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An International Comparison of Technology Adoption and Efficiency: A Dynamic Panel Model

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ABSTRACT. – We propose a dynamic model that extends the neoclassical growth model by including technology diffusion and possible inefficiency caused by institutional rigidities. We use alternative panel data methods to estimate the model for three regions: Europe, Latin America and East Asia. Our results strongly indicate that the technology gap to the leader nation is a significant source of growth, but that regions differ in their absorption capability. In addition, countries show large heterogeneity. When combining the country-specific effects with regional absorption capabilities, we obtain robust "efficiency" results for each country. The estimated efficiency levels are consistent with common beliefs and significantly explained by institutional variables such as bureaucratic efficiency and political and civil rights.

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RÉSUMÉ. – Le modèle néoclassique de croissance est étendu pour inclure la possibilité d'adoption de technologie étrangère et l'hétérogénéité entre pays. En utilisant plusieurs méthodes de données de Panel, le model est estimé pour trois régions : l'Europe, l'Amérique latine, et l'Asie de l'Est. L'écart technologique vis-à-vis du leader (les États-Unis) est une source significative de croissance, mais la capacité d'absorption de chaque région est distincte. De plus, l'hétérogénéité entre pays est importante et peut s'expliquer par la diversité des contextes institutionnels.

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1 Introduction

The neoclassical model predicts that countries converge to their own steady states. Assuming identical technologies across countries, this implies that exogenous differences in savings, employment, and education are the causes of all observed differences in income levels and rates of growth. However, just as countries differ in accumulation rates they also use different technologies. In fact, hardly any group of countries fit the assumption of identical technology. The existence of a technology gap may therefore present an additional opportunity for growth through technology flows. However, nations differ in ability to adopt and absorb new knowledge and thus country heterogeneity must also be considered. Indeed, if "follower" countries suffer from both a large technology gap and a low absorption capacity, then the predictions about rate of growth will be ambiguous. ABRAMOVITZ [1986] proposes that the ability of countries to take advantage of the catching-up potential depends on their respective "social capabilities;" *i.e.*, that systematic variations in social institutions and processes make some countries better or worse at catching-up. In addition, the institutional economics literature highlights the importance of secure property rights and sound government policies as determinants of countries' growth rates (OLSEN [1982], NORTH [1990]). NORTH [1990] states that "*the inability of societies to develop effective, low-cost enforcement of contracts is the most important source of both historical stagnation and contemporary underdevelopment in the third world...*". Empirically the importance of institutions as a determinant of growth has been previously established (KNACK and KEEFER [1995], BARRO [1991], and SCULLY [1988]). However, these studies only consider cross-country regressions.

We formalize the idea that there exists technology gaps and differing abilities to take advantage of this catch-up potential by extending the standard neoclassical framework. The inclusion of technology adoption in the model, with and without institutional inefficiency, slightly modifies the standard results for nations' steady states and rates of convergence. Also, it allows for quite different convergence paths; in particular, it allows countries to overtake each other on the way to their steady state.[1] We include the possibility of technology adoption from countries ahead by adding a catch-up term. In effect, countries face different technology gaps to the leader. Normally, the greater the gap, the greater the catch up potential. However, some countries may face reduced catch up potentials because of institutional rigidities or other country specific factors. In these cases, obtainable technology is less than best-practice technology. In addition, countries differ in their adoption rate: some can translate their catch-up potential into growth faster than others. The paper's novelty thus lies in the introduction of a technology adoption rate which, combined with country specific heterogeneity, yields a measure of nations' relative efficiency in taking advantage of available best-practice technology.

1. An important catalyst for this paper was to consider a model which incorporates overtaking among nations as discussed in QUAH [1993], CHARI *et al.* [1996], and HULTBERG and POSTERT [1997].

In our estimation we use alternative panel data methods to obtain adoption rates and efficiency levels. We use an extension of the least squares dummy variable methodology and address the issue of dynamic panel endogeneity by instrumenting our variables using two consistent I.V. estimators, two-stage least squares and generalized method of moments. The estimation is performed on three samples of countries: Europe, Latin America and East Asia. We assume that the U.S. is the technological leader for the three regions. This assumption is based on the fact that the U.S. is both the leader in terms of per worker GDP and has a relatively efficient institutional framework.[2] We obtain significant results for regional adoption rates and country-specific relative inefficiency. An interesting finding is that Latin America's rate of technology adoption is high (higher than Europe and East Asia) indicating that the region could have rapidly taken advantage of any catch-up potential. However, once levels of inefficiency and growth of factor inputs are considered, it is apparent why Latin American countries have in fact failed to do so: they did not take advantage of their full catch-up potential.

Using the estimated country relative efficiency levels, we ask what factors determine the observed differences. We do this through an estimation that considers a set of variables related to nations' social and political institutions. The variables are related to government policies, political and civil rights, education, and openness to international trade. The institutional environment appears in fact to be an important determinant of differences in average efficiency levels.

Section 2 presents and discusses our growth model. Section 3 presents the data and the econometric model for which empirical results are reported in section 4. Section 5 attempts to determine the role of institutions in explaining countries' relative efficiency levels, while section 6 provides concluding remarks.

2 Theoretical Model

The SOLOW-SWAN growth model is modified to allow for the transmission of technological knowledge across national borders.[3] The standard neoclassical model assumes a closed economy and an exogenous constant saving rate to predict that countries converge to their own steady states determined by levels of accumulation and the depreciation rate. However, in addition to having different accumulation rates, economies also differ in levels of technology. This introduces the possibility that flows of technology may present an additional opportunity for growth. Thus, adoption of technology from abroad is one possible mechanism through which the effective capital stock of a nation

2. The U.S. scores high (at least top 5) for all institutional variables used in the paper.
3. We develop the model in section 2.1 and discuss the steady state analysis and transitional dynamics of the model in Appendix 1.

increases, as better technology improves the productivity of the existing stock of capital. We are thus replacing the closed economy nature of the traditional SOLOW-SWAN model by a partially open economy where only technology flows are possible.[4] This will potentially affect a nation's steady state and transitional dynamics. Our results are similar to those derived for capital and labor mobility; *i.e.* that mobility tends to speed up an economy's convergence toward its steady state. We show in Appendix 1 that technology flows might also augment the level of that steady state.[5]

2.1. A Model with Technology Adoption

Our estimation will build on the standard neoclassical model with a COBB-DOUGLAS production function

$$Q_{it} = A_{it} K_{it}^{\beta_1} L_{it}^{\beta_2} H_{it}^{\beta_3},$$

where output Q, depends on technology A, physical capital stock K, employment L, and human capital H (MANKIW, ROMER, and WEIL [1992]). All countries are represented by i, $i = 1,...,N$, in each time period t, $t = 1,...,T$. We use the common specification of the evolution of exogenous world technology and number of workers so that

$$A_{it} = A_{i0} e^{\gamma t},$$

and

$$L_t = L_0 e^{nt}.$$

We include human capital as a factor of production, although other authors have shown how it might affect the growth process through different channels.[6] We consider the human capital growth rate in our derivation, but we also include its level in the estimation.[7]

The only difference from the standard model appears in our equation for the evolution of capital. The capital evolution depends on an exogenous saving rate, the depreciation rate, and a technology catch-up term, $\xi(T, T^w)$, so that

$$\dot{K}_{it} = sQ_{it} - \delta K_{it} + \xi(T, T^w)_{it} K_{it}. \quad (1)$$

It is worthwhile to point out the difference to models of purely disembodied technical change. These models specify capital evolution as $\dot{K}_{it} = sQ_{it} - \delta K_{it}$, so that the stock K_t can be interpreted as new-machine

4. The assumption of immobility of physical capital and labor is strong, but it allows us to single out some effects of technology on the growth process.

5. The results are similar to those obtained by BARRO and SALA-I-MARTIN [1995] in their model of labor mobility. However, our model with technology flows differ from a model with labor or capital mobility in that technology flows are nonexclusive; *i.e.,* flows of technology benefit the receiving economy without hurting the source economy.

6. LEVINE and RENELT [1992] find that average level of secondary education enrollment is a robust determinant of per capita GDP. The only other two robust explanatory variables in their study are investment share of GDP and initial real GDP per capita. We include employment growth as well.

