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Los, Bart; Timmer, Marcel P.

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The 'Appropriate Technology' Explanation of Productivity Growth Differentials: An Empirical Approach

Bart Los & Marcel P. Timmer
University of Groningen
Faculty of Economics & SOM Research Institute
P.O. Box 800
NL-9700 AV Groningen
The Netherlands
e-mail: b.los@eco.rug.nl, m.p.timmer@eco.rug.nl

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Abstract: Recently, Basu and Weil (1998) proposed a model of economic growth, in which divergence of productivity levels in the world economy is driven by localized innovation and differences in the speed of capital intensification. Using panel data from the Penn World Tables in a data envelopment analysis, this paper gives indications of the empirical relevance of these forces. Further, the differences in abilities to benefit from spillover potential are introduced and analyzed. Labor productivity growth is decomposed into growth due to innovation, spillover benefits and capital intensification. Innovation appears to take place mainly at high levels of capital intensity. Convergence is driven by processes of capital intensification, but many less advanced countries fail to invest sufficiently. They seem to be stuck at technologies characterized by low capital intensities with little potential for further growth by means of spillovers.

JEL: O14, O30, O40, O47.

Keywords: Economic growth, Productivity, Technological change, Data envelopment analysis, Spillovers.

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1. Introduction

Although economists are still debating on appropriate concepts and measures of convergence, they seem to agree on the observation that productivity growth rates of the world's countries do not converge to a common rate. The traditional neoclassical model (Solow, 1956) predicted such 'absolute' or 'global' convergence, due to its feature of decreasing marginal returns to capital and its assumption of a single worldwide production function. In this neoclassical world, differences in productivity growth rates would merely be a temporary phenomenon as a consequence of initial differences in capital intensities. In particular after the publication of Baumol's (1986) empirical analysis and some important subsequent comments, this purely neoclassical view of international growth patterns has been widely dismissed, because the hypothesis of global convergence had to be rejected. Instead, convergence was found *within* certain groups of countries but divergent patterns emerged *between* such groups. The notion of 'convergence clubs' was borne (see, e.g. Mankiw *et al.*, 1992, Durlauf and Johnson, 1995, Quah, 1996).

Broadly speaking, three avenues of research have been pursued to proceed towards a more satisfactory growth theory, which could account for the emergence of convergence clubs. First, the neoclassical assumption of diminishing marginal returns to capital was relaxed in endogenous growth theories, such as Lucas (1988) and Romer (1990). Consequently, two countries with identical savings rates but different initial capital-labor ratios (capital intensities) will experience different productivity growth rates. Second, Mankiw *et al.* (1992) proposed to stick to the basics of the Solowian model, but to add human capital as a third production factor. In this augmented Solow-model, steady state productivity growth rates can differ between countries, because they are dependent on the rates of investment in human capital. Thus, these models can generate divergence between groups of countries within which convergence prevails ('convergence clubs'). A third alternative is the 'technology gap' approach. Proponents of this approach (e.g. Verspagen, 1991, Fagerberg, 1994) argue that the Solowian assumption that each country produces according to a unique worldwide production function is wrong. They see technological differences as the prime cause for differences in GDP per capita across countries. Fundamental is the assumption that many countries are not able to benefit sufficiently from high-productivity production processes operated elsewhere. In this approach the basic two variables of interest are the innovation rate of the leader(s) and the catch-up rates of the relatively backward countries. For a given rate of innovation, a 'bifurcation rate' can be calculated. Countries with a catch-up rate below this rate will face an ever-increasing gap, whereas countries with a higher rate will ultimately reach growth rates similar to the leader.

Recently, Basu & Weil (1998) proposed a new theoretical model of international productivity growth dynamics, which combines elements of the Solow model and the technology gap approach. Like the Solow model, the BW-model (henceforth this abbreviation will be used) assumes that new knowledge about production technologies is immediately public. This new knowledge, however, is only 'relevant' or 'appropriate' for countries that produce according to technologies more or less similar to the innovator's technology. They will follow the innovator immediately, whereas other countries will not benefit at all, like in the technology gap approach.[1]

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[1] In the technology gap approach, countries may be too backward to benefit from spillovers. Generally, the degree of backwardness is measured by a proxy for social capabilities (Abramovitz, 1986), such as

Thus, innovation by leaders does not shift the production possibilities frontier as a whole, but only a part in the neighborhood of the specific combination of production factors currently in use by the leader. If a country, for whatever reason, is not able to invest sufficient resources to adopt a capital intensity similar to that of the leader, this 'localized innovation' (originally introduced by Atkinson and Stiglitz, 1969) yields divergence. BW claim that their theoretical model yields outcomes which are more in line with reality than the results obtained from endogenous growth models.

The aim of this paper is twofold. First, and most prominently, it tries to give quantitative indications of the importance of localized innovation and the notion of appropriate technology for patterns of convergence and divergence observed for a variety of countries between 1965 and 1990. Second, it will be argued that a glance at the data suggests an extension of the model. Countries characterized by comparable capital intensities appear to attain quite different labor productivity levels. In many cases these differences persist for quite a long time, which might be considered as evidence for less than immediate spillovers as assumed in the BW-model. Barriers to benefiting from 'spillover potential' (as stressed by the technology gap literature) should thus be taken into account. Data envelopment analysis (DEA) techniques, combined with a recent decomposition of productivity growth and regression analysis, will provide a useful framework, which will be applied to Penn World tables on GDP, labor inputs and capital inputs to attain the above-mentioned goals. It should be noted that this paper will neither provide a formal test of the BW-model nor construct a 'technology gap-augmented' BW-model.

The rest of the paper is organized as follows. In Section 2 the BW-model will be discussed in somewhat more detail, the decomposition framework will be introduced and the relation between these theoretical and empirical approaches will be shown. Section 3 is devoted to a discussion of the data and the estimation of the set of best-practice production processes, which is the most important point of reference for the decomposition analysis. The decomposition results will be presented and discussed in Section 4. Further, a taxonomy of productivity growth patterns will be proposed in this section. In Section 5 convergence and divergence of labor productivity levels will be studied on the basis of the three sources of growth. Non-parametric techniques are used to test for significant differences in the convergence parameter between clubs of countries. Section 6 concludes.

2. Appropriate Technology and Spillovers: An Empirical Framework

Appropriate technology in the Basu and Weil (1998) model

The BW-model of growth has a number of particular features and assumptions that have to be taken into account in any empirical consideration of the model. In this section we discuss the theory in more detail, single out these features and describe their empirical counterparts in our analysis. BW model growth and technology transfer in a world where technologies are specific to particular combinations of inputs. Technologies are considered to be 'similar' if they are

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educational attainment, innovative activity, flexibility of credit markets and quality of infrastructure. In the BW-model, backwardness is expressed in capital intensities, although BW mention that their notion of capital can also include human capital. Irrespective of the exact meaning of capital, the notion of (in)appropriate technologies fit Abramovitz's notion of technological (in)congruence.

characterized by comparable capital to labor ratios. More advanced technologies have higher capital-labor ratios. Following BW's convention, we call each point in the quadrant spanned by capital intensities and labor productivity levels a *technique*, and denote a set of techniques with identical capital intensities a *technology*. Each technology has its own maximum labor productivity level which is increasing with capital intensity (the capital to labor ratio).[2] By producing with a specific capital intensity a country gains new knowledge about this particular technology and will improve the productivity level of this technology. In fact, countries not only improve the productivity of the specific technology they are using, but also the productivity levels of technologies with slightly different capital intensities. An important assumption in the BW-model states that innovations made in one country are immediately available to all. However, due to the assumption of appropriate technology, a follower country can only benefit from this innovation when it is operating (or starts to operate) at similar levels of capital intensity. Hence history is important: a follower country can benefit from technology improvements made by a leader country in the past. In fact, it inherits the productivity improvements made in the past and thus starts from a higher level than did the leader. As a result of combining localized technological progress, appropriate technology conditions and differences in investment rates, convergence clubs can appear, the labor productivities of which grow at different rates.

