***, **, and * indicate significance at 1, 5 and 10 percent. The sub sample consists of 33 developing countries over six time periods consisting of five years each.

The effects reported in Table 1 may not be homogeneous across all countries included in the sample. We investigate this possibility by using a sample that excludes the 17 African countries, Since they are *a priori* the most heterogeneous group of countries Estimation results using this truncated sample are reported in Table 2, which turned out to be similar to those reported in Table 1 except that results in Table 2 are more precise. As before, we find no evidence that investment in human capital contributes positively to growth in real per capita GDP. We conclude that the heterogeneity of the sample did not greatly influence our inferences. Furthermore, the estimates indicate that the more rapidly technology transfer is made, the greater is the stock of human capital accumulated.[11]

IV. CONCLUSION

This paper aims to use the system-GMM to estimate an augmented Solow growth model with variables to measure the international diffusion of technology. We relax the assumption that technological progress proceeds at the same pace in every country, assuming instead that the pace depends on either international trade or FDI and on the absorptive capacity of a country as measured by its human capital. We also investigate whether the heterogeneity of our sample appreciably affects our inferences.

We find that FDI is the more important channel for technology transfer and that the transfer is sped by an increased stock of human capital. Together, these findings suggest that developing countries with high educational attainment could accept rapid technology transfer if they also received substantial amounts of FDI. We also find that excluding 17 African countries from our sample did not greatly affect our estimates, suggesting that our sample is fairly homogeneous even with the African countries included.

[11] The convergence rate is estimated to be higher than others have estimated it to be. Bond et al. (2001) report that system-GMM estimates a convergence rate of around two percent a year. Evans and Kim (2005) consider a dynamic random variable model that allows country differences and similarities to enter into the analysis of growth and convergence and that corrects for heteroskedasticity and serial correlation in panel data. They find evidence in favor of regional convergence for 17 Asian countries with a speed of around two percent a year over the period 1960-1992. Barro and Sali-i-Martin (1995) report a convergence rate of 0.0197 with a standard error of 0.0026 for the 48 contiguous US states and 0.0279 with a standard error of 0.0033 for Japanese prefectures.

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