7. KYRIACOU [1992] gives reasons for why human capital should be included as a level and not as a rate of growth. One such reason is that the level of human capital is a proxy for the growth of technology. BENHABIB and SPIEGEL [1994] show how an assumption that the growth rate of technology depends on the *level* of human capital leads to an estimable equation.

equivalents implied by the stream of past investments (and δ is the weight that transforms each vintage investment into new-machine equivalents). We assume, in contrast, that new investment might also embody differences in technical design. Thus a new “machine’’ may be more efficient than an old “machine’’ even if there is no difference in physical capacity. The standard capital evolution equation will then tend to understate the true productivity of the capital stock. In our setup, technology from abroad may make the existing and new capital stock more productive and therefore increase the capital stock (capital is measured in efficiency units).[8] We specify the catch-up term as a logarithmic function of the inverse ratio of labor productivity, $Y_i = \left(\frac{Q_{it}}{L_{it}}\right)$, to the “desired’’ level of labor productivity, Y_i^*, which may differ between countries $\xi(T, T^w)_{it} = \rho_i \ln\left(\frac{Y^*_{i,t-1}}{Y_{i,t-1}}\right)$.[9] Thus we assume here that countries use last period’s technology gap (which is observable) as a source of growth.

Using a desired level of labor productivity reflects our belief that all countries are not able to obtain the same level of productivity.[10] For example, the Latin American nations may not be able to adopt the entire technology gap between themselves and the U.S. because of institutional inefficiencies.

Log linearizing and differencing the production function and substituting for the growth rate of capital yields that the growth rate of per worker output depends on the growth of factor inputs as well as the productivity gap,

$$y_{it} = \phi + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 h_{it} + \rho_i [\ln Y^*_{i,t-1} - \ln Y_{i,t-1}], \tag{2}$$

where $\rho_i = \beta_1 \theta_i$ is the country-specific technology adoption rate and $\phi = (\gamma - \beta_1 \delta)$ is net exogenous technology growth.

Next, in an attempt to capture some of ABRAMOVITZ [1986] ideas of “social capabilities,” we suggest that in addition to economies’ varied ability to adopt the technology gap, they may also differ in ability to recognize or use the available technology. To incorporate this into the model we include a term that acts to reduce the available technology gap to economies.[11] The term used is similar to what frontier production literature refers to as “efficiency” and we refer to it in the same way. It is understood that this term captures much more than mere production slack as it encompasses the institutional

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8. An alternative way to derive our capital evolution equation is to consider a production function with an explicit capital-augmenting form: $Q = f(L_t, \Psi_t K_t)$, where $\Psi_t K_t = I_t + (1-\delta)K_{t-1}$ and $\Psi = (1 - \xi(T, T^w)_t)$. This discussion is related to the vintage capital literature and whether technological progress is embodied or disembodied. See for example SOLOW [1960], FISHER [1965], and HULTEN [1992]. We could have chosen to follow DOWRICK and NGUYEN’s [1989] setup where the catch-up term is added to the production function: $Y_{it} = A_{it} K_{it}^{\beta_1} H_{it}^{\beta_2} L_{it}^{\beta_3} \xi_{it}^{\phi_i}$. However, simulations of this model produce unattractive results from its implications on the capital-output ratio. In particular, initially poorer countries will always overtake richer countries with similar accumulation rates on the way to their steady state.
9. Using labor productivity thus means that we implicitly assume that the output-capital ratio remains the same across all countries. See the data section below.
10. It would be better if the rate of catch-up were determined by relative levels of total factor productivity [SOLOW residual], but since this is both harder to obtain and is likely to be highly correlated with labor productivity we choose the above set-up.
11. An alternative approach would be to make the adoption rate, ρ, a function of absorption capacity.

framework, adjustment costs, international openness etc. So, to account for varied institutional rigidities we postulate that the desired or maximum, controlling for institutional features, level of labor productivity is some fraction of the leader's productivity, and that the fraction is determined by the nation's level of efficiency

$$Y_{it}^{*} = \frac{Y_t^L}{E_{it}} \Rightarrow \ln Y_{it}^{*} = \ln Y_t^L - \ln E_{it},$$

where Y_t^L is the leader's labor productivity and E_{it} is the efficiency parameter. Substituting into equation (1) and rearranging yields the equation that we estimate

(3) $y_{it} = \phi - \rho_i \ln E_{i,t-1} + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 h_{it} + \rho_i [\ln Y_{i,t-1}^L - \ln Y_{i,t-1}].$

That is, the growth rate of GDP per worker for country *i* depends on the rate of growth of factor inputs, the common rate of exogenous technological change minus capital depreciation, country-specific inefficiency, and the technology gap between the leader and the follower countries lagged one period. Interpretation of the parameters are straightforward: β_1, β_2 and β_3 show the elasticity of per worker GDP to a change in the growth of factor inputs, ρ_i is the adoption of available technology from abroad and the [estimated] inefficiency measure, $\rho_i \ln E_{i,t-1}$, shows the reduction in growth of labor productivity due to political and social factors reducing the available technology gap.[12] The equation gives growth as a function of last period's level of efficiency, however, in our estimation efficiency is time invariant.

The key to this model is that it allows for countries to either leap ahead or fall behind since countries may differ in both technology adoption rates and inefficiency levels. Figure 1 in Appendix 1 depicts simulations of three possible follower countries' convergence paths. In general, our technology catch-up term leads to initially higher rates of growth depending on the catch-up parameters, but in the end it is the familiar diminishing marginal product of capital that closes the gap.

2.2. Relation with Dynamic Frontier Literature

Our model can be related to the dynamic frontier literature; in particular, the methodology we use is similar to studies of firm heterogeneity that estimate frontier functions and firm-specific inefficiency levels. The model we estimate can be viewed as a special case of the dynamic frontier model of AHN, GOOD, and SICKLES [1997].[13]

As an example, consider the case when countries adopt all technical innovations in a timely manner and a random variable η_{it} (> 0) denotes country *i*'s inefficiency score induced by a technology that has diffused to country *i* at

12. In the estimation we use both 5-year and annually pooled data. The parameters must of course be interpreted accordingly.

13. The AHN, GOOD, and SICKLES [1997] model nests both the deterministic frontier model of AIGNER and CHU [1968] and FORSUND and HJALMARSSON [1979] as well as the stochastic frontier model of AIGNER, LOVELL, and SCHMIDT [1977] and MEEUSEN and VAN DEN BROECK [1977]. AHN *et al.* [1997] uses a variant of the efficient dynamic panel data estimator found in AHN and SCHMIDT [1995].

time t. Assume that the η_{it} are independently distributed over different i and t. Further, assume $E(\eta_{it} \mid \Omega_{i,t-1}) = \kappa_i \geqslant 0$, where $\Omega_{i,t-1}$ is the information set available to country i at the beginning of time t. We can then define

$$\alpha_{it}^* = \alpha_t^F - \eta_{it} = \beta_0 + \gamma t - \eta_{it},$$

where α_{it}^* is country i's productivity level if it adopted technology innovations timely and α_t^F denotes the time-varying component of technology which is commonly accessible to all countries. A deterministic frontier production is then given by

$$y_{it}^F = x_{it}\beta + \alpha_t^F.$$

However, actual production is given by

$$y_{it} = x_{it}\beta + \alpha_{it} = x_{it}\beta + \beta_0 + \gamma t - u_{it},$$

so that the actual productivity level is given by $\alpha_{it} = \alpha_t^F - u_{it}$, where u_{it} ($\geqslant 0$) is country i's technical inefficiency level at time t. In the present paper, u_{it} correspond to the heterogeneity parameter ($\rho_i \ln E_{i,t-1}$) in equation (3).

Another possible source of technical inefficiency, is a country's sluggish adoption of technical innovations. An implicit assumption in the bulk of the frontier literature, as well as the growth literature, is that adjustment rates are instantaneous so that the data is generated from a country in long-run static equilibrium [steady state]. However, if there are costs that inhibit instantaneous adjustment, inefficiency measures developed by the dynamic frontier literature may be proxies for differing adjustment costs and misspecification of the long-run/short-run dynamics. Consider, therefore, the possibility that countries adopt technology only slowly over time. Specifically, assume that technical innovations introduced at the beginning of time t are only partially adopted and that the adoption speed, ρ_i, may differ across countries:

$$\alpha_{it} = (1 - \rho_i)\alpha_{i,t-1} + \rho_i \alpha_{it}^*,$$

where $0 \leqslant \rho_i \leqslant 1$. When a country adjusts its production technology in this fashion, the inefficiency level must be correlated with its lagged levels. Substituting $u_{it} = \alpha_t^F - \alpha_{it}$, one can show that the long-run average technical inefficiency level of country i is given by

$$u_i^{LR} \equiv \lambda_i/\rho_i = \kappa_i + (1 - \rho_i)\gamma/\rho_i.$$

The first component of u_i^{LR}, κ_i, measures the long-run inefficiency due to country i's inability to comprehend and fully utilize newly introduced production technologies while the second component, $(1 - \rho_i)\gamma/\rho_i$, captures the long-run efficiency loss due to the country's sluggish adoption of technological innovations, which are negatively related with the adjustment speed ρ_i.[14] In our paper we divide the heterogeneity parameter by ρ to get at a term similar to κ_i. Thus, the essential nature and interpretation of the above dynamic frontier model closely parallels the models considered in the convergence literature in general and, in particular, our estimable equation.