The BW view of the world (and its deficiencies from an empirical point of view) can best be illustrated by Figure 1, in which the capital intensities and labor productivity levels of 53 countries in 1990 are depicted.[3] As BW suggest, technologies are ranked on the horizontal axis with increasing sophistication. The vertical axis indicates the corresponding labor productivity levels that are attained by the various countries. Two issues stand out immediately. First, more advanced technologies can generate higher labor productivity levels (compare the positions of Morocco (MAR), Canada (CAN) and the USA). This finding is in line with the BW assumptions. Second, techniques within classes of very similar technologies appear to yield quite a variety of labor productivity levels (compare France (FRA) and the USA). This observation is clearly not in line with the BW setup, especially since comparison of the positions of countries in, for example, 1980 (not depicted here) and 1990 tells that such differences are often persistent. BW assume that technology is freely available and instantly transferred. It seems that for the BW-model to have empirical relevance, impediments to the transfer of a specific technology must be taken into account and abilities to benefit from spillover potential must be considered as a separate determinant of growth.

We propose a decomposition of labor productivity growth into three sources: 'learning' (reaping the fruits of knowledge spillovers for a particular technology), 'creating potential' (increasing the spillover potential by shifting towards technologies with a higher maximum productivity) and 'localized innovation' (improvements in the maximum productivity level of a particular technology.).[4]

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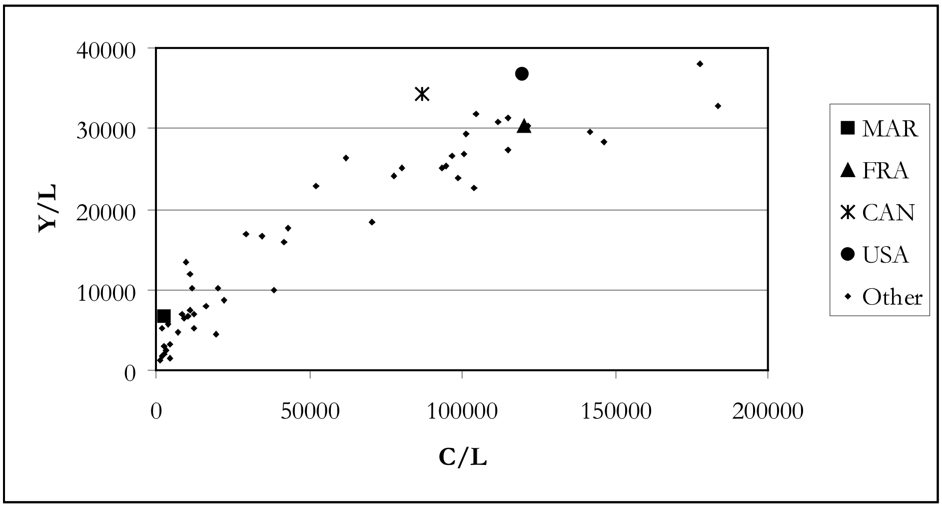
[2] BW ensure this by assuming that innovation for any technology is bounded and that the maximum labor productivity levels are higher for technologies with higher capital intensities.

[3] Details on the construction of the variables will be given in Section 3.

[4] BW use the term 'learning by doing' to indicate improvements in the maximum productivity level of a particular technology. We use the term to denote the use of knowledge spillovers to operate a technology at its maximum capacity. Improvements in the maximum capacity, or innovation, can also take place through learning by doing but could also depend on directed innovative efforts such as R&D etc.

Figure 1: Labor Productivity Levels and Capital Intensity Levels in 1990 (53 countries)



C: capital (in 1985 US$); L: labor inputs (in workers); Y: Gross domestic product (in 1985 US$);[3]

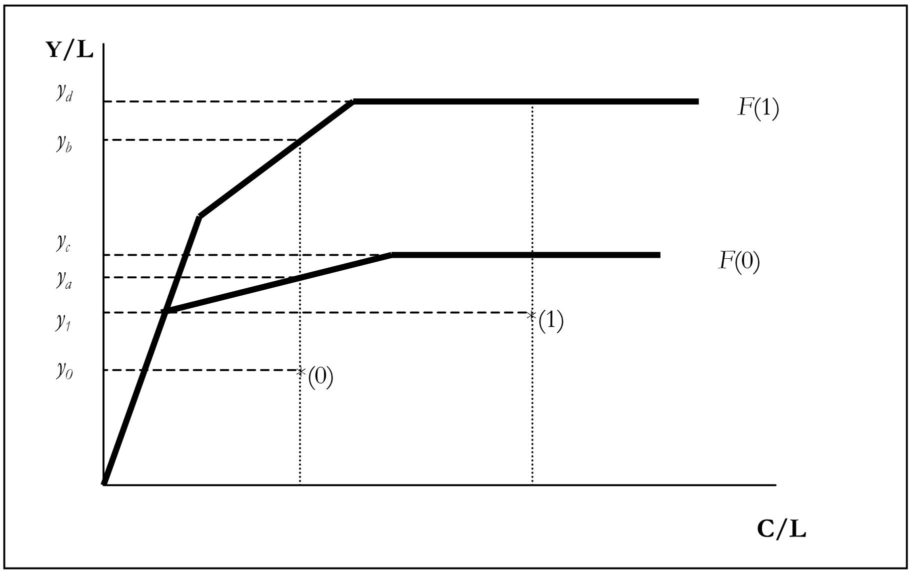
In the BW framework, an assessment of the positions of Morocco and France is rather different from the usual interpretation. From a neoclassical point of view, Morocco produces according to the same worldwide production function as the US and has good chances for catching up by 'simply' increasing its capital intensity. France on the other hand seems to operate below the production frontier and should remove inefficiencies, which is arguably more difficult. From a BW perspective, France's position is considered more positively. It is operating almost the same technology as the US, albeit using a less efficient technique. This indicates that there are ample opportunities for productivity growth by 'simply' using existing knowledge in the US. In addition, the fact that France is using an appropriate technology also ensures that any innovation in the US will also imply an increase in the size of the spillover potential. For Morocco, however, the US technology is completely inappropriate and productivity gains attained in the US will not generate benefits for Morocco. The only way for this country to benefit from spillovers is to increase its capital intensity, which might well require high savings rates and well-functioning credit markets.

The decomposition framework

For our decomposition we need to estimate the maximum labor productivity level for each technology. Figure 1 suggests that the upper observations together constitute a type of frontier, which is roughly represented by a logarithmic curve running from the origin to the upper right. From a neoclassical perspective, this frontier should be interpreted as a single best-practice technology from which producers can choose the most favorable input combination given relative prices (see, e.g., Coelli *et al.*, 1998). However, from a BW viewpoint, this frontier is seen as the set of most productive techniques for each technology. It indicates the highest labor productivity levels that have been attained by any country.

