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The 'appropriate technology' explanation of productivity growth differentials: An empirical approach☆

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Abstract

This paper aims at giving empirical content to the Basu and Weil (1998) [Basu, S., Weil, D.N., 1998. Appropriate technology and growth. Quarterly Journal of Economics 113, 1025–1054] theory of growth, in which localized innovation, assimilation of spillovers and differences in speeds of capital intensification yield diverse patterns of international convergence and divergence. The contributions of these sources to labor productivity growth are quantified for a sample of countries, using data envelopment analysis techniques. Regression analysis shows that the observed patterns were mainly driven by processes of creating spillover potential through capital intensification. Assimilation appears to be much slower than assumed in Basu and Weil's model.

JEL classification: O14; O30; O40; O47
Keywords: Economic growth; Productivity; Technological change; Data envelopment analysis; Spillovers

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1. Introduction

Recently, Basu and Weil (1998) introduced a new theoretical model of international productivity growth dynamics, which could generate patterns of international productivity convergence and divergence that are more in line with reality than the results obtained from other endogenous growth models. These patterns are the net result of two opposing forces in the model. Like in the Solow (1956) model, it is assumed that new knowledge about production technologies is immediately public. These spillover effects imply tendencies towards convergence of productivity growth rates. Tendencies towards divergence are caused by the novel assumption that new knowledge is only 'appropriate' for countries that produce according to technologies similar to the innovator's technology. Such countries will reap the gains from innovation immediately, whereas other countries will not benefit at all. In this set-up, if innovation would take place at similar rates across technologies, the well-known Solow results would follow. Basu and Weil (1998, henceforth denoted as BW), however, assume that innovation is 'localized' at high-end technologies.[1] Countries that operate low-end technologies could thus fall behind the world's technology leaders. The aim of this paper is twofold. First, and most prominently, it tries to give quantitative indications of the importance of localized innovation and BW's notion of appropriate technology spillovers for patterns of convergence and divergence. Second, the empirical validity of the assumption of immediate spillovers of appropriate technology will be investigated. Spillovers appear not to be immediate and arguments will be put forward that the speed of spillover assimilation should be regarded as a third determinant of labor productivity growth.

The empirical analysis will be based on a recently proposed decomposition of productivity growth, which makes use of data envelopment analysis (DEA) techniques (Kumar and Russell, 2002). This methodology will be slightly modified, by adopting an intertemporal perspective suggested by Tulkens and Vanden Eeckaut (1995) that is in line with properties of the BW model. Labor productivity growth rates are decomposed into three parts, which will be interpreted as effects of the three sources of growth identified above: localized innovation, assimilation of knowledge spillovers, and creating potential for appropriate technology spillovers through investment. This methodology will be applied to Penn World Tables data on GDP, labor inputs and capital inputs for a set of 53 countries for the period 1965 to 1990. In a second stage, the decomposition results will be used in a convergence analysis based on regression techniques. Additional outlier analysis investigates how the three sources of growth contributed to the extraordinary performance of growth 'miracles' and 'disasters', i.e. countries that experienced very high or low productivity growth rates, even after correction for potentially favorable initial conditions.

The rest of the paper is organized as follows. In Section 2, the BW model and the decomposition framework will be discussed in more detail and the relation between the theoretical and empirical approaches will be shown. Section 3 is devoted to a discussion of the data and the estimation of the reference production frontier, that is, the set of best-practice production processes. In Section 4, convergence and divergence of labor productivity growth rates and their three sources will be studied. Section 5 deals with an

[1] The term "localized innovation" was first coined by Atkinson and Stiglitz (1969).

analysis of countries that emerge as outliers from the convergence regressions. Section 6 concludes.

2. A Basu and Weil type of productivity growth decomposition

2.1. Basics of the BW model

BW model growth and technology transfer in a world in which knowledge is specific to particular combinations of inputs. These combinations are called 'technologies'. BW index technologies by capital intensities (capital to labor ratios). Technologies are considered to be 'similar' if they are characterized by comparable capital intensities. 'More advanced' technologies have higher capital intensities. Each technology has its own maximum labor productivity level, which we will denote as 'targets'. Targets for advanced technologies are higher than for less capital-intensive technologies. By producing with a specific capital intensity a country gains new knowledge about this particular technology and will improve the target labor productivity level of this technology. Importantly, countries do not only improve the productivity of the specific technology they are using, but also raise the productivity levels of technologies with slightly different capital intensities. We will denote this process as 'localized innovation' (Atkinson and Stiglitz, 1969).

