PANOECONOMICUS, 2018, Vol. 65, Issue 5, pp. 531-550
Received: 03 February 2016; Accepted: 24 April 2016.

UDC 330.357 UDC 330.45
https://doi.org/10.2298/PAN160203009K
Original scientific paper

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Growth and Convergence under Uniform and Varying Rate of Change of Technology

Summary: This paper seeks to extend the debate on growth and convergence by estimating growth equations which allow for varying rate of change in technology (TFP) as well as the standard assumption of uniform rate. Rate of change of TFP is proxied using an index of patent protection. The dataset used in the paper includes 25 high income countries, 20 middle income countries, 28 low income countries and 16 countries which have transitioned across income categories during the time period considered in this paper. The results of the paper, estimated using the generalized method of moments (GMM) approach, show significant differences when the rate of change of TFP is assumed to be varying as opposed to being uniform. Significantly, the rate of convergence differs significantly across the subgroups of countries under the assumption of varying rate of change of TFP. Rates of convergence under the assumption of varying rates are clearly higher than those under the uniform rate for high income countries while the results for countries in other income categories are mixed.

Key words: Economic growth, Convergence, Patents, TFP, Panel data.

JEL: C33, O47.

Estimating growth regressions has been a very active research industry in economics. The usual procedure has been to explain long-run economic growth by fitting regression equations with growth rate of real GDP as the dependent variable and a wide variety of determining variables. The sample of countries chosen for such estimation has usually been quite large. Examples of such research abound and we discuss these in the next section. The main objectives of research in this area have been: (i) estimating a robust growth equation and (ii) estimating convergence rates, whether unconditional or conditional. Most studies have assumed unchanging rates of technological change or total factor productivity (TFP) across countries in their models, an approach that has been critiqued in recent years. The novel aspect of this paper is that it seeks to remedy this lacunaby allowing for varying rates of TFP change in the growth equations. A second related extension of the existing literature that has been attempted in this paper is a consideration whether the shift away from uniform to varying rate of TFP growth affects all countries in an identical manner.

The plan of the paper is as follows. Section 1 provides an overview of the literature in the area of growth equations. Section 2 sets out in brief the methodology employed in this paper. The dataset used in the econometric exercises is also described in this section. Section 3 presents the results of estimating the growth equation for all countries (ALL) in our sample. Sections 4, 5, 6 and 7 present similar results for the high income countries (HIC) sub-group, middle income countries (MIC) sub-group, low income countries (LIC) sub-group and for a group of countries (CIC) that has graduated from lower income groups to higher income groups. Section 8 concludes.

1. Overview of Literature

The genesis of the research in this area dates back to Robert M. Solow (1956), which, despite the passage of half a century, continues to inspire researchers. The second landmark study is Gregory N. Mankiw, David Romer, and David N. Weil (1992) which, for the first time, proposed a way of empirically modelling and estimating Solow's growth model. Recent work in this area continues to be guided by these two contributions (see Stephen R. Bond, Asli Leblebicioglu, and Fabio Schiantarelli 2010 and Danish Ahmed Siddiqui and Qazi Masood Ahmed 2013, among many others).

Early studies in estimating growth equations used cross-section data to estimate the growth equation but that soon changed with the increasing availability of time-series data for a large number of countries. Models employing panel data have been increasingly used over the last fifteen years (see Markus Eberhardt and Francis Teal 2011 for a survey).

A very important dimension of estimating growth equations has been the issue of convergence, whether conditional or unconditional (Jens Arnold, Andrea Bassanini, and Stefano Scarpetta 2011 and Andrev Korotayev et al. 2011). Korotayev et al. (2011) discuss the various dichotomies proposed by Nazrul Islam (2003), which have had a bearing on the research on convergence. Among these dichotomies, the notable ones are: (1) β-convergence and σ-convergence; (2) unconditional convergence and conditional convergence.