14. For a derivation of u_i^{LR} see AHN, GOOD, and SICKLES [1997].

3 Data and Econometrics

3.1. Data

For the empirical estimation we predominantly use variables from SUMMERS and HESTON data set (PWT 5.6). The study covers the period 1960-1985 and includes a total of 40 countries (see Table 4 for a list of the included nations). We use number of workers as the labor variable. The number of workers was found by multiplying each nation's population by its labor force participation rate.[15] For physical capital growth we use the share of investment in output as a proxy:

$$k_{it} = \frac{K_{i,t} - K_{i,t-1}}{K_{i,t-1}} \cong \frac{I_{i,t-1}}{K_{i,t-1}} = \frac{I_{i,t-1}}{Y_{i,t-1}} \cdot \frac{Y_{i,t-1}}{K_{i,t-1}}$$

so that if $\frac{Y_{i,t-1}}{K_{i,t-1}}$ is constant for all i and t, the growth rate of physical capital will be proportional to the investment ratio. If this is true, we have

$$k_{i,t} = \frac{I_{i,t-1}}{Y_{i,t-1}} \cdot z$$

where z is a constant.[16] This is an assumption that finds validation in DOWRICK and NGUYEN [1989] for the OECD sample and OROZCO, HULTBERG, and SICKLES [1996] for the Latin American countries. The risk is that there is a systematic relation between capital intensity and level of output. If poorer nations have a lower capital intensity a fixed investment share will have greater proportional effect on the capital stock. This assumption could possibly over-state country heterogeneities because we do not allow countries to move along their isoquants. However, our paper focuses on the technological change aspect of growth as in ABRAMOVITZ [1986] and BAUMOL [1986], which should not be seriously affected by the constant capital-output assumption since the technological change argument relates to how different countries have different rates of isoquant's contraction toward the origin; that is, how technology makes countries' factors of production more productive at different rates. In addition, we do not allow factor shares to vary over time and across countries.

For the human capital variable we use the percentage share of total population that attained secondary education from BARRO and LEE [1993]. We use secondary schooling instead of primary education since many countries in the sample are likely to have reached their upper limits for primary education. See Table 7 in Appendix 2 for summary statistics.

15. We would have preferred to use a measure of labor input such as hours of work but this variable was not available. From SUMMERS and HESTON, number of workers = (RGDPCH / RGDPW) * POPULATION. See SUMMERS and HESTON [1991].

16. We wanted to use the rate of growth of depreciated capital stock which can be obtained from PWT 5.6. However, this variable is missing for several nations and time periods so its use was not possible.

3.2. Econometric Issues

There are several possible problems with the existing empirical growth studies. It is usually assumed that country-specific effects are uncorrelated with other right-hand side variables, but as shown by CASELLI, ESQUIVEL, and LEFORT [1996] this assumption is necessarily violated. This incorrect treatment of country heterogeneity due to differences in technology or tastes gives rise to omitted variable bias. In addition, most studies do not deal with the presence of endogeneity problems. In particular, for any dynamic relationship that contains a lagged dependent variable among the regressors, so that $y_{i,t} = \rho y_{i,t-1} + x_{i,t}\beta + \varepsilon_{i,t}$, where $\varepsilon_{i,t} = \mu_i + \nu_{i,t}$ (one-way error component model), ordinary least squares will be both biased and inconsistent. That is, since $y_{i,t}$ is a function of μ_i, $y_{i,t-1}$ must also be a function of μ_i. Hence, an explanatory variable is correlated with the error term. The omitted variable bias is readily removed in a panel data estimation by the use of country effects. This method is valid when the effects are fixed rather than random, which is true when the sample of countries is the entire population. A Within estimator using fixed effects (Least Squares Dummy Variable) will eliminate the omitted variable bias and deal consistently with the correlation between effects and regressors. However, the Within transformation $(y_{i,t} - \overline{y}_{i.-1})$ will still be correlated with $(\nu_{i,t} - \overline{\nu}_{i.})$ since $y_{i,t}$ is correlated with $\overline{\nu}_{i.}$ by construction (see BALTAGI [1995]). That is, LSDV will still be inconsistent due to this endogeneity problem. This problem is only removed if both N and T go to infinity. Hence, only if the number of periods were very large would LSDV be appropriate. In most panel estimations, however, T will tend to be small (in our main estimation T is equal to 5).

Several solutions to the endogeneity problem have been suggested in the econometric literature (see SEVESTRE and TROGNON [1996]). The most obvious is to use an instrumental variable technique. For example, ARELLANO and BOND [1991] argue that to get a consistent estimate of the lagged dependent variable for large N but small, fixed T, one needs to (a) first difference to eliminate the individual effects and (b) use lagged differences or levels as instruments.[17] CASELLI *et al.* [1996] utilize this approach in a generalized method of moments framework with the result that estimated rates of convergence increase significantly.

In this paper we perform our estimations using three alternative methods: least squares dummy variable (LSDV), two-stage least squares (2SLS), and generalized method of moments (GMM) estimators. The LSDV estimation we perform is the standard ordinary least squares estimation with dummies for all countries, but we allow one slope coefficient to vary across regions. The 2SLS is very similar, except that we instrument our technology gap variable with its lagged value. Finally, the GMM estimation is similar to that performed by CASELLI *et al.* [1996] in that we first difference our estimable

17. AHN and SCHMIDT [1993] point out that there are additional moment conditions that are ignored by the IV estimators suggested by ARELLANO and BOND [1991]. AHN and SCHMIDT suggest a GMM estimator that is asymptotically equivalent to CHAMBERLAIN's [1982, 1984] optimal minimum distance estimator. Incidentally, ISLAM [1995] compares the MD estimator with LSDV in a Monte Carlo study using a similar data set as us. ISLAM's result is that the LSDV, although it is consistent in the direction of T only, actually performs very well.

equation for all four available time periods, stack the four equations and use all lagged exogenous variables as instruments.[18]

4 Results

4.1. Testing the Standard Model

When estimating growth models, ordinary least squares is commonly used for either a cross-section of countries or for a panel of countries.[19] We perform these estimations mostly to show that our data yield results similar to previous studies and to be able to relate our later results to the existing literature (see Table 1).