An important assumption in the BW model is that new knowledge generated in one country is immediately available to all other countries. However, due to the assumption of technology-specific knowledge, a follower country can only benefit from this knowledge spillover if it is operating (or starts to operate) at a similar capital intensity. Otherwise, the new knowledge generated is not 'appropriate' for the follower country.[2] Thus, the productivity gains associated with technology transfer are often not immediate, because follower countries need time and funds for investment to adopt technologies that can take advantage of the progress made by the technology leaders. As a result of the joint effects of localized technological progress, appropriate technology conditions and differences in investment rates, the labor productivity levels of (groups of) countries may grow at different rates.

2.2. An augmented model of appropriate technology and growth

In the BW view of the world, the productivity gains of international knowledge transfer materialize immediately, provided that it is 'appropriate'. However, there is a large body of evidence that stresses that only a small portion of what one needs to know to operate a new technology is codified in handbooks and similar documents; much of it is tacit and can only be acquired through learning by doing. Case study research strongly suggests that internationally competitive levels of productivity are seldom achieved through simple acquisition of advanced capital goods alone, but are also

[2] BW give the example of advances in transportation technology in Japan (a refinement of the newest maglev train). Such an advance will have very few spillovers to the technology of the transportation sector in Bangladesh, which relies in a large part on bicycles and bullock carts.

dependent on social and technological capabilities, shaped by investment in human and public capital (Abramovitz, 1986).[3] Hence similar technologies can be operated at widely different levels of (labor) productivity, and differences in levels of technical efficiency should be a key element of any theory of economic growth (Evenson and Westphal, 1995; Nelson and Pack, 1999). This view is supported by recent evidence from cross-country regressions in the technology gap approach (Fagerberg, 1994) and in a more neo-classical framework (Hall and Jones, 1999). Hence, a country's ability to assimilate appropriate knowledge should probably be considered as a separate determinant of growth, alongside localized innovation and investment in capital. Our empirical analysis could be conceived as an attempt to quantify the productivity effects of the mechanisms present in such an 'augmented' BW model.

2.3. The decomposition framework

A recently proposed decomposition of productivity growth based on data envelopment analysis (DEA) techniques will provide a useful framework for empirical analysis. Kumar and Russell (2002) decompose labor productivity growth into components attributable to shifts in the world production frontier, movements toward (or away from) the frontier and movements along the frontier.[4] Suppose the frontiers at time 0 and 1 are given by F(0) and F(1) in Fig. 1. The global production frontier should be seen as the set of targets. It indicates for each technology the maximum labor productivity level at which it can be operated, given the knowledge available at the time. In the particular case of Fig. 1, maximum attainable labor productivity levels have improved for most technologies. Countries may operate on the frontier, or below. In Fig. 1 two observations for a particular country are depicted, indicated by *(0) and *(1). During the period (0,1), labor productivity increased, but at both points in time the country operated well below the maximum attainable levels given by the frontiers. Hence it had the potential to improve its productivity. This potential is measured by the gap between the actual labor productivity level of the country and the maximum attainable level for the specific technology the country is operating.

Changes in labor productivity of a country (y_1/y_0) can be decomposed as follows:

$$\frac{y_1}{y_0} = \left(\frac{y_1}{y_d} \cdot \frac{y_a}{y_0}\right) \cdot \left(\frac{y_c}{y_a} \cdot \frac{y_d}{y_b}\right)^{0.5} \cdot \left(\frac{y_b}{y_a} \cdot \frac{y_d}{y_c}\right)^{0.5}$$

or

$$\left(1+\hat{y}^{\mathrm{T}}\right) = \left(1+\hat{y}^{\mathrm{A}}\right) \cdot \left(1+\hat{y}^{\mathrm{C}}\right) \cdot \left(1+\hat{y}^{\mathrm{I}}\right) \tag{1}$$

The augmented BW model suggests a natural growth-theoretic interpretation of the three components in the right hand side of Eq. (1). We call them 'assimilation', 'creating potential' and 'localized innovation', respectively. 'Assimilation' refers to the movement

[3] Note that this perspective on the role of human capital in the growth process is different from the view that rising human capital is equivalent to an increase in the quality of labor, as is suggested by adding a third factor to the conventional production function in most mainstream cross-country regressions. Temple (1999) provides a good overview of this literature.

[4] See also Maudos et al. (2000) for a similar decomposition framework.