In the next section we will discuss the way in which we estimate the frontier for each time period. For now, we take the frontier for granted. Figure 2 contains two frontiers, *F*(0) and *F*(1),

Figure 2: Labor productivity growth decomposition



for periods 0 and 1, respectively, as well as two observations, indicated by *(0) and *(1). The total labor productivity ratio (y_1/y_0) is decomposed as follows:[5]

$$\frac{y_1}{y_0}=\left(\frac{y_1}{y_d}\cdot\frac{y_a}{y_0}\right)\cdot\left(\frac{y_c}{y_a}\cdot\frac{y_d}{y_b}\right)^{0.5}\cdot\left(\frac{y_b}{y_a}\cdot\frac{y_d}{y_c}\right)^{0.5} \qquad (1)$$

The first factor ('learning') measures the ratio between the vertical distance to the frontier in period 1 to that in period 0. A ratio larger than 1 thus indicates that the country under consideration has succeeded in using part of the spillover potential. The second factor is a Fisher index for vertical movements of the 'target' (the maximum attainable labor productivity for the country's technology) due to a horizontal shift of the country considered. If this factor exceeds 1, the new appropriate technology for the country allows for a higher labor productivity level if all spillover potential would be used. The third factor is also a Fisher index, for vertical movements of the target due to localized innovation. If the first two factors equal 1, a value for this factor exceeding 1 would mean that the country would have gained from innovation by the leader for the appropriate technology.

3. Frontier Estimation using Data Envelopment Analysis

In order to decompose labor productivity growth along the lines described above, a production frontier is needed. This frontier is an efficient subset of all feasible input-output combinations at a certain point in time. Various approaches to the construction of production frontiers have been proposed and used in the literature. They can be divided into the 'econometric' approach and the 'programming' approach (see Lovell, 1993, for an overview). The econometric approach has a parametric nature and requires an a priori specification of the functional form of the frontier. In

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[5] See Maudos *et al.* (2000) for a similar decomposition framework.

contrast, the programming approach is non-parametric, but has the drawback that it is deterministic and makes no accommodation for noise in the data. Here we use Data Envelopment Analysis (DEA) techniques to determine the frontiers.[6] 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 localized technical change, which is an important feature in our framework. This is the main reason why we opt for this approach rather than the econometric approach as used in for example Koop *et al.* (2000).

Assuming constant returns to scale in capital and labor, the determination of the enveloping frontiers for one input (C/L) and one output (Y/L) as depicted in Figure 2 can be stated as a rather simple linear programming problem (see e.g. Coelli *et al.*, 1998). Assume the data on the inputs and outputs are known for each of n countries. For the i-th country, they are represented by the scalars c_i and y_i respectively. Let **c** denote the (nx1)-input vector and **y** the (nx1)-output vector with observations for all countries. Then the problem (to be solved for i=1..n) can be stated as :

$$\begin{aligned}
&\max\text{imize } \theta_i \\
&\text{subject to:} \\
&-\theta_i y_i + \mathbf{y}'\boldsymbol{\lambda} \geq 0 \\
&c_i - \mathbf{c}'\boldsymbol{\lambda} \geq 0 \\
&n\mathbf{e}'\boldsymbol{\lambda} = 1 \\
&\lambda \geq 0
\end{aligned}$$

Primes denote transposed vectors, **e** is an (nx1)-summation vector containing ones, $\boldsymbol{\lambda}$ is an (nx1)-vector of constants and θ_i are scalars ($1 \leq \theta_i < \infty$). The countries for which the envelopment problem yields $\theta_i = 1$ together determine the position and shape of the frontier. Thus, $\theta_i - 1$ is the proportional increase in output that could be achieved with the input quantities held constant and $1/\theta_i$ indicates the level of technical inefficiency in the sense of Farrell (1957). In our interpretation, these statistics indicate the spillover potential of country i. The model, an extension of the output-oriented model originally proposed by Charnes *et al.* (1978), allows for identification of a frontier characterized by decreasing marginal returns to capital. Referring to Figure 1, this means that the inefficiency score $1/\theta$ for France will be related to the part of the frontier with appropriate technologies (say, the labor productivity level of the US), instead of to the labor productivity implied by a straight line through the origin and the observation for Morocco and France's capital intensity.

In most DEA studies, the frontier at time t is calculated using data from period t. However, when panel data are available, the history of data up to t can also be included. There are two important reasons to calculate the frontier at time t in this way. First, technical regress cannot occur. Because the production frontier is constructed sequentially, it can never shift inward (Lovell, 1993, p.48). This possibility of 'technical regress' (often encountered in standard DEA practice due to reduced utilization rates of production factors) seems awkward and hard to defend from a knowledge perspective on technology, as it would involve 'forgetting'. Second, as

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[6] Although DEA was originally developed for firm-level analysis, it has frequently been used at the country level (see Färe *et al.*, 1994, and Perelman, 1995).

discussed above, a crucial element in the BW model of appropriate technology is the possibility for countries to use knowledge 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*.[7]

Data

In our study, we used data on one type of output (GDP) and two types of inputs (labor and capital). We took our data 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 our labor productivity measure, 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 buildings (DeLong and Summers, 1991). The annual data span the period from 1965 to 1990 and cover 53 countries.[8]

Results

In Table 1 we provide an overview of the input-output combinations on the frontier in 1965 and 1990. As is clear from these results, the frontier in 1990 does not solely consist of input-output combinations realized in 1990. For example, the output generated in Canada in 1973 with the technology used in that country at that time, has still not been surpassed by any other country, notwithstanding that other countries used the same technology in a later stage. For example, in 1990, 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 remains on the frontier as the best technique for that particular technology up to 1990.

In Figure 3, the actual frontiers for 1965, 1980 and 1990 are drawn. As implied by our application of standard DEA techniques the frontiers are convex, running from the bottom left to the upper right, as more sophisticated technologies (characterized by higher capital intensities) can yield higher labor productivity levels. Points in the figure indicate the techniques that have been found to shape the frontiers (see Table 1). The figure clearly shows that most innovations have taken place in the advanced, capital-intensive, technologies. This includes the development of new technologies with high capital-intensities hitherto unexplored, as well as improvements in already existing technologies.

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[7] Surprisingly, this approach is rarely used in empirical studies, although it has been developed for time series in linear programming tests of the efficiency hypothesis by Diewert (1980) and in the sequential Full Disposable Hull approach by Tulkens (1986). For the actual calculation of the frontiers, we made use of the DEAP computer program developed by Tim Coelli (see Coelli, 1996).