TABLE 1
Traditional Growth Accounting

Variables	Entire Sample					Europe		East Asia		L.A.	
Cross-Selectional Analysis - OLS Regressions											
Constant	–0.221	–0.267	–0.205	3.445	3.713	3.554	3.637	2.605	4.970	2.354	2.510
	(0.263)	(0.277)	(0.261)	(0.506)	(0.521)	(0.466)	(0.587)	(1.775)	(1.077)	(0.705)	(0.827)
I/GDP	0.034	0.033	0.038	0.043	0.011	0.015	0.015	0.038	0.050	0.032	0.032
	(0.009)	(0.009)	(0.010)	(0.006)	(0.006)	(0.007)	(0.006)	(0.024)	(0.010)	(0.011)	(0.013)
$\Delta\ln(L)$	0.380	0.325	0.282	–0.096	–0.107	–0.597	–0.617	0.432	0.030	0.126	0.072
	(0.215)	(0.219)	(0.214)	(0.146)	(0.140)	(0.206)	(0.223)	(0.688)	(0.343)	(0.237)	(0.248)
ΔHC		0.047		–0.005		–0.002		–0.010		–0.096	
		(0.082)		(0.051)		(0.046)		(0.215)		(0.101)	
HC			–0.011		0.008		0.001		0.042		0.003
			(0.009)		(0.006)		(0.005)		(0.015)		(0.011)
LnY_0				–0.413	–0.445	–0.335	–0.345	–0.321	–0.710	–0.285	–0.309
				(0.053)	(0.056)	(0.049)	(0.065)	(0.152)	(0.154)	(0.080)	(0.095)
R2	0.28	0.28	0.30	0.73	0.75	0.83	0.83	0.73	0.93	0.63	0.60
Panel Analysis (5–year Pooled Data) – OLS Regressions											
Constant	–0.036	–0.043	–0.018	1.117	1.123	1.183	1.207	0.939	1.268	0.950	0.968
	(0.038)	(0.039)	(0.037)	(0.121)	(0.136)	(0.134)	(0.161)	(0.207)	(0.318)	(0.264)	(0.317)
I/GDP	0.007	0.007	0.008	0.011	0.011	0.006	0.006	0.008	0.013	0.012	0.012
	(0.001)	(0.001)	(0.001)	(0.011)	(0.011)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)
$\Delta\ln(L)$	0.211	0.231	0.127	–0.369	–0.372	–0.948	–0.960	0.044	0.367	–0.141	–0.153
	(0.169)	(0.170)	(0.163)	(0.151)	(0.150)	(0.200)	(0.206)	(0.387)	(0.404)	(0.335)	(0.339)
ΔHC		0.035		–0.001		0.014		–0.162		0.062	
		(0.032)		(0.027)		(0.022)		(0.075)		(0.060)	
HC			–0.005		0.000		–0.000		0.006		–0.000
			(0.001)		(0.001)		(0.001)		(0.003)		(0.003)
LnY_0				–0.130	–0.131	–0.120	–0.123	–0.102	–0.167	–0.118	–0.113
				(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.035)
R2	0.12	0.13	0.20	0.42	0.42	0.60	0.66	0.45	0.43	0.27	0.26

Notes: Numbers in parentesis are standard errors

(1) The dependent variable is the growth of GDP per worker. I is investment, L is labor, HC is human capital (in levels), Y_0 is initial income. The regression is over the 1960–85 period and includes a total of 40 countries: 17 European, 6 East Asian, and 16 Latin American nations.

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18. The difference from CASELLI *et al.* [1996] is that we first difference our growth equation (not levels) so that the equations are actually in second differences.

19. Cross-sectional growth studies are numerous, *e.g.* BARRO [1991], BARRO and SALA-I-MARTIN [1992], MANKIW *et al.* [1992]. ISLAM [1995], KNIGHT, LOAYZA, and VILLANEUVA [1993], and BARRO and SALA-I-MARTIN [1995] consider panel data.

The cross-sectional estimation for the entire sample of 40 countries yields that the investment ratio is positive and significant whether or not human capital growth (level) or initial wealth are included. Its magnitude is similar to previous studies which consider investment ratios.[20] Similar results are obtained when splitting the sample into three regions, Europe, East Asia and Latin America. Including initial wealth, we obtain that the investment ratio is significantly positive for all regions, but of a lesser magnitude in Europe, perhaps indicating diminishing returns. Employment growth affects growth of *per worker* income negatively in Europe, but positively, although insignificantly so, in East Asia and Latin America. The growth of human capital is insignificant and negative for all regions. The average level of human capital has a positive coefficient, but is significant only for East Asia. Both results for human capital are similar to the ones obtained in BENHABIB and SPIEGEL [1994]. In all cases, initial per worker income is significantly negative, which indicates conditional convergence.

Using a panel data estimation only affects the magnitudes of the coefficients, not the signs and significance levels.

4.2. **Testing the New Model**

We estimate our new model as described in equation (3). We include a fixed effect to the panel data estimation in order to capture the inevitable country heterogeneity due to political and social institutions. As mentioned above, we perform three kinds of estimations. We use LSDV as our base estimation, to obtain results that are more comparable to previous studies. In addition, we use 2SLS and GMM estimations to obtain results that might be more consistent.

We first consider the initial income results with fixed effects. For the GMM estimation, since fixed effects are differenced away, we back out the effects from residuals. In order to obtain comparable numbers to the other two estimations, we find the time average of each country's residuals, then subtract from it the average for the U.S. plus the intercept term. The results are shown in Table 2.[21] The initial income results are similar in spirit to those of CASELLI *et al*. [1996] and others, in that the more consistent estimation methods yield faster rates of convergence. The convergence rate for LSDV is calculated to be 0.07 while the convergence rate for the GMM estimation is 0.20.[22] These rates of convergence are very fast indeed when compared to the standard convergence results of 0.02-0.03. These standard convergence results,

20. See for example DOWRICK and NGUYEN [1989], OROZCO, HULTBERG and SICKLES [1996], and BARRO [1991, 1994]. Human capital is insignificant in the estimation both in growth and average level.

21. We only include human capital level in Table 2 because of its higher significance compared to growth rates.

22. Although these numbers appear very high they are not outliers compared to previous research. For example, ISLAM's [1995] LSDV results lead to a rate of convergence around 0.10, CASELLI *et al*. [1996] find a rate of about 0.10 with GMM, and KNIGHT *et al*. [1993] using CHAMBERLAIN's [1983] Π matrix approach even obtains an implied rate of convergence for 59 developing countries of 0.23.

however, are obtained from models that might suffer from both omitted variable bias and endogeneity; for example, the convergence rate from our estimation in Table 1 (column 5) yields a rate of convergence of 0.024. In addition to producing a higher convergence rate, the GMM estimation also leads to more statistically (and economically) significant results.

The next task is to compare our initial income results to those with a productivity gap variable (see Table 2). Replacing initial income with the technology gap variable greatly improves significance results on fixed effects. In the LSDV estimation, the Netherlands and the U.K. are the only countries for which the effect is insignificant at the 10 percent level.[23] Using the gap variable does not affect the sign of our variables and only slightly changes the magnitudes in front of our explanatory variables. If we calculate the rate of catch-up to the leader (and not the steady state), the results for the LSDV is 0.11 and for GMM 0.14.[24]

In Table 2 we also include the average level of heterogeneity for the three regions and it appears as if Europe is the least inefficient, followed by Latin America and East Asia. The relative inefficiency of East Asia and Latin America is somewhat surprising, and in fact when we consider the three regions separately a different regional heterogeneity ranking is obtained (see Table 3). However, the change in estimated fixed effects is accompanied by technology adoption rates of different magnitudes across the three regions. This indicates that fixed effects may in fact pick up the countries' different abilities to incorporate new technology as well. To explore whether the fixed effects contain the ability of nations to adopt new technology, we estimate the model using an extension of the LSDV methodology in which we allow one slope coefficient (the technology adoption parameter) to vary across regions (see CORNWELL, SCHMIDT and SICKLES [1990]).[25] We thus estimate both adoption speeds and "inherent" inefficiency levels as country-specific parameters.[26] The added fixed effect (whether 5-year or annual pooling is used) yields negative coefficients for all countries confirming our hypothesis that the U.S. is the productivity leader in our sample(s). The results from the regional adoption rate estimation can be seen in Table 2. Once again the explanatory variables remain fairly stable, but we see that the technology adoption rates might differ across the three regions.

23. When using initial income the fixed effects have no real economic interpretation. Our model provides such economic interpretability to the estimated country heterogeneities.

24. The catch-up rates are calculated from $(1 - e^{-\lambda t}) = \rho$.

25. The general panel data model with heterogeneity in slopes and intercept takes the following form: $y_{it} = Z_i'\gamma + X_{it}'\beta + W_{it}'\delta_i + \varepsilon_{it}$, $i = 1,...,N$ and $t = 1,...,T$, and where Z_i is $J \times 1$, X_{it} is $K \times 1$, and W_{it} is $L \times 1$, and the parameter vectors are dimensioned conformably. The difference from the standard model is then that W has coefficients, δ_i, which vary with the individual (country).

26. The methodology we use is similar to studies of firm heterogeneity which usually estimate frontier functions and firm-specific inefficiency levels (see SCHMIDT and SICKLES [1984], CORNWELL, SCHMIDT and SICKLES [1990]). For an additional illustration for assessing relative efficiencies using the North American and Asian airline industries see AHN, GOOD, and SICKLES [1998]. We attempt to allow for a dynamic interpretation of the inefficiency levels by using a time dummy. However, splitting sample in two (1972-1973) the results are not significant. Using an index of institutional environment as the basis for trend break yields some significant result, but in most cases not enough information is available.