Most research has focused on β-convergence which implies that, with similar savings rate, poorer countries will grow faster. If this is to happen, then countries with lower initial level of income would grow faster than countries with higher initial income: the correlation between growth and initial income would be negative. In the context of estimating an equation - known as a growth-initial income level regression - the coefficient (β) of the initial (or lagged) income variable is expected to pick up this negative correlation. σ-convergence on the other hand is concerned with the dispersion of the cross-sectional distribution of income and it has been proposed that a negative β may not imply a reduction in this dispersion. Despite the importance of this dispersion, β-convergence has dominated research in the area.

The distinction between unconditional and conditional convergence is probably the most important from a conceptual point of view (Islam 2003, p. 314). Unconditional convergence assumes that the level of TFP, investment rate, exponential growth rates of TFP and labour, rate of depreciation and the exponent of capital in a Cobb-Douglas production are the same across the economies being studied. Conditional convergence, on the other hand, points to differences in the steady state income of countries and requires inclusion of additional variables on the right hand side of the growth-initial income equation to control for these differences. The conditional rate of convergence is understood as the rate at which a country approaches its steady state income. Robert J. Barro's (2015) estimates have suggested an "iron law" whereby the rate of convergence hovers around 2% per annum. As discussed later, there is no consensus that the "iron law" always holds. Moreover, it is worth remembering Dani Rodrik (2014) who points out that convergence has been the exception rather than the rule.

While there have been innumerable papers that have sought to estimate rates of convergence, one particular assumption has caused much disquiet. This assumption relates to the treatment of technology or TFP. While the Solow model does take technology to be exogenous, it is a misinterpretation to assume that technology grows at the same rate in all countries (Kieran McQuinn and Karl Whelan 2007). Chang-Tai Hsieh and Peter J. Klenow (2010) have noted that the data point to substantial differences across countries in TFP growth rates and the differences in growth rates are systematically related to differences in output per worker across countries.

This paper seeks to advance the debate on growth equations and convergence by allowing for varying rates of change in TFP. We do this by introducing technology in the manner suggested by Erich Gundlach (2007) and examine the effects of including varying rates of change in TFP into the growth equations. A second related issue that we consider is whether the shift away from uniform to varying rate of TFP growth affects all countries in an identical manner. We address this by grouping the countries in our dataset into different income categories.

2. Methodology and Data

The starting point for research in this area is the now standard approach employed by Mankiw, Romer, and Weil (1992). This consists of specifying a Cobb-Douglas production function of the following form:

$$Y_t = {K_t}^{\alpha}(A_t L_t)^{1-\alpha}, 0 < \alpha < 1, \quad (1)$$

where Y is output, K is capital, L is labour and A is the level of technology/TFP. L_t and A_t are assumed to grow exogenously as:

$$L_t = L(0)e^{nt}, \quad (2)$$

$$A_t = A(0)e^{gt}. \quad (3)$$

Equation (3) will be modified subsequently to reflect the thrust of this paper.

The use of the Cobb-Douglas production function to estimate growth of equations has been the subject of criticism (Eberhardt and Teal 2011). In view of such criticism, is it still a good idea to continue to use the Cobb-Douglas production function specification in estimating growth equations for a cross-section of countries? One important reason to continue to do so is to make the results of one's work comparable to the existing literature. Eberhardt and Teal (2011) offer a similar justification: "We confine the discussion to the Cobb-Douglas form as this allows us to show the importance of the econometric issues we highlight in the context of the most influential results in the empirical literature" (p. 144).

The development of Equation (1) into a form that may be estimated follows Mankiw, Romer, and Weil (1992) and is not described in detail here. However, interested readers may refer to the Appendix. Equation (4) is the typical form in which a Solow model is estimated:

$$ln\left[\frac{Y_t}{L_t}\right] = ln\, A_0 + gt + \frac{\alpha}{1-\alpha} ln\, s - \frac{\alpha}{1-\alpha} ln(n + g + \delta). \tag{4}$$

Mankiw, Romer, and Weil (1992) show that A_0 may be specified as:

$$lnA_0 = a + \varepsilon, \tag{5}$$

where a is a constant and ε is a country specific shock.