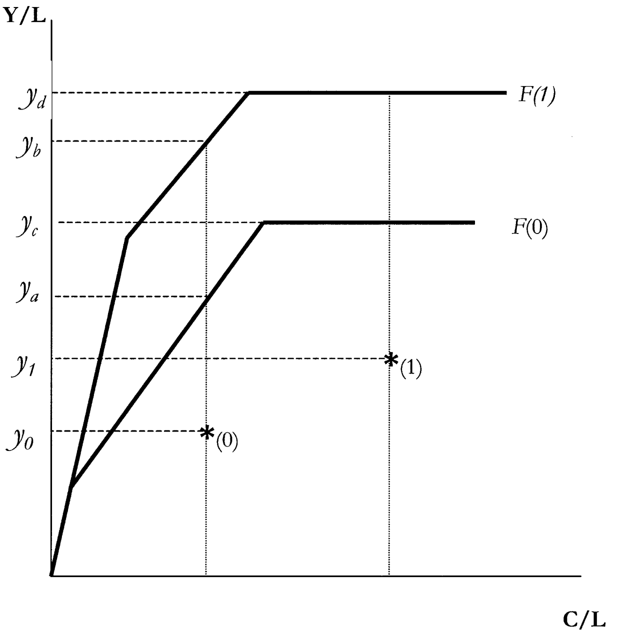

Fig. 1. Labor productivity growth decomposition.

of a country towards the frontier at a given level of technology. If a country operates below the frontier, it has the potential to benefit from knowledge spillovers. Realizing this potential requires assimilation of the knowledge which is appropriate for the particular technology it operates. A value of $\hat{y}^{\mathrm{A}}$ larger than 0 thus indicates that the country under consideration has succeeded in realizing (part of) its spillover potential leading to an improvement of its productivity level. 'Creating potential' refers to the process of technology upgrading, measured here as capital intensification.[5] If $\hat{y}^{\mathrm{C}}$ exceeds 0, the country has shifted to a more advanced technology. This new technology will have a higher target. It potentially allows for a higher labor productivity level by opening up new possibilities for knowledge spillovers. $\hat{y}^{\mathrm{C}}$ measures the increase in labor productivity under the assumption that all spillover potential had been used, i.e., that the country had been on the frontier throughout the period.

Finally, 'localized innovation' refers to movements of (parts of) the frontier itself, that is, improvements in the labor productivity targets of particular technologies. A positive value for $\hat{y}^{\mathrm{I}}$ means that the country gained from improvements in the target for its technology. This improvement might be due to innovation by the country itself, or by another country that pushed the frontier.

[5] An increase in the amount of capital per worker does not necessarily indicate technology upgrading. Addition of more capital identical to the capital already in place will lead to an increase in capital intensity without a concomitant increase in the level of technology. However, in the spirit of BW, we assume that capital intensity increases by addition of new types of capital, rather than by mere duplication of the existing stock.

3. Data and frontier estimation

3.1. Data

We used data on one type of output (GDP) and two types of inputs (labor and capital) from the Penn World Tables (PWT) Mark 5.6. This data set gives GDP per worker and stocks of capital at international prices using expenditure PPPs from the International Comparison Program (see Summers and Heston, 1991, for details). To obtain the number of workers we divided real GDP (series RGDPCH) by real GDP per worker (series RGDPW). For capital stocks, we used the stocks of producer durables calculated as the non-residential capital stock per worker (series KAPW) multiplied by the share of producer durables in the stock (series KDUR). We focus on producer durables rather than on total capital stocks, as we believe the former is more interesting from a technology perspective. Technology transfer and embodied spillovers are mediated through machinery rather than through structures (DeLong and Summers, 1991).[6] The annual data span the period from 1965 to 1990 and cover 53 countries.[7] A list of countries is given in Appendix A.

3.2. Frontier estimation method

In constructing the world production frontier we use Data Envelopment Analysis (DEA) techniques.[8] DEA involves the use of linear programming methods to construct a piece-wise linear function over the data. Because of its non-parametric nature, it naturally allows for any form of localized technical change, which is an important feature in our framework. Kumar and Russell (2002) provide a formal description of this approach. An important deviation from their methodology is our use of intertemporal frontiers. As most DEA studies, Kumar and Russell (2002), calculate the frontier at time t using data from period t. However, if panel data are available, the history of data up to t can also be included using the "intertemporal" reference production set.[9] We have two important reasons to calculate the frontier at time t in this way.