We also test whether adoption rates differ across countries in the LSDV estimation by including an interactive dummy variable for each country's technology gap. This produces two general results for the 5-year pooled data: approximately half of the fixed effects become insignificant at 5 percent and only two of the 38 different slope coefficients are statistically significant. For the annual data the results are even less significant. Furthermore, several adoption rate parameters are nonsensical being either negative or greater than one. We attribute the weakness of these results to the reduced degree of freedom stemming from insufficient data points. We can however reject the hypothesis that all technology adoption rates are the same at the 5 percent significance level.

Our previous results suggest that the Latin American adoption rate might be greater than the other two regions (see Gap_0 in Table 2). If we include an interactive *regional* dummy we can indeed reject the equality of Latin America's adoption rate to that of Europe and East Asia at the 99 percent significance level. However, we are unable to reject the equality of Europe's and East Asia's adoption rates for the LSDV estimation, although East Asia

TABLE 2
Growth Accounting: Initial Income Vs. Technology Gap
5-year Pooled Data: Full Sample

	Initial Income			Common Adoption Rate			Regional Adoption Rate		
Variables [1]	LSDV	2SLS	GMM	LSDV	2SLS	GMM	LSDV	2SLS	GMM
Constant	2.84** (0.26)	3.64** (0.40)	0.050** (0.004)	– 0.028** (0.09)	– 0.31** (0.13)	– 0.0089** (0.005)	– 0.23** (0.09)	– 0.27** (0.13)	– 0.0015 (0.005)
I/GDP	0.016** (0.002)	0.011** (0.002)	0.024** (0.0008)	0.015** (0.002)	0.012** (0.003)	0.020** (0.001)	0.014** (0.002)	0.011** (0.003)	0.020** (0.001)
$\Delta\ln(L)$	– 0.36 (0.26)	– 0.19 (0.28)	– 0.37** (0.03)	–0.30 (0.26)	– 0.21 (0.29)	– 0.34** (0.05)	– 0.26 (0.26)	– 0.081 (0.30)	– 0.40** (0.08)
HC	0.0035* (0.002)	0.0044* (0.003)	0.0056** (0.0005)	0.0013 (0.002)	0.0032 (0.003)	0.0080** (0.0006)	0.00045 (0.002)	0.0028 (0.003)	0.0062** (0.001)
$\mathrm{Ln}Y_0$	– 0.31** (0.03)	– 0.39** (0.04)	– 0.64** (0.02)	–	–	–	–	–	–
Gap_0 [2]	–	–	–	0.41** (0.04)	0.46** (0.06)	0.51** (0.03)	0.36** (0.06)	0.44** (0.10)	0.46** (0.03)
$EAgap_0$	–	–	–	–	–	–	– 0.036 (0.08)	– 0.097 (0.13)	0.076** (0.03)
$LAgap_0$	–	–	–	–	–	–	0.24** (0.09)	0.35** (0.14)	0.30** (0.07)
R2	0.66	0.72	–	0.67	0.70	–	0.69	0.71	–
Average heterogeneity									
Europe	– 0.13	– 0.10	0.45	– 0.23	– 0.17	– 0.17	– 0.21	– 0.16	– 0.19
East Asia	– 0.29	– 0.34	1.36	– 0.51	– 0.50	– 0.52	– 0.39	– 0.32	– 0.62
Latin America	– 0.21	– 0.29	– 1.16	– 0.40	– 0.42	– 0.33	– 0.69	– 0.88	– 0.72

Notes: ** significant at the 5 percent level or better, * significant at the 10 percent level or better. Numbers in parentesis are standard errors.
[1] I is investment, *L* is labor, HC is human capital (in levels), Y_0 is initial income, Gap_0 is initial productivity difference to the leader nation.
EAgap and LAgap are, respectively, dummies for East Asia and Latin America interacted with the Gap variable.
[2] The coefficient on Gap_0 is the average adoption rate when there are no slope dummies. With slope dummies, it is the European adoption rate.

TABLE 3
Regional Estimation with Technology Gap
5-year Pooled Data: Regional Samples

Variables [2]	Europe LSDV	Europe 2SLS	Europe GMM	East Asia [1] LSDV	East Asia 2SLS	East Asia GMM	Latin America LSDV	Latin America 2SLS	Latin America GMM
Constant	– 0.0039 (0.08)	– 0.049 (0.13)	– 0.020* (0.01)	– 0.33** (0.15)	– 0.27 (0.21)	–	– 0.15 (0.18)	– 0.24 (0.38)	– 0.0013 (0.01)
I/GDP	0.0058** (0.002)	0.0037 (0.004)	0.0047 (0.003)	0.018** (0.003)	0.009 (0.006)	–	0.018** (0.004)	0.016** (0.008)	0.026** (0.004)
$\Delta\ln(L)$	– 0.39 (0.28)	– 0.44 (0.44)	– 1.04** (0.16)	– 0.27 (0.47)	– 0.007 (0.48)	–	0.11 (0.53)	0.27 (0.91)	0.030 (0.31)
HC	– 0.0006 (0.001)	0.0016 (0.002)	0.0044* (0.002)	0.00088 (0.003)	0.0035 (0.005)	–	– 0.0056 (0.005)	– 0.0024 (0.01)	– 0.0043 (0.006)
Gap_0	0.38** (0.04)	0.48** (0.10)	0.33** (0.10)	0.37** (0.06)	0.34** (0.09)	–	0.58** (0.09)	0.71** (0.20)	0.86** (0.15)
R2	0.81	0.82	–	0.71	0.72	–	0.58	0.62	–
Average heterogeneity	– 0.21	– 0.19	– 0.10	– 0.46	– 0.29	–	– 0.82	– 0.90	– 1.11

Notes: ** significant at the 5 percent level or better, * significant at the 10 percent level or better. Numbers in parentesis are standard errors

(1) The East Asian sample is not large enough to estimate the model using GMM.

(2) *I* is investment, *L* is labor, HC is human capital (in levels), Y_0 is initial income, Gap_0 is initial productivity difference to the leader nation.

appear to adopt technology at a slightly slower rate than European countries. However, under the GMM estimation this result is reversed, not only is the East Asian interactive slope dummy significantly different from zero, it is also positive. When considering the regions separately we also reject the equality of adoption rates of all Latin American countries but cannot reject the equality for both European and East Asian countries at any standard level of significance. Thus there is some evidence of heterogeneity of adoption rates for Latin American countries. However, considering individual countries once again produces nonsensical results. We choose to only consider a separate technology adoption rate for the three regions. Regional results on adoption rates prove sufficient to obtain country-specific efficiency results.

4.2.1. **Technology Adoption Rates**

The results for 5-year adoption rates once again differ across estimation methods. Europe's adoption rate range between 0.36 (LSDV) and 0.46 (GMM), while East Asia has a similar range of 0.32 and 0.54 and Latin America goes from 0.60 to 0.76 (0.79 for 2SLS).[27] That is, before considering institutional inefficiencies, Europe closes between 36 and 46 percent of the initial technology gap every five years. The numbers indicate that Latin America has been more successful at adopting foreign technology than

27. When performing the same estimation for each region separately we obtain the following adoption rates using LSDV: Europe 0.38, East Asia 0.37, and Latin America 0.58.

Europe and East Asia – a perhaps surprising result.[28] However, recall that we have separated out the technology adoption which presumably is included in the growth of physical and human capital. Also, we can speculate that a possible reason why Latin America has adopted technology faster than Europe might be that they are further behind and "older" technologies might be easier to adopt whereas more effort is needed to adopt new production techniques. This does not, however, explain why Latin America has a greater adoption rate than East Asia. Perhaps, again we are speculating, East Asia's technology adoption is to a larger degree embodied in new capital, and the large amount of foreign direct investment to Latin America might have contributed significantly to the region's technology adoption. The amount of foreign direct investment is less for the East Asian countries.

4.2.2. **Efficiency**

Next we explore the inefficiency of the follower nations; *i.e.*, the negative effect on the potential technology gap stemming from inefficient social and institutional factors. For the LSDV and 2SLS regressions, efficiency is found by dividing nation's estimated fixed effect by the regional adoption rate. For the GMM estimation we must calculate the inefficiency levels from the regression residuals. These numbers are reported in Table 4.