As in Mankiw, Romer, and Weil (1992) we shall measure s as the share of investment in real GDP. The term n which is sometimes taken to be rate of growth of working age population (Mankiw, Romer, and Weil 1992; Arnold, Bassanini, and Scarpetta 2011) has been assumed to be the rate of growth of population in view of the difficulty of getting data on working age population for all the countries considered in this paper. Since the data used in our exercises (see below for details) are measured at intervals of five years, the rate of growth of population in each time period is the average computed for the current and previous four years. As far as $(n + g + \delta)$ is concerned, Arnold, Bassanini, and Scarpetta (2011) state that g and δ are not observable while Mankiw, Romer, and Weil (1992) assume $(g + \delta)$ to be equal to 0.05. We carry forward this assumption in one part of our exercises.

Equation (4) after substituting for $\ln A_0$ may be re-written as a growth-initial income level regression (Bond, Leblebicioglu, and Schiantarelli 2010) as in Equation (6). We write this equation using notation appropriate for panel data.

$$ln\, y_{it} = (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln\, s_{it} - (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln(n_{it} + g + \delta) + e^{-\lambda\tau} ln\, y_{i,t-1} + (1 - e^{-\lambda\tau})\, ln\, A_0 + g[t - e^{-\lambda\tau}(t-1)], \tag{6}$$

where:

y_{it} = real *per capita* GDP in country i in period t;
s_{it} = ratio of investment to GDP in country i in period t;
n_{it} = average rate of growth of population in country i in period t;
g = rate of growth of TFP assumed to be uniform across countries and across time;
δ = rate of depreciation assumed to be uniform across countries and across time;
λ = rate of convergence;
τ = the time interval between the observations.

Equation (6) can be extended to include human capital as in Mankiw, Romer, and Weil (1992) and Michael S. Delgado, Daniel J. Henderson, and Christopher F. Parmeter (2014). Equation (6) then becomes:

$$ln\, y_{it} = (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln\, s_{it} - (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln(n_{it} + g + \delta) + +(1 - e^{-\lambda\tau})\frac{\phi}{1-\alpha} ln\, h + e^{-\lambda\tau} ln\, y_{i,t-1} + (1 - e^{-\lambda\tau})\, ln\, A_0 + g[t - e^{-\lambda\tau}(t-1)], \tag{7}$$

where φ is the exponent of the human capital variable in the extended Solow equation. Hence, it is the elasticity of *per capita* output with respect to human capital.

We measure human capital h, in terms of average schooling years in the total population over age 25 (Arnold, Bassanini, and Scarpetta 2011). It may be noted that human capital, even though it resides in labour, is treated differently from labour. In fact, it is often included as part of total capital stock of a country (Mankiw, Romer, and Weil 1992, p. 415). We source our data on human capital from Barro and Jong Wha Lee (2013). This variable is measured in three different ways:

(a) School = average number of years of total schooling in population aged 25 years and above;
(b) Primary = average number of years of primary schooling in population aged 25 years and above;
(c) Secondary = average number of years of secondary schooling in population aged 25 years and above;
(d) Tertiary = average number of years of tertiary schooling in population aged 25 years and above.

A crucial assumption in the derivation of the growth-initial income level equation is the uniformity of g (i.e. rate of growth of TFP) across countries (Bhaskara B. Rao 2010). Reference was made earlier to Hsieh and Klenow (2010) regarding the diversity of growth rates of TFP across countries. This has been criticised earlier by Gundlach (2007), McQuinn and Whelan (2007) and by Solow (2007) himself. Discomfort with ignoring growth in TFP or assuming it to be constant has been growing in the literature. Solow (2007) states: "Nearly everyone takes it for granted that the *rate of growth* of TFP is the same everywhere. The only thing that justifies this remarkable presumption is the fairly mechanical thought that knowledge of new technology diffuses rapidly around the world. Maybe so, but productivity performance depends on many other influences besides the content of the latest engineering textbook (which may well be available instantaneously to all countries of the world)" (p. 10). Clearly, many factors are at work, which determine how each country makes use of the "latest engineering book", among which could be included the level of competition, the enthusiasm with which a country adopts new technology and the institutional structure (Solow 2007). Human capital could well be an important element determining the adoption of new technology, but this is included separately in most growth equations. Gundlach (2007) notes that differences in technology cannot be directly observed and recent contributions to the literature suggest the use of proxy measures to account for cross-country differences in technology. In this context, the role of culture, institutions and geography has been invoked (Antonio Ciccone and Marek Jarocinski 2010; Guido Tabellini 2010; Chih Ming Tan 2010).