First, because the production frontier is constructed sequentially, it can never shift inward and hence 'technological regress' cannot occur. The possibility of 'technological regress' seems awkward and hard to define from a knowledge perspective on technology, as it would involve 'forgetting'.[10] Second, a crucial element in the BW model is the possibility for

[6] For the output measure to be fully consistent with the capital input concept, the output generated by housing and structure services should be excluded from GDP. However, PWT does not provide this information. When the share of these services is small and/or these shares do not vary widely across countries and over time, the results of our analysis will not be affected.

[7] PWT provides capital stock estimates for 63 countries, but we followed common practice by excluding less developed oil-exporting countries (Ecuador, Syria, Venezuela, Iran and Nigeria) and Sierra Leone because of its diamond mining activities. Further, we excluded Botswana, Nepal, Poland and Swaziland because data points were lacking for these countries. The total sample contained 1378 observations.

[8] Although DEA was originally developed for firm-level analysis, it has frequently been used at the country level. See Färe et al. (1994) for an early contribution.

[9] See Tulkens and Vanden Eeckaut (1995), for a discussion.

[10] Kumar and Russell (2002, pp. 539 ff.) indeed found technological regress during the period 1965 to 1990, which required an ad hoc explanation.

Table 1
Input–output combinations on frontier in 1990

		C/L (a)	Y/L (b)
Malawi	1965	16	846
Morocco	1990	249	6770
Spain	1965	650	12,451
Argentina	1969	834	14,110
Argentina	1971	935	15,029
Spain	1969	1070	16,024
Argentina	1980	1446	17,828
Canada	1973	3497	27,426
Canada	1979	4397	29,191
Canada	1988	7319	34,521
Canada	1989	8024	35,069
USA	1989	11,413	36,859
Luxembourg	1990	17,781	37,903

(a) Producer durable capital stock per worker (in 1985 International \$); (b) GDP per worker (in 1985 International \$).

countries to use knowledge that was generated by technology leaders in the past. Labor productivity levels of past technology leaders should be attainable for latecomers. Hence, we used all data up to and including period t in our construction of the frontier at time t.[11]

3.3. Frontiers

In Table 1 we provide an overview of the countries, technologies and maximum labor productivity levels that determined the frontiers in 1990. Apparently, the frontier for 1990 does not solely consist of techniques in use in 1990. For example, the labor productivity level attained by Canada in 1973 had still not been surpassed by any other country in 1990, notwithstanding that other countries had used the same technology in the meantime. In 1990 itself, for example, countries such as Greece, Portugal, South Korea and Yugoslavia produced at comparable capital intensity levels, but labor productivity levels in these countries were much lower. As a consequence, the technique used by Canada in 1973 still remained on the frontier as the best technique for that particular technology up to 1990.

Fig. 2 provides a sketch of the progress that was made for various technologies over the past decades. The figure gives the maximum labor productivity levels in 1980 and 1990 as a percentage of the corresponding targets in 1970. It is clearly shown that the most remarkable advances have been achieved in the technologies characterized by high capital intensities. Whereas technologies with intensities below \$3000 per worker were barely

[11] A potential problem is that not all input–output combinations realized in the past have been observed as the data set starts only in 1965. It is possible that frontier techniques observed for the first years of the analysis are dominated by unobserved combinations in the past. In that case, part of what would be interpreted as frontier movements would in fact be assimilation of knowledge associated with these unobserved appropriate technology targets. To accommodate this problem, we limit the decomposition analysis to the time span that starts five years after the first observations available to us. Hence, the first year of the analysis is 1970, for which we estimate the frontier on the basis of observations for the period 1965–1970. For the actual calculation of the frontiers, we made use of the DEAP computer program developed by Tim Coelli (see Coelli, 1996).

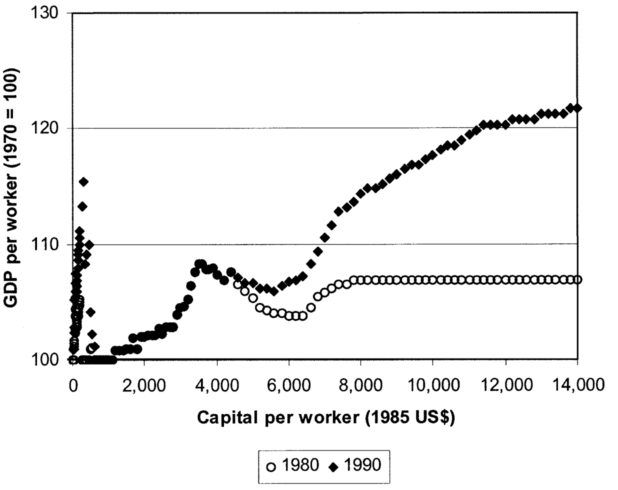

Fig. 2. Movement of frontier labor productivity levels for a range of technologies, 1970–1990 (1970=100).