The efficiency measures are quite similar across different sample estimations; for the pooled data the minimum correlation between the different measures is 0.93. If we consider the three estimations that use the entire sample with regional adoption rates, the different estimations inefficiency levels are even more correlated. In addition, the rankings are very much correlated; for East Asia and Latin America we find exactly the same rankings, while for Europe the rank correlation is approximately 0.93. It therefore appears as if efficiency, as we define it, is quite robust to different estimations and samples. Furthermore, the relative efficiencies of nations within each region appear to conform to common beliefs. For example, in Europe, the Netherlands and the U.K are the most efficient while Turkey and Portugal are the least efficient. In East Asia, Hong Kong is the most efficient while Indonesia and Thailand are the least efficient. Finally, in Latin America, Mexico and Argentina are at the top, while Honduras and Bolivia are at the bottom. The similarity across estimations indicate that something systematic must lie behind these results; the question of what determines these inefficiencies should be asked.

28. To test the robustness of these measures we estimate the model using annual data as well. The annual results are also significant. Using annual data requires two modifications since (1) there are no annual measures of human capital and (2) the investment ratio is unlikely to affect the contemporaneous growth of per capita output (the investment ratio is insignificant in the regression). To somewhat remedy the latter concern we lag the investment ratio one period. The advantage of annual data is more data points, however, the disadvantage of possible short-term fluctuations [business cycles] might affect the results. Using LSDV, the estimated adoption rates for the annual data are 0.09 (0.09 in regional estimation) for Europe, 0.05 (0.06) for East Asia, and 0.12 (0.13) for Latin America.

TABLE 4

Estimated Inefficiencies

Level of Country-Specific Inefficiency								
Country	5-year Pooled Data ($T = 5$)						Annual Pooled Data ($T = 25$)	
	Entire Sample Estimation (1)			Regional Estimation			Entire Sample Estimation	Regional Estimation
	LSDV	2SLS	GMM (2)	LSDV	2SLS	GMM (2)(3)	LSDV	LSDV
EUROPE								
Austria	– 0.50	– 0.27^{ns}	– 0.34	– 0.49	– 0.33	– 0.33	– 0.47	– 0.40
Belgium	– 0.28	– 0.08^{ns}	– 0.12	– 0.29	– 0.16^{ns}	– 0.14	– 0.28	– 0.24
Denmark	– 0.54	– 0.34	– 0.34	– 0.49	– 0.36	– 0.26	– 0.46	– 0.39
Finland	– 0.91	– 0.54	– 0.79	– 0.65	– 0.43	– 0.44	– 0.64	– 0.42
France	– 0.40	– 0.14^{ns}	– 0.16	– 0.36	– 0.17^{ns}	– 0.03	– 0.32	– 0.22
Germany	– 0.47	– 0.15^{ns}	– 0.24	– 0.41	– 0.20^{ns}	– 0.17	– 0.38	– 0.27
Greece	– 0.83	– 0.61	– 0.66	– 0.82	– 0.68	– 0.54	– 0.81	– 0.74
Ireland	– 0.73	– 0.52	– 0.59	– 0.71	– 0.55	– 0.51	– 0.69	– 0.63
Italy	– 0.47	– 0.13^{ns}	– 0.28	– 0.41	– 0.19^{ns}	– 0.15	– 0.38	– 0.27
Netherlands	– 0.23^{ns}	– 0.01^{ns}	0.01	– 0.22	– 0.06^{ns}	0.10	– 0.20	– 0.14
Norway	– 0.61	– 0.36	– 0.53	– 0.41	– 0.25	– 0.20	– 0.38	– 0.22
Portugal	– 1.01	– 0.85	– 0.81	– 1.15	– 0.95	– 0.74	– 1.10	– 1.07
Spain	– 0.47	– 0.27^{ns}	– 0.22	– 0.49	– 0.35	– 0.14	– 0.46	– 0.40
Sweden	– 0.32	– 0.23^{ns}	– 0.28	– 0.30	– 0.25	– 0.30	– 0.32	– 0.28
Switzerland	– 0.39	– 0.19^{ns}	– 0.30	– 0.27	– 0.16^{ns}	– 0.19	– 0.25	– 0.14
Turkey	– 1.49	– 1.30	– 1.19	– 1.59	– 1.40	– 1.13	– 1.55	– 1.56
U.K.	– 0.28^{ns}	– 0.15^{ns}	0.01	– 0.46	– 0.34	– 0.23	– 0.45	– 0.50
AVERAGE	– 0.59	– 0.36	– 0.40	– 0.56	– 0.40	– 0.32	– 0.54	– 0.47
EAST ASIA								
Japan	– 1.02	– 0.65	– 0.97	– 1.14	– 0.53	–	– 0.53^{ns}	– 0.85
Hong Kong	– 0.51	– 0.40^{ns}	– 0.60	– 0.58	– 0.36	–	– 0.13^{ns}	– 0.34^{ns}
Indonesia	– 1.87	– 1.60	– 1.78	– 1.86	– 1.54	–	– 1.78	– 1.84
S. Korea	– 1.18	– 0.94	– 1.23	– 1.24	– 0.88	–	– 0.77	– 0.98
Malaysia	– 1.12	– 0.90	– 1.01	– 1.16	– 0.83	–	– 0.84	– 0.97
Singapore	– 0.97	– 0.55	– 0.88	– 1.08	– 0.44	–	– 0.38^{ns}	– 0.67
Thailand	– 1.66	– 1.47	– 1.53	– 1.66	– 1.41	–	– 1.52	– 1.60
AVERAGE	– 1.19	– 0.93	– 1.14	– 1.24	– 0.86	–	– 0.85	– 1.04
LATIN AMERICA								
Costa Rica	– 0.98	– 0.97	– 0.75	– 1.29	– 1.18	– 1.14	– 1.07	– 1.10
El Salvador	– 1.35	– 1.41	– 1.09	– 1.58	– 1.53	– 1.43	– 1.55	– 1.51
Guatemala	– 1.12	– 1.14	– 0.86	– 1.38	– 1.27	– 1.23	– 1.30	– 1.27
Honduras	– 1.73	– 1.72	– 1.50	– 2.02	– 1.90	– 1.88	– 1.83	– 1.84
Mexico	– 0.50	– 0.46	– 0.29	– 0.82	– 0.67^{ns}	– 0.70	– 0.56	– 0.59
Panama	– 1.23	– 1.16	– 1.08	– 1.49	– 1.35	– 1.43	– 1.19	– 1.23
Argentina	– 0.61	– 0.55	– 0.41	– 0.81	– 0.68	– 0.70	– 0.74	– 0.69
Bolivia	– 1.64	– 1.57	– 1.47	– 1.89	– 1.73	– 1.79	– 1.69	– 1.69
Brazil	– 1.11	– 0.99	– 0.91	– 1.43	– 1.21	– 1.33	– 1.11	– 1.15
Chile	– 1.02	– 0.98	– 0.84	– 1.24	– 1.14	– 1.11	– 1.09	– 1.08
Columbia	– 1.16	– 1.12	– 0.96	– 1.42	– 1.27	– 1.32	– 1.23	– 1.24
Ecuador	– 1.33	– 1.20	– 1.16	– 1.64	– 1.42	– 1.56	– 1.29	– 1.33
Paraguay	– 1.48	– 1.49	– 1.27	– 1.74	– 1.64	– 1.63	– 1.60	– 1.60
Peru	– 1.11	– 1.08	– 0.91	– 1.37	– 1.26	– 1.24	– 1.18	– 1.19
Uruguay	– 0.90	– 0.85	– 0.67	– 1.09	– 0.96	– 0.94	– 1.12	– 1.03
AVERAGE	– 1.15	– 1.11	– 0.95	– 1.41	– 1.28	– 1.29	– 1.24	– 1.24

Note: *ns* means that the country effect is not significant at the 10 percent significance level.
(1) We use the model with slope dummies for each regional adoption rate.
(2) We do not get significance levels for the GMM estimates of country effects, since they are based on residuals.
(3) The East Asian sample is not large enough to estimate the regional model using GMM.

5 Determinants of Efficiency

Next we attempt to find the determinants of the nations differing efficiency levels. We use an econometric approach which considers a set of variables related to nations' social and political institutions. The variables relate to government anti-diversion policies, political and civil rights, levels of education and openness to international trade.

Earlier studies that consider the determinants of country efficiency include SCULLY [1988] and (when considering productivity) HALL and JONES [1996]. SCULLY defines efficiency by *per capita* income relative to the leader and finds that the institutional environment (as proxied by political and civil rights indices) are significant in determining levels of efficiency and growth. HALL and JONES regress total factor productivity on a set of variables. They find that countries which are close to the equator, do not speak an international language, have ineffective government anti-diversion policies, or are not open to international trade have low productivity.