We follow Gundlach (2007) in our effort to bring technological differences into the equation. Thus, we modify A_t, introduced in Equation (1) and described in Equation (2), to be made up of two parts: one part can be assumed to grow at the same constant rate as assumed in Mankiw, Romer, and Weil (1992) while a second part grows at different rates for different countries:

$$A_i(t) = A(0)e^{gt}e^{\varphi PATENTINDEX_{it}}, \tag{8}$$

where ϕ is the coefficient that shows the percentage change in y_{it} for a unit change in the *PATENTINDEX* as specified in Equation (9); $PATENTINDEX_{it}$ = index of patent protection as developed by Walter G. Park (2008) and discussed in Yee Kyoung Kim et al. (2012)[1]. The values of the index range from 0 (absence of patent system) to 5 (strongest level of patent rights protection).

The use of patent statistics to measure TFP is now quite common. Numerous studies have sprung up which have used data on patents to measure rate of TFP progress (see Keun Lee and Byung-Yeon Kim 2009 and Petra Moser 2013).

However, the impact of patent protection on growth of TFP is not unambiguous. The general argument is that protection to intellectual property rights (IPR) encourages innovation which results in TFP progress leading to economic growth (Albert G. Z. Hu and I. P. L. Png (2013) but see Michele Boldrin and David K. Levine (2013) for a contrary position. Less developed countries may be more concerned with adaptation, imitation and incremental innovation which, though not patentable, might yield such countries considerable adaptation benefit (Kim et al. 2012).

Incorporating Equation (8) into Equation (7) yields:

$$\begin{aligned} ln\, y_{it} = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln\, s_{it} - (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln(n_{it}+g+\delta) + \\ (1-e^{-\lambda\tau})\frac{\phi}{1-\alpha} ln\, h + e^{-\lambda\tau} ln\, y_{i,t-1} + (1-e^{-\lambda\tau})\, ln\, A_0 + g \\ \left[t - e^{-\lambda\tau}(t-1)\right] + \varphi PATENTINDEX_{it}. \end{aligned} \tag{9}$$

It may be noted that in one of the exercises discussed below, we have also used the one-period lagged value of *PATENTINDEX*[2].

The data used in our econometric exercises stretch from 1995 to 2010 for a set of 89 countries and is sourced from Alan Heston, Robert Summers, and Bettina Aten (2011). We use data that are spaced at intervals of 5 years. Our data are ordered in a manner similar to Islam (1995). Thus, the data which are in levels pertain to the relevant years while growth rates and investment rate are averages for previous 5 years. The set of 89 countries in our sample consists of 25 countries which belong to the high income group, 20 belong to middle income group and 28 belong to low income group. In addition, there is a group that consists of countries that have changed their income groups during the time period under consideration. There are 16 such countries. Our classification of countries into income groups is based on World Bank (2011)[3] and is designed to examine the impact of varying rates of technical change on countries at differing levels of income. Table 1 provides summary statistics for the variables used in the paper.

While grouping countries according to their levels of income, the possibility that countries will migrate across income groups over the time period considered in this paper must be allowed for. While such a change of income groups is interesting to study (and this paper does, in fact, study such countries), the income groups considered here have remained stable over the time period of the analysis. It has been ensured

[1] I would like to thank Walter Park for sharing the data on patent protection.
[2] I would like to thank an anonymous referee for this suggestion.
[3] List of countries and basic statistics related to the data used in this study available on request.