improved during the period from 1970 to 1990, for technologies with capital intensities of more than $7000 per worker improvements of 10% and more were attained.[12] Interestingly, since 1980 innovation stagnated for a large range of intermediate technologies (roughly between $700 and $4400). This is an important finding, given that in 1990, 19 out of the 53 countries operated in this range of technologies, including countries such as Argentina, Thailand, Portugal and South Korea. This means that these countries could not benefit at all from progress being made at the frontier.

4. Sources of convergence and divergence

Kumar and Russell (2002) analyzed the changes in cross-country distributions of labor productivity applying a kernel-estimation method in the spirit of Quah (1996). Using a decomposition framework similar to ours, but with slightly different data and frontier estimation methods,[13] they found that innovation was decidedly non-neutral, but appeared not to be a major force in driving bipolar international divergence. Further, they found substantial evidence of improved efficiency. The efficiency gains appeared to be related to the initial distance to the frontier. Differences in investment, however, turned out as the primary drivers of divergence. Here, we complement Kumar and Russell (2002) by following Temple's (1999) suggestion to focus more in depth on growth 'miracles' and 'disasters'. To identify these countries, one needs techniques that first identify

[12] The only exception is innovation by Morocco in the 1980s, which moved the frontier at very low capital intensity levels.

[13] Kumar and Russell (2002) used also PWT 5.6, but used total capital stock rather than producer durables. More importantly, their frontier estimation was not based on the preferred intertemporal reference set. Qualitatively, their decomposition results are comparable to ours.

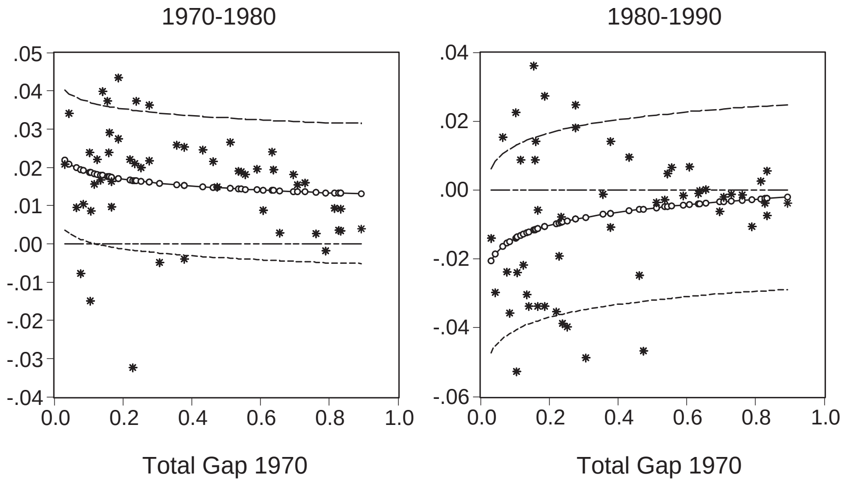

Fig. 3. Labor productivity growth rates relative to US.

'representative' behavior. We define this behavior in terms of β-convergence equations. This popular notion of convergence focuses on the question whether initially lagging countries tend to grow faster than countries initially close to the leader.[14]

The general regression equation we estimate is a fairly simple one:

$$\hat{y}_i^{\mathrm{T}} - \hat{y}_{\mathrm{US}}^{\mathrm{T}} = \alpha_{\mathrm{T}} + \beta_{\mathrm{T}} \log\left(\frac{y_{0,i}}{y_{0,\mathrm{US}}}\right) + \varepsilon_i^{\mathrm{T}}, \tag{2}$$

in which hats denote annual growth rates, averaged over the period under consideration (see also Eq. (1)). The term between parentheses indicates the labor productivity ratio between country i and the United States, which was the productivity leader in 1970.

We report estimates for two periods, 1970–1980 and 1980–1990, as it is well known that in the 1980s growth collapsed in many countries.[15] The results are depicted in Fig. 3.