Government anti-diversion policies

Previous researchers have used several variables to capture this aspect of nations' institutional framework. BARRO [1991] used two variables measuring political instability: revolutions and coups, and assassinations. However, as discussed in KNACK and KEEFER [1995], these variables might not measure what we have in mind since they are only loosely correlated to the more general institutional environment. Instead we use other institutional indices: the GASTIL indices and indices of various institutional variables from Business International (now incorporated into The Economist Intelligence Unit). In general, the effect of government policies can be of two kinds; either the government provides growth promoting public goods and designs taxes which close the gap between private and social costs, or, alternatively, the government waste funds and impose taxes and regulations that distort private decisions. Hence, the government may not only suppress diversion but often act as the most effective diverter.

The GASTIL indices are aggregate measures which directly consider the institutional environment. We use both his political rights index and his civil rights index, each of which range from 1 to 7, where 1 represents the most freedom (GASTIL [1981]). Since the two indices are related we use a weighted average of the two and normalize it to be between zero and one.

The indices from Business International (BI) are thought to proxy some general institutional variables. The numbers are obtained from MAURO [1995] who restricts his attention to nine different indicators of institutional efficiency that are all independent of macroeconomic variables and apply to both domestic and foreign firms. The BI indices range between 0 and 10, where a high value signifies "good" institutions. These nine indicators are grouped into two categories: political stability and bureaucratic efficiency. The political stability index contains the following six indicators: political change–institutional, political stability–social, probability of takeover by opposition group, stability of labor, relationship with neighboring countries, and terrorism. The bureaucratic efficiency index consists of three variables: judiciary system, red tape and bureaucracy, and corruption (see Table 7 in Appendix 2 for the regions' averages of the institutional variables).[29]

Openness

We include openness to international trade for two reasons; its relation to the diversion of resources from their free market allocation, and because international trade is a leading source of technology diffusion. LEVINE and RENELT [1992] find that the relationship between trade and growth is mostly based on enhanced resource accumulation and not as much on improved resource allocation. Since we already include accumulation rates in our estimation of efficiency levels, we might expect that openness will not be a significant determinant of relative productivity. Two measures of openness are used, the Index compiled by SACHS and WARNER [1995] and the measure of openness obtained from SUMMERS and HESTON.[30]

In our index we only consider whether the country was classified as being open or closed during the 1960-85 period. The variable is numbers of years open during the sample period. The SUMMERS and HESTON openness variable is simply the fraction of imports and exports summed to GDP.

Education

Since countries may be unproductive because their level of education does not allow for efficient use of resources and the adoption of new technology, we also include it in our regression. The significance of the level of education is likely to be affected by its use in the estimation of efficiency levels.

5.1. **Results**

We initially find the simple Pearson correlation coefficient of our different indices to the levels of efficiency across countries (see Table 5). The Bureaucratic Efficiency index, BE, has a correlation coefficient of approximately 0.70 and the GASTIL index, Freedom, has a correlation of about – 0.70 with respect to efficiency.[31]

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29. Two alternative risk measures are the International Country Risk Guide (ICRG) and the Business Environmental Risk Intelligence (BERI). They both contain many categories of risk assessment and have been used in KNACK and KEEFER [1995] and HALL and JONES [1996]. KNACK and KEEFER [1995] compared the above two institutional variables to the GASTIL indices. They found that the GASTIL index had a correlation of – 0.661 with ICRG 1982, and – 0.761 with BERI 1972. KNACK and KEEFER [1995] concludes that the political violence variables used by BARRO [1991] and the GASTIL indices are insufficient proxies for the quality of the institutions which protect property rights. They also conclude that the effect of institutions on growth is highly significant, even after its effect in investment is subtracted.

30. The SACHS-WARNER index measures the fraction of years during the period 1950 to 1994 that an economy has been considered open. A country is open if five criteria are satisfied: (1) nontariff barriers cover less than 40 percent of trade, (2) average tariff rates are less than 40 percent, (3) any black market premium was less than 20 percent during the 1970s and 1980s, (4) the country is not socialistic, and (5) the government does not monopolize major exports (SACHS and WARNER [1995]).

31. Efficiency from 5-year pooled data and regional estimations. Similar results are obtained from the other efficiency estimates.

Thus, as bureaucratic efficiency and political and civil freedoms deteriorate (BE falls and Freedom increases) efficiency falls. The political stability (PS) has a correlation coefficients of about 0.50, which tells the same story. Regarding openness, the SACHS-WARNER index has a correlation around 0.45, while the SUMMERS-HESTON index only has a correlation of 0.15 (and insignificant). The openness result is therefore ambiguous. The average level of education is also correlated with efficiency, having a correlation coefficient of about 0.50. One problem with the simple correlations is, however, that all the institutional variables are related to each other.

We therefore regress our institutional indices on efficiency (see Table 6). The results are that bureaucratic efficiency and the Freedom index remain significant, while the other variables do not. These results are not, as expected, very sensitive to which efficiency estimates are used in the regression. Also, dropping the insignificant variables do not affect the results on the BE and Freedom variables markedly (BE is still significant at around 0.10 and Freedom is significant at about – 0.80). It thus appears that our estimated

TABLE 5
Correlation Matrix

	lsdv	2sls	GMM	BE	Freedom	PS	Education	SW	SH
lsdv	1								
2sls	0.97*	1							
GMM	0.98*	0.94*	1						
BE	0.72*	0.75*	0.65*	1					
Freedom	– 0.69*	– 0.72*	– 0.69*	– 0.58*	1				
PS	0.45*	0.56*	0.38*	0.68*	– 0.45*	1			
Education	0.53*	0.55*	0.41*	0.70*	– 0.49*	0.50*	1		
SW	0.46*	0.59*	0.38*	0.43*	– 0.54*	0.38*	0.51*	1	
SH	0.15	0.21	0.07	0.45*	– 0.01	0.47*	0.22	0.31	1

TABLE 6
OLS Estimation between Efficiency and Institutional Variables

Variables	LSDV Efficiency [(1)]	2SLS Efficiency	GMM Efficiency
Constant	– 1.16*	– 1.35**	– 0.80
	(0.58)	(0.53)	(0.62)
BE	0.13**	0.12**	0.16**
	(0.05)	(0.04)	(0.05)
Freedom	– 0.76*	– 0.76**	– 0.93**
	(0.38)	(0.34)	(0.40)
PS	– 0.02	0.03	– 0.04
	(0.07)	(0.06)	(0.07)
Education	– 0.007	– 0.01	– 0.02
	(0.01)	(0.01)	(0.01)
SW	– 0.002	0.004	– 0.004
	(0.007)	(0.006)	(0.008)
SH	– 0.001	– 0.001	– 0.001
	(0.001)	(0.001)	(0.001)
R^2	0.63	0.71	0.62

Notes: ** significant at the 5 percent level or better, *significant at the 10 percent level or better.
Numbers in parentesis are standard errors.
[(1)] These are the efficiency results for the entire sample estimation with regional adoption rates.

inefficiencies are potentially related to countries' institutional frameworks as we hypothesized. In particular, Bureaucratic efficiency and political and civil rights affect the level of efficiency of economies.[32] In other words, the level of a nation's efficiency is affected by its judiciary system, bureaucracy, corruption, as well as political and civil rights.

6 Concluding Remarks

Including only the common factors of production in growth accounting is not sufficient to explain the growth process. It is only in the long-run, if we define the long-run to be when technology has diffused to all nations, that countries' rates of growth may merely be a function of input accumulation. However, this steady state story does not hold presently as countries differ in levels of technology. It is therefore important to model these heterogeneities in order to understand the present dynamics of growth.

Our model contains three growth effects in addition to varying accumulation rates. Each nation is faced with a technology gap, approximated by the difference to the leader in per worker output, which can potentially increase the productivity of capital. This is interpreted as the catching-up potential described in Abramovitz [1986]. Also, we include a heterogeneous efficiency parameter (e) and adoption rates (ρ) in the growth term: $\rho[\ln Y^L - \ln Y - e]$. Thus a nation might not take advantage of the catch-up potential if it either fails to adopt foreign technology ($\rho = 0$) or technology absorption is seriously compromised due to the nation's level of inefficiency. The new model thus provides a mechanism for explaining why some countries forge ahead while others fall behind, while maintaining all the essential steady state predictions of the neoclassical model.