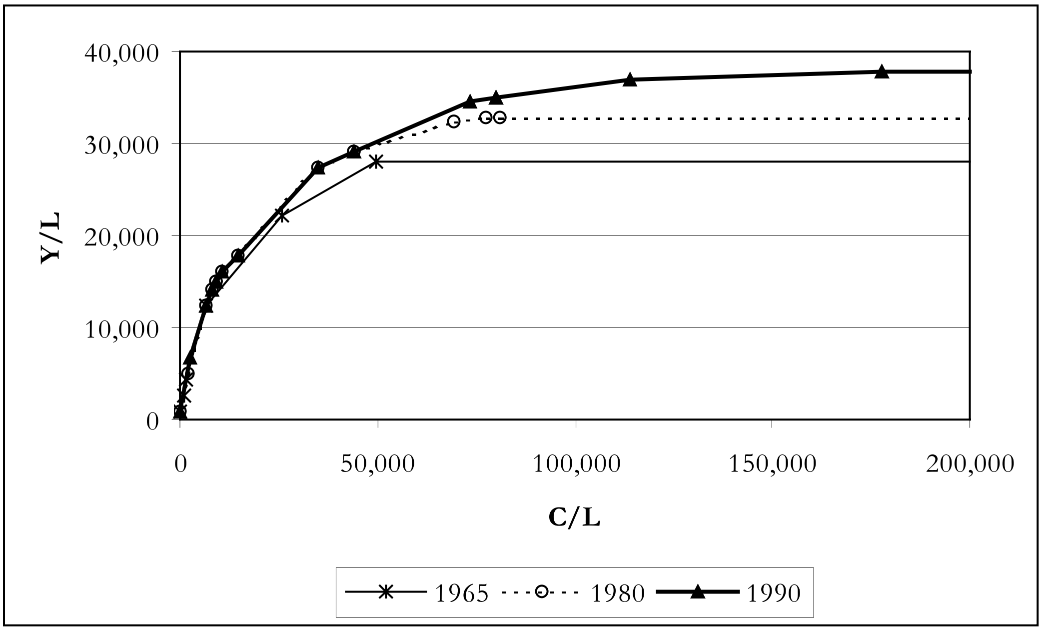
[8] PWT provides capital stock estimates for 63 countries, but we followed common practice by excluding less developed oil-exporting countries (Ecuador, Syria, Venezuela, Iran and Nigeria) and Sierra Leone because of its diamond mining activities. Further, we excluded Botswana, Nepal, Poland and Swaziland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

Table 1: Input-output combinations on frontier in 1965 and 1990

Frontier in 1965				Frontier in 1990			
		C/L (a)	Y/L (b)			C/L (a)	Y/L (b)
MWI	1965	159	846	MWI	1965	159	846
CIV	1965	947	2,674	MAR	1990	2,489	6,770
MAR	1965	1,719	4,428	ESP	1965	6,503	12,451
ESP	1965	6,503	12,451	ARG	1969	8,337	14,110
CAN	1965	25,798	22,245	ARG	1971	9,350	15,029
USA	1965	49,720	28,051	ESP	1969	10,699	16,024
				ARG	1980	14,462	17,828
				CAN	1973	34,969	27,426
				CAN	1979	43,970	29,191
				CAN	1988	73,186	34,521
				CAN	1989	80,240	35,069
				USA	1989	114,128	36,859
				LUX	1990	177,813	37,903

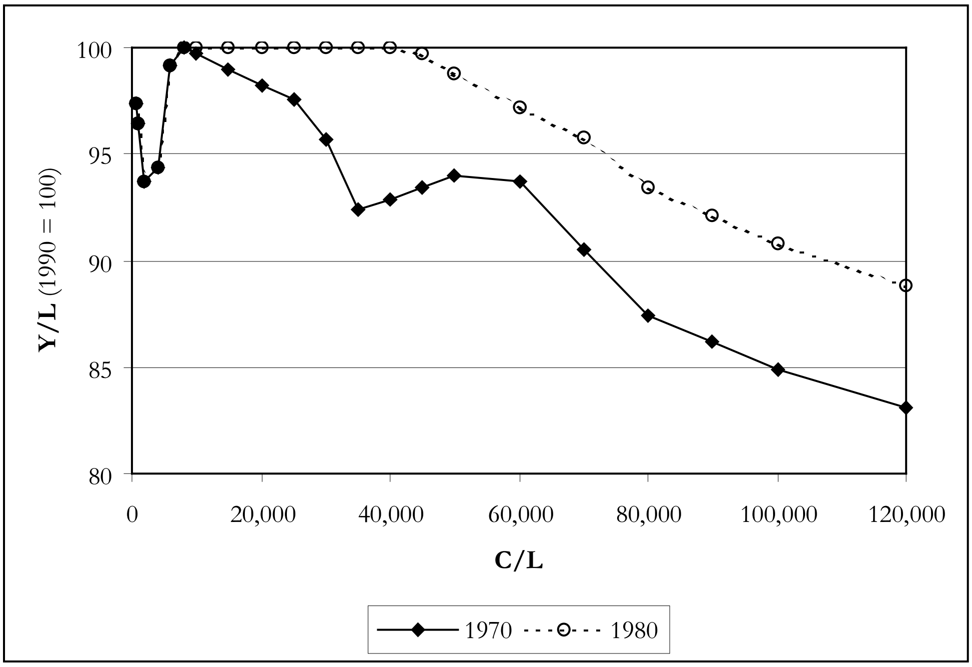
Notes: (a) Producer durable capital stock per worker (in 1985 International $)
(b) GDP per worker (in 1985 International $)

Figure 3: Global Production Frontiers for 1965, 1980 and 1990.



In Figure 4, we provide a sketch of the progress that was made for various technologies over the past decades. For a range of technologies, the figure gives the maximum labor productivity level in 1970 and 1980 as a percentage of the maximum level in 1990. It is clearly shown that the biggest advances have been made in the technologies characterized by higher capital intensities. Whereas technologies with an intensity just below $10,000 were barely improved, for technologies with capital intensities of more than $70,000 improvements of 10 percent and more were attained. Interestingly, since 1980 there has been technological stagnation for a large range of intermediate technologies (between $10,000 and $40,000), indicating that innovation was non-existent there. This is an important finding, given that countries as diverse as Thailand, Portugal and Korea operated in this range of technologies in 1990. The localized nature of innovation indicated by Figures 3 and 4 stresses the empirical relevance of the BW model.

Figure 4: Movement of Labor Productivity Levels for a Range of Technologies, 1970-1990 (1990 =100)



4. A Taxonomy of Growth Patterns

As formalized in equation (1), the extended BW-framework with non-immediate knowledge spillovers distinguishes three sources of labor productivity growth. Countries are known to differ with respect to the relative importance of these three sources. Moreover, the relative importance could well change over time. In this section we provide a taxonomy of the growth patterns experienced by countries between 1965 and 1990, based on the labor productivity growth decomposition results. First we take a look at the gap, and the change in the gap, between the actual and the maximum level of labor productivity (the 'target') as determined by the frontier. Subsequently, attention is focused on the various sources of the movement of the actual level: learning, creating spillover potential and localized innovation. As will become clear, four basic patterns can be distinguished:

A. 'Tracking the frontier'. The actual level was close to the target level, so there was not much spillover potential to benefit from. Examples include countries such as the US, Canada, Spain and Morocco.

B. 'Losing ground regarding appropriate technology'. The target labor productivity level was first increasing and then decreasing with hardly any learning. The most prominent representatives are located in Latin America.

C. 'Learning within increasingly beneficial appropriate technologies'. The target labor productivity level was slowly increasing and the spillover potential was slowly fished out. Most OECD countries experienced this growth pattern.

D. ‘Making a miracle’. The target productivity level rose rapidly without negative developments regarding backwardness relative to the frontier. The most well-known examples are the ‘Asian Tigers’.