In both panels, the horizontal zero-line indicates the productivity growth rate exactly equal to the US. Apparently, the majority of countries grew faster than the US in terms of labor productivity in the 1970s, but slower in the later period. The dotted logarithmic curves represent the estimated relationships. Table 2 provides the regression results. The slope coefficient for the 1970s was negative, but the corresponding p-value of 0.192 shows that convergence was not significant. For the 1980s, the slope was significantly positive (at the 10% level), indicating that divergence prevailed.[16] The huge variety of growth performances is reflected in the very low values for R^2.

[14] Studies of β-convergence can both be found in the mainstream tradition in which it is mostly ascribed to the effects of diminishing returns to investment (see e.g. Mankiw et al., 1992) and in the technology gap literature in which the main reason for β-convergence to occur is the gradual assimilation of knowledge related to new innovations (see e.g. Verspagen, 1991).

[15] It should be noted that the explanatory variable is always evaluated in 1970. Hence, the performance of a country in 1980–1990 is also linked to its productivity position in 1970.

[16] White's procedure to compute heteroscedasticity-consistent t-values was used.

Table 2
Regression results, by source of productivity growth

Period	α_T	β_T	R^2
Total (Eq. (2))			
70–80	0.0127 (p=0.000)	−0.0026 (p=0.192)	0.025
80–90	−0.0015 (p=0.630)	0.0055 (p=0.053)	0.049
Period	α_A	β_A	R^2
Assimilation (Eq. (3a))			
70–80	−0.0063 (p=0.195)	−0.0116 (p=0.045)	0.062
80–90	−0.0051 (p=0.112)	−0.0116 (p=0.034)	0.089
Period	α_C	β_C	R^2
Creating spillover potential (Eq. (3b))			
70–80	0.0036 (p=0.028)	−0.0196 (p=0.000)	0.558
80–90	−0.0006 (p=0.827)	0.0129 (p=0.012)	0.113
Period	α_I	β_I	R^2
Innovation (Eq. (3c))			
70–80	−0.0006 (p=0.025)	0.0032 (p=0.000)	0.730
80–90	−0.0037 (p=0.000)	0.0014 (p=0.132)	0.052

To get more insight into the roles played by the determinants of productivity growth as specified in our augmented BW-framework, we also ran regressions similar to Eq. (2), based on the decomposition results, as follows:[17]

$$\text{assimilation}: \quad \hat{y}_i^{A} - \hat{y}_{US}^{A} = \alpha_A + \beta_A \log\left(\frac{y_{0,i}}{y_{a,i}} \Big/ \frac{y_{0,US}}{y_{a,US}}\right) + \varepsilon_i^{A} \tag{3a}$$

$$\text{creating spillover potential}: \quad \hat{y}_i^{C} - \hat{y}_{US}^{C} = \alpha_C + \beta_C \log\left(\frac{y_{a,i}}{y_{a,US}}\right) + \varepsilon_i^{C} \tag{3b}$$

$$\text{localized innovation}: \quad \hat{y}_i^{I} - \hat{y}_{US}^{I} = \alpha_I + \beta_I \log\left(\frac{y_{a,i}}{y_{a,US}}\right) + \varepsilon_i^{I} \tag{3c}$$

with $(y_{0,i})/(y_{a,i})$ the gap between the actual labor productivity level in country i and its target at time 0, and $(y_{a,i})/(y_{a,US})$ the gap in the target labor productivity levels between country i and the US.

The regression results for (3a) are presented in the second panel of Table 2. One might expect countries with an initial larger gap between their actual and target productivity level to have a larger contribution of assimilation to labor productivity growth. They would

[17] Wong (2001) provides a formal decomposition of β-convergence into various elements derived from a growth accounting decomposition, which is similar in spirit.

profit from their higher potential by assimilating existing knowledge of a given technology. Indeed, this appears to hold true. In both decades, countries that initially operated well below the frontier managed to close a larger gap (in an absolute sense) to the frontier than countries relatively close to the frontier, as indicated by negative estimates for β_A. However, the low values of the estimates imply that it would take about 60 years to reduce the gaps to half of their initial sizes. This indicates that the assumption of immediate spillovers in the original BW model is not warranted. Efficient assimilation of new technologies takes a long time, suggesting that it depends on the development of sufficient social and technological capabilities, and, more broadly, on changes in local culture. This process is inherently slow, as suggested by Clark (1987), for example.