Estimations of our model yields results comparable to previous research, as well as indicating that country heterogeneity and technology adoption rates play a very significant part in the three regions' growth. The same qualitative results are obtained from the model estimation whether we use least squares dummy variable, two-stage least squares, or generalized method of moments estimations. However, magnitudes and significance levels change between the three estimation methods. In particular, 2SLS and GMM estimations, in general, provide slightly higher rates of catch-up compared to LSDV. All three methods yield convergence results that are much higher than the standard convergence rate results of two to three percent. Our results compare to previous research that have attempted to remove omitted variable bias and the endogeneity problem inherent in dynamic models. However, we give addi-

32. We also ran the efficiency levels against the log of the institutional variables. The results in terms of significance are the same. The results for log of BE is 0.76 and for log of Freedom – 0.27. Thus increasing BE by 1 percent, would increase the level of efficiency by 0.76, and improving political and civil rights by 1 percent would improve efficiency by 0.27.

tional structure to the growth process that allows us to interpret country-specific heterogeneity.

In general, although the various estimations differ in magnitudes, we find that Europe benefitted the least from the technology gap to the United States. The reason being that Europe, as a group, simply does not lag too far behind the U.S. in terms of technology; its catch-up potential is relatively low despite high relative efficiency measures. This would explain why Europe is a region for which the standard neoclassical model (which assumes identical technology across countries) performs well. Latin America and East Asia appear to have taken better advantage of the technology gap. Latin America mainly because of its high technology adoption rate. East Asia took advantage of the technology gap mainly due to the fact that the region started out being quite far behind in terms of labor productivity. Nonetheless, the main difference in growth performance between East Asia and Latin America still remains their different rates of factor input growth; East Asia (as well as Europe) had high accumulation rates while Latin America lagged behind.

We show, furthermore, that the institutional framework is likely to be important in achieving improved efficiency. In particular, we find that the judiciary system, red tape and corruption, as well as political and civil rights, are the main explanations for nations different levels of efficiency. Political stability and levels of education do not seem to be as significant, although they are certainly important in the overall growth process. The paper indicates the importance of countries' institutional framework, and further research in this area is promising. Making institutional rigidities endogenous to the growth model is needed and should further our understanding of countries growth paths. This, combined with other research on technology flows, should enhance our understanding of how nations leap ahead and fall behind over time.

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APPENDIX 1

Transitional Dynamics and Simulations

This Appendix discusses a simplified version of the model which we estimate, so that

$$Q_t = (K_t)^\alpha (A_t L_t)^{1-\alpha},$$

with exogenous growth for population and technological progress. The only difference from the standard model appears, again, in our equation for the evolution of capital. The capital evolution depends on an exogenous saving rate, the depreciation rate, and a technology catch-up term, $\xi(T, T^w)$, so that

$$\dot{K}_t = sQ_t - \delta K_t + \xi(T, T^w)_t K_t.$$

Transforming our model into an "intensive form" model so that all variables are divided by $A_t L_t$, the capital evolution equation becomes $\dot{k}_t = sk_t^\alpha - (\delta + n + g)k_t + \xi(T, T^w)_t k_t$. This means that the growth rate of capital intensity, k, is given by

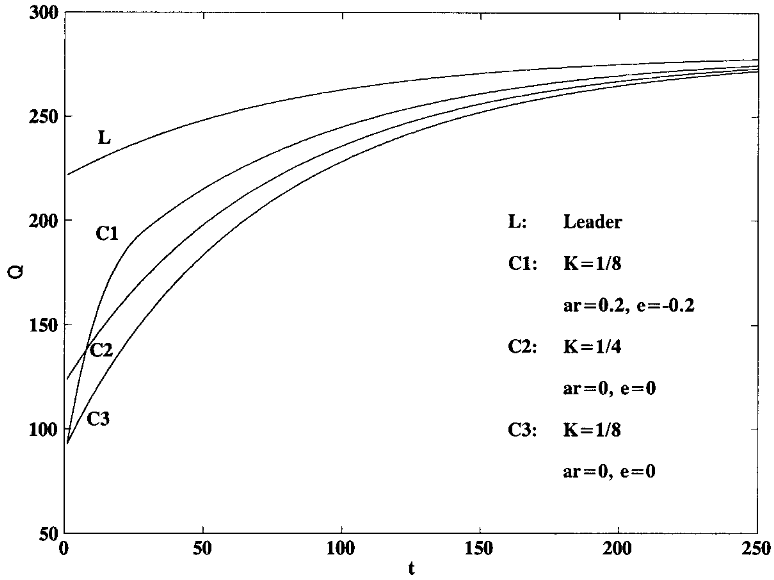
$$\frac{\dot{k}}{k} = \gamma_k = sk^{\alpha-1} - (\delta + n + g - \xi(T, T^w)),$$

so the effective depreciation rate, $(\delta + n + g - \xi(T, T^w))$, includes the term $\xi(T, T^w)$. Thus the adoption of foreign technology acts to reduce the rate of effective depreciation. In the standard SOLOW-SWAN model a lower rate of effective depreciation yields a higher steady state, so we expect this to be true in our model as well. The common rate of effective depreciation, $(\delta + n + g)$ has been replaced by the upward-sloping curve $(\delta + n + g - \xi(T, T^w))$, which implies that a steady state greater than predicted by the standard neoclassical model can be achieved for a sufficiently low savings rate.

The model with technology adoption introduces the possibility of rapid growth in addition to being below the steady state position. However, once the technology gap has been exploited, the economy is left with the traditional source of growth, namely the difference $s\frac{f(k)}{k} - (\delta + n + g)$. Thus the convergence rate only depends on these factors when steady state is independent of the technology gap. However, this does not mean that an economy whose steady state is above the leader's cannot take advantage of a technology gap when such an opportunity is presented. Instead, the follower economy will be able to grow rapidly in the early stages of its catch-up due to both the diminishing returns to capital effect and the adoption of foreign technology. However, once the technology gap is used up, the economy's capital growth is reduced to that predicted by the diminishing returns effect. The point at which the potential technology gap becomes zero will occur earlier if inefficiency is included in the model.

The fact that the convergence time will be identical to the SOLOW-SWAN model, but that the convergence path is very different can be seen if our model is simulated (see Figure 1). The simulations show the effect on the convergence path when an economy does or does not adopt technology when we assume identical steady states for all economies (*i.e.* identical saving rates). Figure 1 adds technology adoption to one follower country (C1), but not to the others (C2 and C3), and assumes that the income leader is also the technological leader. We see that this changes the convergence paths dramatically without changing the economies' steady states. However, although the same steady state is reached, the economy which adopts technology will have a higher level of income at any point in time until the steady state is reached.

FIGURE 1
Simulation of Possible Growth Paths



Note: *K* refers to inital capital stock relative to the leader, ar refers to adoption rate, and e is the level of inefficiency relative to the leader. C2 and C3 show the standard neoclassical model, while C1 shows our model.

APPENDIX 2

Data

TABLE 7
Summary Statistics

	Europe		East Asia		Latin America		United States	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
GGDP (1)	0.14	0.10	0.23	0.12	0.08	0.04	0.06	0.05
I/GDP	26.23	4.58	23.23	8.57	16.29	4.91	21.56	0.42
$\Delta \ln(L)$	0.04	0.03	0.13	0.04	0.12	0.04	0.09	0.02
HC/Education	11.14	7.96	8.18	8.57	5.26	2.87	32.19	10.24
Gap_0	0.60	0.45	1.70	0.63	1.34	0.39	0	0
BE	8.17	1.66	6.62	3.15	6.23	1.14	9.75	
Freedom	0.23	0.12	0.55	0.20	0.58	0.16	0.14	
PS	8.41	0.71	8.28	1.53	7.09	0.96	9.33	
SW	23.18	6.15	20.71	3.77	4.64	7.28	25	
SH	59.85	25.11	109.10	106.18	41.43	18.24	15.4	
LSDV (2)	– 0.59	0.33	– 1.19	0.45	– 1.15	0.34	0	
2sls	– 0.36	0.33	– 0.93	0.46	– 1.11	0.35	0	
GMM	– 0.40	0.32	– 1.14	0.40	– 0.95	0.34	0	

(1) Growth rate of per worker GDP, all growth rates are over 5-year periods.
(2) Estimated efficiencies using the entire sample and regional adoption rates.