‘Tracking the Frontier’

By definition, countries that track the frontier closely have little room for learning. Countries such as the USA, and Canada to a lesser extent, relied on innovation as the main source of labor productivity growth. They frequently pushed the frontier. This is indicated in Figure 5a. The left-hand figure presents the development of the actual and the target labor productivity levels over the period 1965-1990 in the US. The right-hand side figure gives the results of the decomposition of the sources of actual labor productivity growth. Depicted is the cumulative index, taking 1965 as the base year. The ‘total’ line corresponds to the ‘actual’ line in the left-hand figure. In addition, the contribution of the three sources are given. From the figure it is clear that innovation contributed most to actual labor productivity growth, whereas the contribution of learning was virtually nil.

Other countries in this category tracked past developments in more advanced countries and did not (or barely) move the frontier themselves. In these countries creating potential was the main source of labor productivity improvement. Morocco is a good example of the latter. From Figure 5b can be inferred that learning even contributed negatively for a long period, when creating potential was by far the most important source. Innovation did only contribute in the last years of the period covered.

Figure 5a: United States

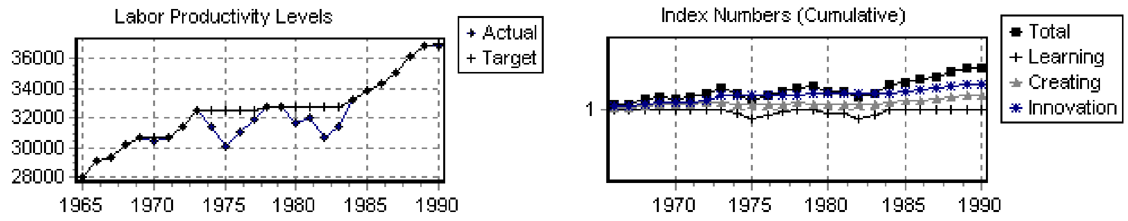
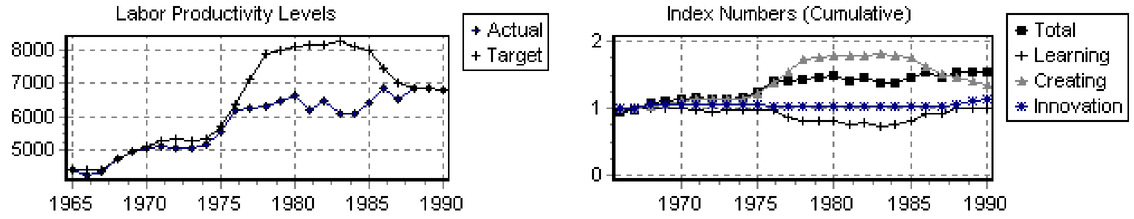


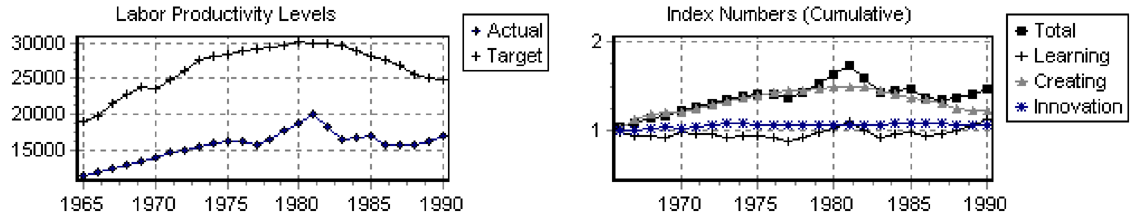
Figure 5b: Morocco



‘Losing Ground Regarding Appropriate Technology’

The target productivity level for most of the Latin American countries was first increasing and then decreasing, together with a long period of stagnation in the actual labor productivity level. This pattern is due to the effects of the debt-crisis. In 1982, default of Brazil on its foreign debt obligations resulted in a ‘lost decade’ for the whole Latin-American continent. In particular, with soaring inflation, falling exchange rates and starvation of foreign capital, capital-intensity levels actually decreased quite dramatically.[9] In effect, the target is moving towards the rather maximum labor productivity levels (see Figure 4) and learning takes place, but arguably of the less-desired kind. Figure 5c indicates the overriding importance of creating potential for actual labor productivity development in Mexico up to 1982, and of learning afterwards.

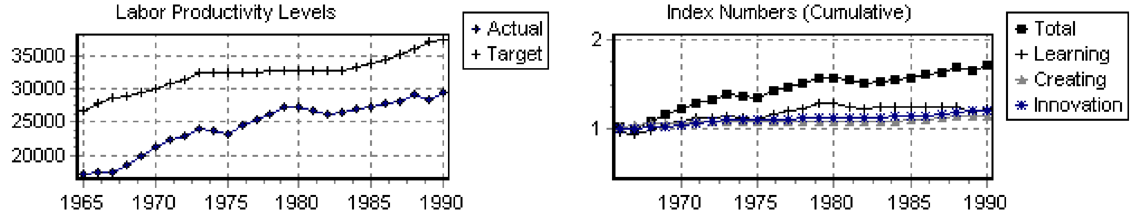
Figure 5c: Mexico



'Learning within increasingly beneficial appropriate technologies'

In most OECD countries the target was slowly increasing, and the actual labor productivity levels were converging to the target. In these countries, all sources were important contributors to improvements in the actual levels of labor productivity. Western Germany is a good example (see Figure 5d). After an initial period of rapid capital intensification following the Second WW, learning became the most important source of growth after 1973. The positive contribution of localized innovation in the 1970s already indicates that Germany quickly entered that range of technologies were most developments at the global frontier take place. In the latest years localized innovation became the main contributor to labor productivity growth. Nevertheless, a sizeable gap with the target level still existed, indicating the potential for further labor productivity growth on the basis of learning.

Figure 5d: Western Germany



'Making a Miracle'

In this category, the target levels rose rapidly and the actual levels were converging to these moving targets. Creating spillover potential was by far the most important source of catch up. Global innovation plays no role here. Interestingly, the importance of creation versus learning evolved over time. A sequence can be discerned in which learning gradually became more important as a contributor to catch up. This is illustrated by Figures 6e to 6h, which depict the developments in India, South Korea, Taiwan and Japan.

India is an example of a country in the first phase, in which creation was the only source of labor productivity growth (Figure 5d). In South Korea, development obviously progressed

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[9] This finding depends crucially on the way capital is measured. In the Penn World Tables, capital stock is measured by the perpetual inventory method using geometric depreciation. When a rectangular pattern is used instead, capital intensity growth slows down, but does not decline (see Hofman, 1999).

further and although creating was still by far the most important source of growth in the late 1980s, learning has made its contributions since the mid 1980s (Figure 5e). The Korean pattern can also be found for other countries like Thailand, the Philippines and Chile. In Taiwan, the contribution of learning was bigger and it was the main source of catch up since the end of the 1970s, as can be inferred from the stagnating cumulative index for creating in Figure 5g. Developments in Turkey resemble those in Taiwan. Japan was the most mature Asian country in which learning already contributed since the mid 1970s and innovation started to make contributions in the 1980s.