Table 1 Summary of Basic Statistics

Variables	Groups	1995	2010
POP: population (million)	ALL	5,214,292	7,597,770
	HIC	855,091	696,727
	MIC	609,182	392,445
	LIC	832,272	3,711,921
	CHNG	2,917,748	2,796,677
n_{it}: population growth rate (% per annum)	ALL	1.35	1.13
	HIC	0.77	0.52
	MIC	1.54	1.25
	LIC	1.94	1.90
	CHNG	1.10	0.73
CP: government spending/GDP (%)	ALL	9.06	8.79
	HIC	7.29	6.72
	MIC	7.22	7.33
	LIC	11.58	11.30
	CHNG	9.35	9.11
Average growth rate (% per annum)	ALL	1.26	2.20
	HIC	1.58	0.61
	MIC	2.39	2.55
	LIC	-0.73	2.84
	CHNG	2.53	2.90
s_{it}: investment/GDP (%)	ALL	21.29	24.01
	HIC	23.64	24.99
	MIC	23.74	23.10
	LIC	15.72	22.75
	CHNG	23.79	25.27
INDEX: index of economic freedom	ALL	6.3328	6.7701
	HIC	7.5854	7.6114
	MIC	6.1091	6.4378
	LIC	5.1679	5.9959
	CHNG	6.2473	6.8519
POLITY2	ALL	4.6628	5.6047
	HIC	9.3333	9.2857
	MIC	3.1176	3.5882
	LIC	0.3333	2.7407
	CHNG	6.8095	7.2381
Patent index	ALL	2.7584	3.4975
	HIC	4.1300	4.4063
	MIC	2.0265	3.3188
	LIC	2.0815	2.7478
	CHNG	2.6538	3.5676
Total schooling (years)	ALL	6.35	7.69
	HIC	9.74	10.87
	MIC	5.53	7.17
	LIC	3.31	4.52
	CHNG	6.61	8.11
Primary schooling (years)	ALL	4.04	4.62
	HIC	5.47	5.59
	MIC	3.70	4.62
	LIC	2.45	3.23
	CHNG	4.51	5.09
Secondary schooling (years)	ALL	1.98	2.65
	HIC	3.64	4.46
	MIC	1.52	2.17
	LIC	0.80	1.20
	CHNG	1.81	2.61
Tertiary schooling (years)	ALL	0.32	0.43
	HIC	0.63	0.83
	MIC	0.31	0.37
	LIC	0.06	0.08
	CHNG	0.29	0.41
Government size index	ALL	5.93	6.48
	HIC	4.92	5.84
	MIC	6.93	6.77
	LIC	6.08	6.55
	CHNG	6.12	6.90

*Regulation of labour index**	ALL	-	-
	HIC	5.34	6.53
	MIC	-	-
	LIC	-	-
	CHNG	-	-

Notes: * data are available for most HIC but very little data are available for other countries.

Source: Author's calculations.

that each selected country in the high, middle and low income groups remains in its income category over the entire length of the time period under consideration. It must, of course, be remembered that having countries remain within their sub-group does not freeze the growth process; countries in each sub-group will be experiencing growth - even negative growth in some cases - over the period of our analysis. It would be obvious to anyone interested in growth economics that if we had restricted ourselves only to stable groups we would have left out of consideration important growth experiences, such as those of Republic of Korea and China. Hence, we have created a separate group of 16 countries which have experienced a transition from one income group to another during the time period of our analysis.