The third panel of Table 2 presents the regression results for (3b). It can be seen that creation of spillover potential by capital intensification has had a far from steady impact on convergence, unlike assimilation. For the 1970s, there is a clear tendency towards convergence. The absolute value of the estimated negative coefficient β_C is large, and the autonomous productivity growth differential with the US through creating spillover potential was substantial. In the 1980s, though, this source of labor productivity growth has caused a clear tendency towards divergence. One might link this divergence to differences in social and technological capabilities. Investment in more advanced capital goods does not only require well-functioning credit markets, but also an overlay of supporting services and skills (see, for example, Nelson and Pack, 1999).

The bottom panel of Table 2 gives a more systematic insight into the convergence effects of localized innovation. The estimated intercepts are significantly negative and the estimated slope coefficients are positive, although not significant at 10% in the later decade. Both results reveal that localized innovation has put a pressure towards divergence on labor productivity growth rates. It should be noted, though, that the estimated βs are an order of magnitude smaller than the corresponding estimates for creating spillover potential, which indicates a less prominent role in driving divergence in the 1980s.

In terms of the BW model, the regression results indicate that the observed patterns of convergence in the 1970s and divergence in the 1980s were mainly due to international differences in the ability to create spillover potential by investment in physical capital goods. In addition, localized innovation has generally been a source of divergence among countries, while assimilation has been a driver of convergence. This means that the technologies appropriate to the countries with highest productivity levels have advanced the fastest, while low-productivity countries benefited more than high-productivity countries from assimilating already existing knowledge. However, assimilation tends to promote convergence at a much slower pace than assumed by BW. This suggests that their model would gain in empirical relevance if barriers to appropriate technology spillovers would be taken into account.

5. Outlier analysis: miracles and disasters

Representative behavior as revealed by the previous analysis can hide important and insightful differences in growth patterns between countries. Hence, a closer look at growth ‘miracles’ and ‘disasters’ is warranted (Temple, 1999). We identify these countries in a rather straightforward way. The upper and lower curves in Fig. 3 indicate the bounds of the (two-sided) 80% confidence intervals associated with regression equation (2). Miracles and disasters are identified by positions above the upper bound and below the lower bound, respectively. We followed a similar procedure to identify the outliers with respect to assimilation and creating potential (Eqs. (3a) and (3b)). The leftmost columns of Table 3 indicate the outliers with regard to actual labor productivity growth. The miracles include the usual suspects: South Korea, Taiwan and Hong Kong are the only countries to emerge as miracles in both the 1970s and 1980s. Not surprisingly, the disasters are mainly located in Africa and Latin America, in particular Zambia and Peru. Some of the miracles in total growth can be clearly linked to outstanding performance in creating spillover potential (South Korea in both decades and Taiwan in the 1970s), and disasters to abysmal performance in this respect (Jamaica and Madagascar in the 1970s, Panama in the 1980s and Zambia in the whole period). But clearly not all miracle and disastrous performances are driven by capital intensification or lack of it. Hong Kong seems to owe much of its performance to effective assimilation of knowledge about technologies already in use, rather than attempting to acquire new technologies at neck-breaking speed. On the other hand, Yugoslavia in the 1980s is a clear case of an assimilation disaster. Probably, other factors, less closely related to technology, caused this bad performance.

The outlier results suggest more subtle patterns of economic growth through the interaction of creating spillover potential and assimilation. In the 1970s, rapid acquisition of new technologies in the Dominican Republic and South Korea seem to come at the cost of an assimilation disaster. Conversely, the backtracking of Bolivia in the 1980s into less capital-intensive technologies led to a significant reduction of its gap to the frontier. These experiences suggest that countries can be too quick in the upgrading of their technology. The appropriate speed of upgrading will depend crucially on the level of social and technological capabilities. Productive investment in human capital is an important determinant of these capabilities. The experience of South Korea is a good case in point. During the 1980s it was able to capitalize on its spillover potential creation in the 1970s and appeared as an assimilation miracle. Much of

Table 3
Miracles and disasters as identified from regression equations

	Actual labor productivity growth		Assimilation		Creating spillover potential	
	Miracles	Disasters	Miracles	Disasters	Miracles	Disasters
1970–1980	Hong Kong	Chile	Hong Kong	Chile	Dominican Rep.	India
	Paraguay	Jamaica		Dominican Republic	South Korea	Jamaica
	South Korea	Madagascar		Malawi	Taiwan	Kenya
	Taiwan	Peru		South Korea		Madagascar
	Yugoslavia	Zambia		Sri Lanka		Peru
				Zimbabwe		Zambia
1980–1990	Hong Kong	Argentina	Bolivia	Madagascar	India	Bolivia
	South Korea	Panama	Hong Kong	Paraguay	South Korea	Honduras
	Taiwan	Peru	Malawi	Yugoslavia		Panama
	Thailand	Yugoslavia	South Korea	Zimbabwe		Zambia
		Zambia	Sri Lanka			

this seems to be due to its relatively well-educated workforce.[18] These findings suggest a sequence in which countries first create opportunities for labor productivity growth by rapidly increasing capital intensities. Next, learning through the effective assimilation of these new technologies gains in importance, to be followed by profiting from innovations at the global technology frontier. However, this last phase was not reached by any of the Asian miracle countries in 1990 as they operated technologies that were still far away from the technologies in use in countries where innovation took place.