Figure 5e: India

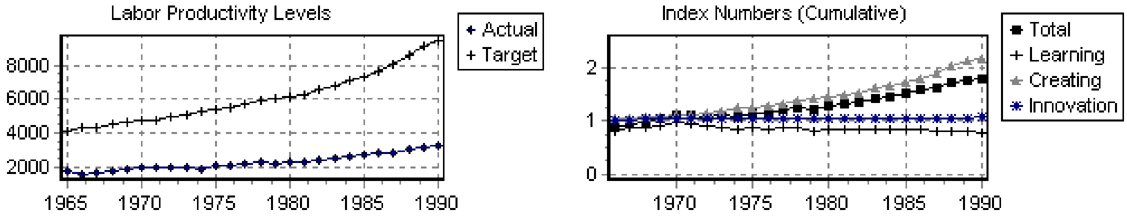


Figure 5f: South Korea

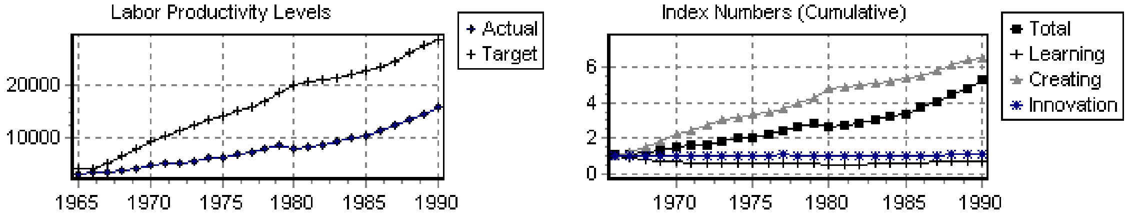


Figure 5g: Taiwan

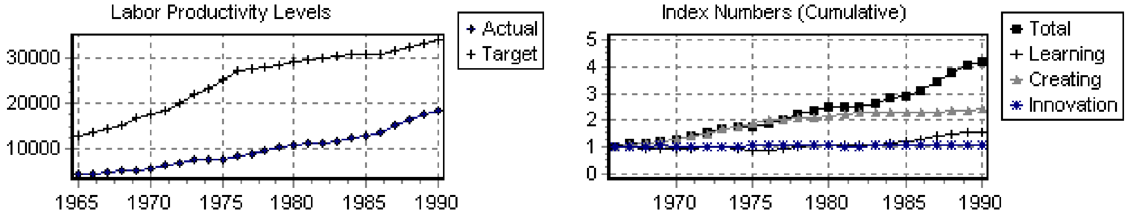
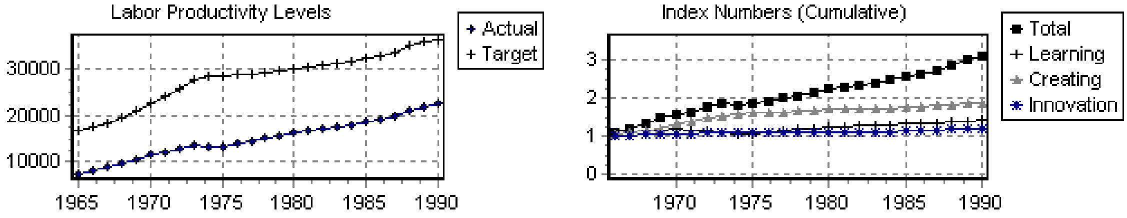


Figure 5h: Japan



These findings suggest a sequence in which countries first created opportunities for labor productivity growth by rapidly moving up the technology ladder. After a certain moment, learning and the effective assimilation of new, appropriate technologies gained in importance, to be followed in a later stage by profiting from developments at the global technology frontier. The important question is how to define this switching moment. As the figures show, the potential for catch up solely by learning was still very large at the end of the 1980s, as indicated by the gaps between actual and target labor productivity levels.

The four classes of growth patterns as identified above can be linked to the availability of sufficient social capabilities or, in other words, the presence of sufficient absorptive capacity. It seems that the group of countries denoted "losing ground regarding appropriate technology" did not have the ability to invest in new technologies, whereas the "making a miracle" countries did. This could be due to different propensities to save, but is more likely to be the consequence of ill-functioning credit markets. Some of the "tracking the frontier" countries at low capital intensities (Morocco, for example) seem to suffer from similar problems. Further, the class of countries "learning within increasingly beneficial appropriate technologies" appears to have had enough absorptive capacity to learn from countries operating appropriate technologies at a higher labor productivity level. The "making a miracle" did so to a lesser extent. It remains to be seen whether this due to lacking social capital, or whether it is the result of the very fast capital intensification, which allows less time to learn (see Timmer, 2000). In the next section, we will analyze such is issues in a more systematic way.

5. *Convergence and divergence*

The analysis in the previous section has been rather descriptive. In this section, we want to confront the data generated by our decomposition analysis with econometric techniques, in order to find general explanations (or even 'laws') of growth differentials. To this end, we will estimate convergence regressions. Simple linear equations that link growth rates to initial productivity levels do not seem to be a useful tool, since the previous section offered circumstantial evidence that countries faced various convergence regimes. Therefore, we will combine a technology gap equation with piecewise linear equations. We will not only take the entire 1965-1990 period into account, but also run regressions for the subperiods 1965-1980 and 1980-1965. We do this for two reasons. First, 1980 marked the start of the 'lost decade' for many Latin American countries, in which debt crises prevented them from investing in more capital intensive technologies. Second, the diagrams for East-Asian countries indicated that there are different 'phases of productivity growth'.

Methodology

The general technology gap equation we estimate is a fairly simple one:

$$\dot{y}_i - \dot{y}_{US} = \beta \log\left(\frac{\overset{*}{y}_i}{\overset{*}{y}_{US}}\right) + \varepsilon_i \quad , \tag{2}$$

in which dots denote proportional average annual growth rates and asterisks indicate levels at the initial period of analysis. Hence, the labor productivity growth rate relative to the US (the world leader) is related to the initial labor productivity gap to the US. The absence of an intercept implies that we assume that lagging countries do not have different autonomous rates of productivity growth, and are therefore purely dependent on creating spillover potential and using that potential in managing to raise their productivity levels. If β were negative, convergence would prevail and all countries would asymptotically grow at the same rate. In this respect, our approach differs from the literature on conditional convergence (such as Barro, 1991).

As we argued before, however, it seems implausible to impose *a priori* that more backward countries automatically grow faster, especially if there are barriers to create or use spillover potential, such as a lack of social capabilities. Hence, not all countries are likely to face the same productivity growth regime. Our approach to consider this explicitly is partly inspired by Durlauf and Johnson's (1995). First, we estimate equation (2) for the entire sample.[10] We will denote the estimate for the convergence parameter that is obtained $\hat{\beta}$. Next, we order the countries on the basis of their initial gap to the US, and split the sample into two mutually exclusive subsamples. The first subsample consists of the n_1 countries that initially face the largest gaps to the US, whereas the second subsample contains the 52-n_1 remaining countries. Equation (2) is estimated twice (for both subsamples) for $10 \leq n_1 \leq 42$. This implies that each subsample contains at least ten countries. The value for n_1 for which the sum of squared residuals (added over the two regressions) is minimized identifies the optimal split.