A variety of estimation techniques is available for estimating the specified models. If the models being considered were static i.e. without the lagged dependent variable on the right hand side, fixed effects (FE) models could be readily used. However, when the models are dynamic, the FE approach has deficiencies which make it inappropriate to use. Qing Zhou, Robert Faff, and Karen Alpert (2014) point out that using FE models produce biased results. Since the models that we use do include a lagged dependent variable and the time dimension of our dataset is small, FE models seem inappropriate to use. Generalised method of moments (GMM) estimation techniques provide a way out in such situations and we shall be using the Manuel Arellano and Bond (1991) single-step estimation technique. Bond (2002) suggests that the efficiency gain from employing a two-step GMM estimator is marginal and this has persuaded us to use the Arellano and Bond (1991) single-step estimation technique (see Siddiqui and Ahmed 2013 for a similar justification). GMM estimation techniques are designed for short and wide panels i.e. few time periods and large number of groups. According to David Roodman (2009), as the number of time period increases there is a tendency towards instrument proliferation. As a result of being too numerous, instruments can overfit the endogenous variable. Consequently, the Sargan tests that are typically reported with GMM estimation tend to have low *p*-values leading to a rejection of the null hypotheses leading to a conclusion of overfitting. To safeguard against this problem, for the purpose of estimating GMM models, we have confined our data set to only 1995-2010 even though we have data available for a much longer time period. In what follows, we report results of estimating growth equations for: (i) the group of all 89 countries; (ii) the group of high income countries; (iii) the group of middle income countries; (iv) the group of low income countries and (v) the group of countries which moved from one income group to another during the period of our analysis.

3. Empirical Results: All Countries (ALL)

We estimate the growth equations under two scenarios. In the first, the rate of growth of population varies across countries and over time, but the rate of change of TFP is uniform across all countries. This corresponds to Equation (5). Remaining within this scenario, we extend Equation (5) to include a human capital variable. This corresponds to Equation (6). In the second scenario, not only does the rate of growth of population vary, but the rate of change of TFP also varies across countries. This is captured by introducing the index of patent protection (*PATENTINDEX*) into the equation. This corresponds to Equation (8).

Table 2 gives the results of estimating the growth equations for this group. Before we discuss the results of Table 2, a word of explanation of the tests reported is in order. The Sargan test of overidentifying restrictions is a test of the othogonality condition that the instruments are independent of the error process. A rejection of the null hypothesis implies that the instruments do not satisfy the orthogonality conditions required for their use. The Sargan test excluding group is the difference-in-Sargan test which checks for the exogeneity of a subset of instruments. The Arellano-Bond test for autocorrelation has a null hypothesis of no autocorrelation and is applied to the differenced residuals. The test for AR(1) process in first differences usually rejects the null hypothesis. The more important test is the one for AR(2) in first differences because it will detect autocorrelation in levels. We report AR(2) in our tables below.

Equation (4.1) deals with the situation where the rate of change of TFP is assumed to be uniform and constant across all countries and across all time periods. The closest comparison to the group in equation (4.1) is the group of non-oil producing countries in Mankiw, Romer, and Weil (1992) for which the rate of convergence was found to be 0.0048. Equation (4) reports a higher value of λ, the rate of convergence, at 0.0165 (1.65%). As far as the regressors are concerned, investment ($\ln s_{it}$) contributes positively to growth but population growth (as seen in the coefficient of $\ln(n_{it} + \delta + g)$ is seen to be not significant.

In Equation (4.2) we introduce the human capital variable. This variable is seen to be positive but not significant at conventional levels of significance. The investment variable continues to remain positive and significant while the population variable is not significant. However, the introduction of human capital brings about a significant change in the speed of convergence which is now 0.0226 (2.26%).

Finally, Equation (4.3) introduces differential TFP change using the variable *PATENTINDEX*. This variable is seen to be significant at a p-value of only 8% or 0.08, suggesting that it may not be a significantly important ingredient in the growth process. However, with the introduction of this variable, the human capital variable ceases to be significant while the investment variable continues to be significant. It is important to note that, despite the relative non-significance of the TFP variable, the speed of convergence, jumps to 0.0403. The speed of convergence that we have obtained in Equation (4.3) may seem high in comparison to the so-called Barro's "iron law" of convergence which expects the rate to be around 2% or 0.02 (Barro 2015). It needs to be borne in mind that there is nothing sacrosanct about the "iron law". For example, Thomas Andersen and Carl-Johan Dalgaard (2013), for African countries, estimate convergence rates at much below 2% while Ken Sagynbekov (2014), for six countries in the middle-east, obtains convergence rates much greater than 2%. Steven N. Durlauf, Paul A. Johnson, and Jonathan R. W. Temple (2005) state that this assumed uniformity of the rate of convergence (as in Barro's "iron law") implies a uniformity of preferences, technology and endowments, which is, of course, very unrealistic.