6. Conclusions

This study provides an empirical framework to study the labor productivity growth performance of countries from a perspective suggested by the model of economic growth by Basu and Weil (1998). A prominent feature of this model is the localized nature of innovation. Innovations for capital-intensive technologies do not affect the performance of capital-extensive technologies, and the other way round. Analysis of convergence processes suggests that localized innovation causes a tendency towards divergence. At low levels of capital intensity, hardly any innovation was found, whereas the global technology frontier was steadily pushed at high capital intensities. This does not bode well for developing countries that were mostly stuck within a range of technologies characterized by low capital intensities with little potential for further growth by means of spillovers.

The results of a decomposition of labor productivity growth along the lines of Kumar and Russell (2002) indicate that for the original BW model to have empirical relevance, the assumption of immediate spillovers of appropriate technology needs to be relaxed. Assimilation of technologies new to a country is a costly and slow process. As a result, many countries perform at labor productivity levels that are far from the global technology frontier. We find evidence of catching up through assimilation, but the process is slow and assimilation rates are very heterogeneous across countries.

In our view, the results of this study ask for a number of future research efforts. First, our analysis is based on aggregate economies. Some of them experienced rapid industrialization, whereas others had already entered the stage of tertiarization and still others generated their outputs predominantly in agricultural activity. Sector-specific analyses would add to the empirical operationalization of the appropriate technology concept. Second, it may be worthwhile to link both assimilation performances and creating spillover potential performances to social and technological capability indicators like schooling, infrastructure, openness to trade, etc. (see e.g. Verspagen, 1991; Hall and Jones, 1999). In earlier convergence studies, such factors turned out to be critical, but it is unknown which factors relate most predominantly to knowledge assimilation, and which to creating potential.

[18] According to the Barro and Lee (2001) data set on schooling, in 1980 the average number of years of education of the Korean population over 15 years old was 60% higher than the average for the four countries that were closest to Korea in terms of capital intensity (Peru, Turkey, Portugal and Panama).

Finally, findings for a growth miracle like South Korea suggest a sequence in which countries first created opportunities for labor productivity growth by rapidly increasing capital intensities. Next, learning through the effective assimilation of new, appropriate technologies gained importance. A final step towards full development is further investment in modern equipment to be able to profit from current innovations at the global technology frontier. A natural question to ask is whether other countries should try to copy this behavior, in view of different initial endowments of social and technological capabilities. Given non-immediate assimilation, countries are basically faced with a choice between two extreme alternative policies: assimilating knowledge specific to the technology currently in use, or investing into more advanced technologies. New technology has a higher potential for productivity growth, but involves the costs of starting a new process of assimilation. Predictions about the optimal policy mix can only be based on a Basu and Weil type of model augmented with non-immediate spillovers. Construction and estimation of such a model is a challenging task ahead.

Appendix A

Countries in samples, ordered by labor productivity levels in 1970.

Rank	Country	Rank	Country
1	Malawi	28	Greece
2	Kenia	29	Japan
3	India	30	Chile
4	Madagascar	31	Ireland
5	Zimbabwe	32	Mexico
6	Thailand	33	Argentina
7	Zambia	34	Iceland
8	Ivory Coast	35	Israel
9	Sri Lanka	36	Spain
10	Philippines	37	Finland
11	Honduras	38	Austria
12	Paraguay	39	United Kingdom
13	South Korea	40	Italy
14	Turkey	41	Norway
15	Mauritius	42	Denmark
16	Morocco	43	Germany
17	Bolivia	44	France
18	Taiwan	45	Belgium
19	Dominican Republic	46	Sweden
20	Guatemala	47	New Zealand
21	Jamaica	48	Canada
22	Colombia	49	Australia
23	Yugoslavia	50	The Netherlands
24	Panama	51	Luxembourg
25	Portugal	52	Switzerland
26	Hongkong	53	United States
27	Peru		

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