Next, the decision should be made whether the difference between the estimates for the two convergence parameters, $\hat{\beta}_1$ and $\hat{\beta}_2$, is sufficiently large to justify the distinction of two separate 'convergence clubs'. A simple *F*-test is inappropriate, since the 'optimal' location of the split has already been generated by the data. Hence, the null hypothesis of $\beta_1 = \beta_2$ would be rejected too easily in favor of the alternative hypothesis $\beta_1 \neq \beta_2$. Instead, we apply a non-parametric exact test, for which $|\hat{\beta}_1 - \hat{\beta}_2|$ is the test statistic. The above-described procedure is repeated 1000 times. Instead of ordering the countries by their initial productivity levels, however, we now order them by randomly assigned values. Comparison of the test statistic with the frequency distribution of the estimated differences on the basis of these random orderings leads us to our final decision: if $|\hat{\beta}_1 - \hat{\beta}_2|$ exceeds (100-α)% of the estimated differences (in absolute value) in the splits based on random orders, the null hypothesis is rejected at a significance level of α%.

In comparison to the complex procedure proposed by Durlauf & Johnson (1995), our identification methodology has the advantage that it is much more transparent. Currently, a drawback of our method is that we have not yet developed an extended version which is able to identify more than two convergence regimes.[11] In a future version of this paper, we hope to include such an interesting extension.

Results

The first results we report are the ones obtained for actual labor productivity growth rate differentials and the initial labor productivity gaps (both relative to the US). The results are in Table 2.

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[10] The sample consists of the 52 countries that trailed the US in terms of labor productivity levels and for which the Penn World Tables contain the required data for 1965, 1980 and 1990. See the Appendix for the countries included.

[11] In their study of conditional convergence, Durlauf & Johnson (1995) conclude that four convergence regimes should be identified.

Table 2: Regression results, actual labor productivity growth

1965-1990		Point estimate	p-value*	
Whole sample		$\hat{\beta} = -0.00495$	0.008	
Subsample 1	Malawi-Panama	$\hat{\beta}_1 = -0.00286$	0.134	n_1=23
Subsample 2	Portugal-New Zealand	$\hat{\beta}_2 = -0.01416$	0.000	
	Significance of split	0.057		
1965-1980				
Whole sample		$\hat{\beta} = -0.01161$	0.000	
Subsample 1	Malawi-Honduras	$\hat{\beta}_1 = -0.00620$	0.010	n_1=12
Subsample 2	Turkey-New Zealand	$\hat{\beta}_2 = -0.01842$	0.000	
	Significance of split	0.045		
1980-1990				
Whole sample		$\hat{\beta} = 0.00713$	0.015	
Subsample 1	Malawi-Panama	$\hat{\beta}_1 = 0.00857$	0.006	n_1=23
Subsample 2	Taiwan-Switzerland	$\hat{\beta} = -0.00305$	0.744	
	Significance of split	0.353		

*Two-sided

The results reveal both major differences between countries and between time periods. To start with the results for the entire period 1965-1990, the estimate for the full sample points towards significant convergence, although the speed would be slow. Allowing for two different regimes yields a different picture. Convergence was much stronger for countries with a moderate to small gap to the US (see the Appendix for the countries which rank between Portugal and New Zealand), whereas the countries that faced larger initial gaps show no significant convergence at all. Furthermore, the difference in the estimated convergence parameters is highly significant according to the non-parametric test.

Focusing on the early subperiod, we see that both the low-productivity and the high-productivity countries converged to the world leader, be it that moderate to small gaps enabled countries to make up for a much larger share of their gaps. Again, the analysis shows that this difference is significant at reasonable levels. These patterns appear to have changed dramatically in the period after 1980. For the second subperiod, the sample as a whole indicates divergence of labor productivity growth rates. The poorest countries lose ground to the world leaders (the estimated coefficient is significantly positive), and gaps to the US remain approximately constant within the richer subsample. There is no strong evidence of a difference in growth regimes, however.

The results in Table 3 are obtained by relating the growth rates of the labor productivity targets (relative to the US) to the initial labor productivity gap. As such, they indicate whether countries succeeded in adopting more capital-intensive technologies which could offer them opportunities to use spillovers to close part of the gap. For the period as a whole, this seems to be the case. It seems unlikely that different regimes exist, and especially for the countries that faced the largest initial gap the estimate for the convergence parameter is significantly negative. These results, however, turn out to be driven completely by developments in the earlier subperiod. Between 1965 and 1980, convergence of targets was taking place at substantial annual rates of about 1.5% for the poorest countries. After 1980, however, this trend was reversed to quite a dramatic extent. The seemingly uniform regime switched to a pattern of strong divergence. From a BW viewpoint, we find that countries did not remain able to adopt technologies that would yield localized spillovers from the innovating part of the world. Extension of our dataset towards more recent years should reveal whether this is a long-run phenomenon or not.

Table 3: Regression results, target labor productivity growth

1965-1990		Point estimate	p-value*	
Whole sample		$\hat{\beta} = -0.00479$	0.023	
Subsample 1	Malawi-Yugoslavia	$\hat{\beta}_1 = -0.00553$	0.037	n_1=19
Subsample 2	Jamaica-New Zealand	$\hat{\beta} = -0.00216$	0.313	
	Significance of split	0.974		
1965-1980				
Whole sample		$\hat{\beta} = -0.01424$	0.000	
Subsample 1	Malawi-Yugoslavia	$\hat{\beta}_1 = -0.01550$	0.000	n_1=19
Subsample 2	Jamaica-New Zealand	$\hat{\beta} = -0.00882$	0.001	
	Significance of split	0.836		
1980-1990				
Whole sample		$\hat{\beta} = 0.01200$	0.000	
Subsample 1	Malawi-Morocco	$\hat{\beta}_1 = 0.01320$	0.003	n_1=14
Subsample 2	Turkey-Switzerland	$\hat{\beta}_2 = 0.00657$	0.065	
	Significance of split	0.858		

*Two-sided

Table 4: Regression results, actual vs. target labor productivity growth

1965-1990		Point estimate	p-value*	
Whole sample		$\hat{\beta} = 0.00089$	0.607	
Subsample 1	Malawi-Paraguay	$\hat{\beta} = 0.00375$	0.079	n_1=14
Subsample 2	Bolivia-New Zealand	$\hat{\beta}_2 = -0.00553$	0.026	
	Significance of split	0.099		
1965-1980				
Whole sample		$\hat{\beta} = 0.00381$	0.159	
Subsample 1	Malawi-Dominican Rep.	$\hat{\beta}_1 = 0.00793$	0.014	n_1=18
Subsample 2	Yugoslavia-N. Zealand	$\hat{\beta}_2 = -0.00834$	0.001	
	Significance of split	0.006		
1980-1990				
Whole sample		$\hat{\beta} = -0.00476$	0.018	
Subsample 1	Malawi-Yugoslavia	$\hat{\beta}_1 = -0.00520$	0.050	n_1=27
Subsample 2	Hongkong-Switzerland	$\hat{\beta}_2 = -0.01938$	0.063	
	Significance of split	0.077		

*Two-sided

In Table 4, we report the results of regressions in which the dependent variable is the actual labor productivity growth rate minus the target labor productivity growth rate. Again, the (log of the) initial labor productivity gap to the US is the explanatory variable. This regression should be viewed as an investigation into the abilities of countries to benefit from localized spillovers. The results are quite strong. For each of the specified periods, two separate regimes are identified. In each of these cases, countries with a relatively small productivity to the US seem to have benefited much more from spillovers than poorer countries did. For the entire 1965-1990 period and the early subperiod, countries with a large initial gap generally moved away from the frontier, probably as a consequence of the rather rapid movement towards more capital-intensive technologies as evidenced by Table 3. In the last subperiod, many countries appear to have benefited from spillovers, but this time after having lost ground in terms of potentially productive technologies.[12]

Interestingly, the structural break in worldwide labor productivity dynamics around 1980 seems to be due to a coincidence of changes in the two factors paramount in our analysis. First, the process of convergence of targets until 1980 was substituted by divergence afterwards, which emphasizes the importance of the mechanisms BW focus on in their theoretical contribution. Simultaneously, a relatively small group of already developed countries kept learning from appropriate technologies at a much faster pace than a big group of backward countries. This stresses the importance of social capabilities to learn.

6. Concluding remarks

In a recent model of economic growth, Basu and Weil (1998) explain divergence in labor productivity growth between countries by introducing the concept of 'appropriate technology'. Innovations are assumed to be localized at high-end technologies and to provide spillovers only for countries using more or less similar production technologies. This implies that already advanced countries forge ahead and less developed countries fall behind. In this paper, we try to indicate the empirical relevance of the BW-model using data for a large number of countries in the period 1965-1990.

We used a data envelopment analysis technique that allows for incorporating panel data in the calculation of annual frontiers, which represents the set of maximum attainable labor productivity levels for all technologies (indexed by capital intensities) in existence. Inspection of the results showed that the BW-theory captures two important empirical issues, but neglects another one. First, the frontiers indicate that innovations are indeed localized at the higher end of the technology ladder. Especially in the 1980s, the improvement in the intermediate and lower end technologies stagnated. Second, differences in the rate of adopting more advanced technologies might be an important cause of divergence. As more advanced technologies have higher maximum labor productivity levels and provide bigger opportunities for spillovers,

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[12] A thorough regression analysis of the performance of countries belonging to the four classes in the growth pattern taxonomy proposed in the previous section should offer quantitative evidence for the conjecture.

investment by lagging countries does not necessarily suffer from diminishing returns. Finally, we found that knowledge spillovers are not automatic as assumed in the BW model. Most countries do not operate their technology at the productivity level attained by other countries using similar technologies. Differences in abilities to learn from the experience by other countries can thus be another important cause of divergence.

Next, we proposed a taxonomy of growth patterns. Using the global frontiers, we formally decomposed actual labor productivity growth into the contributions of the above-mentioned sources: learning, creating spillover potential and innovation. One class of countries (such as Canada and the US) determined the frontier or track the frontier closely, thereby relying on innovation. A second class of (mainly European) countries slowly moved up the technology ladder and fished out their high spillover potential in the 1960s and 1970s. In contrast, many countries in Latin America and Africa failed to move up to more capital intensive technologies and fell back in the 1980s. Finally, the Asian miracle countries were able to move up the ladder and simultaneously, or at a later stage, also used the spillover potential provided by this move by closing the gap to the global frontier.

Finally, we adopted a simple piece-wise linear regression approach to identify 'laws' of labor productivity growth in the period 1965-1990. The worldwide convergence found for 1965-1980 appeared to be mainly driven by convergence of the growth rates of the maximum attainable labor productivity levels. After 1980, however, a reverse tendency was found. Convergence of these 'targets' was substituted by a process of divergence. This effect was strengthened by the result that at least two regimes turned out to exist with regard to learning. The positive relationship between learning and backwardness appeared to be much stronger for moderately backward countries than for very backward countries, although more backward countries generally benefited more from learning than less backward countries. This can be considered as support for the hypothesis that learning is conditional on the presence of sufficient absorptive capacity. Such a result was not found for the target labor productivity rate dynamics, which is probably mainly due to the extraordinary performance in adopting new technologies by initially very backward countries like Southern Korea and Taiwan, which are clear outliers in the analysis.

The analysis provided in this paper must be seen as a first step towards a comprehensive test of models of growth based on appropriate technology. Several improvements can be thought of, but we will restrict our (brief) discussion to only three issues. First, the analysis presented in this paper does not offer an econometric test of the empirical validity of the BW-model. Instead, it just shows that the most important mechanisms in the model seem to be influential indeed. A formal test grounded in the decomposition framework would require a BW-like model extended with barriers to benefit from spillover potential, a derivation of its steady-state behavior and (if possible) its transitory dynamics and subsequently, appropriate and more specific regression equations. Although many growth analyses suffer from this drawback, a second weakness in this analysis is the high degree of aggregation. The notion of 'a technology' is much more tenable for studies at the level of industries than for economywide studies, in particular as a consequence of substantial interindustry productivity growth rate differences and differences in the industry specialization patterns of countries. Third, and finally, our indicator of social capabilities (initial labor productivity gaps to the world-leader) is an extremely crude one. Inclusion of variables that consider education, infrastructure, political stability, functioning of credit markets etc. could not only enrich the regression analysis, but might also yield results with a higher relevance from a policy perspective. Despite these objections, we think that models and empirical studies that emphasize the role of localized innovation and learning could well contribute to the understanding of the complex dynamics of productivity growth rates.

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Appendix:

Countries in samples, ordered by labor productivity levels in 1965 and 1980

Rank 1965	**Country**	**Rank 1980**	**Country**
1	Malawi	1	Malawi
2	Kenia	2	Madagascar
3	India	3	Kenia
4	Zimbabwe	4	India
5	Madagascar	5	Zambia
6	Thailand	6	Zimbabwe
7	Côte d'Ivoire	7	Côte d'Ivoire
8	Southern Korea	8	Thailand
9	Zambia	9	Sri Lanka
10	Philippines	10	Philippines
11	Sri Lanka	11	Honduras
12	Honduras	12	Jamaica
13	Turkey	13	Bolivia
14	Paraguay	14	Morocco
15	Bolivia	15	Turkey
16	Taiwan	16	Mauritius
17	Morocco	17	Paraguay
18	Dominican Republic	18	Southern Korea
19	Yugoslavia	19	Dominican Republic
20	Jamaica	20	Guatemala
21	Guatemala	21	Peru
22	Colombia	22	Colombia
23	Panama	23	Panama
24	Portugal	24	Taiwan
25	Mauritius	25	Portugal
26	Hongkong	26	Chile
27	Japan	27	Yugoslavia
28	Greece	28	Hongkong
29	Peru	29	Greece
30	Chile	30	Japan
31	Ireland	31	Argentina
32	Mexico	32	Ireland
33	Spain	33	Mexico
34	Israel	34	Israel
35	Argentina	35	UK
36	Austria	36	Denmark
37	Finland	37	Spain
38	Italy	38	Finland
39	Iceland	39	Iceland
40	United Kingdom	40	Austria
41	France	41	New Zealand
42	Norway	42	Sweden
43	Germany	43	Norway
44	Belgium	44	France
45	Denmark	45	Italy
46	The Netherlands	46	Germany
47	Sweden	47	Australia
48	Luxemburg	48	Belgium
49	Australia	49	Luxemburg
50	Canada	50	Canada
51	Switzerland	51	The Netherlands
52	New Zealand	52	Switzerland