Table 2 Estimating Growth Equations: All Countries

Variables	Equation (4.1)	Equation (4.2)	Equation (4.3)
$\ln(y_{i,\, t-1})$	0.9207 (0.00)	0.8933 (0.00)	0.8171 (0.00)
$\ln(s_{it})$	0.4278 (0.00)	0.4128 (0.00)	0.3951 (0.00)
$\ln(n_{it} + \delta + g)$	0.1270 (0.56)	0.2070 (0.32)	0.1971 (0.32)
$\ln(h_{it})$	-	0.0677 (0.21) @	-0.0349 (0.66) @
PATENTINDEX	-	-	0.0475 (0.08)
Time period	1995-2010	1995-2010	1995-2010
No. of observations	320	316	314
No. of groups*	80	79	79
No. of instruments	12	16	16
F-test (3, 17)	243.92 (0.00)	194.31 (0.00)	167.13 (0.00)
Instruments used for GMM estimation	*POLITY2*, *INDEX*, *CG*, *POP*	*POLITY2*, *INDEX*, *CG*, *POP*	*POLITY2*, *INDEX*, *CG*, *POP*
Sargan test of overidentifying restrictions	12.18 (0.20)	13.15 (0.36)	10.17 (0.52)
Sargan test excluding group	7.57 (0.11)	6.36 (0.17)	5.39 (0.25)
Allerano-Bond test for AR(2)	0.64 (0.53)	0.93 (0.35)	0.71 (0.48)
Speed of convergence	0.0165	0.0226	0.0403

Notes: * some countries from the dataset of 89 are dropped due to data not being available. @ *h* (human capital) refers to average years of total schooling. Instruments used: *POLITY2* is a measure of freedom ranging from -10 (least free) to +10 (most free) (Monty G. Marshall, Ted R. Gurr, and Keith Jaggers 2014). *INDEX* is economic freedom index ranging from 0 (least free) to 10 (most free) (James Gwartney, Robert Lawson, and Joshua Hall 2013). *CG* is ratio of government spending to GDP. *POP* is total population of the country. Figures in brackets are *p*-values.

Source: Author's calculations.

The instruments that I have used for the GMM estimation have been employed in other studies as well. Suffice it to note that the instruments used have the quality that they will be correlated with the endogenous variables but not with the error process. For all the three equations, the two Sargan tests provide validation of the choice of instruments used for estimation. Further, the autocorrelation test does not indicate any problem.

The results obtained in Table 2 regarding the difference in the rates of convergence under uniform and varying rate of change of TFP (as proxied by *PATENTINDEX*) throws up a curious result. It would have been expected that the assumption of uniform TFP change would imply that knowledge about improvement in technology would be available to all countries without exclusion - a kind of a public good - and this would raise productivity in all countries. This, in turn, would elevate the rate of convergence to steady state income more rapidly for all countries. What we have found, however, is that where TFP change is not uniform, that is, knowledge about TFP does not spread in a uniform manner across countries, the rate of convergence for the group as a whole rises. Of course, the single number that has been for the rate of convergence hides the variability that might exist among the countries in the group. It is quite possible that countries at differing levels of economic development might show different responses when the rate of change of TFP is assumed to be varying. I turn to such an exercise now.

4. Empirical Results: High Income Countries (HIC)

In this section, the exercises of the previous one are repeated but attention is restricted only to countries in the high income group. The number of countries in this group is 25 and, as stated above, all these countries have remained in the HIC group for the duration of our analysis. Table 3 reports our results.

Table 3 Estimating Growth Equations: High Income Countries

Variables	Equation (5.1)	Equation (5.2)	Equation (5.3)
$\ln(y_{i,t-1})$	0.7924 (0.00)	0.7002 (0.00)	0.5496 (0.00)
$\ln(s_{it})$	0.0834 (0.68)	-0.0196 (0.91)	0.0128 (0.94)
$\ln(n_{it} + \delta + g)$	1.3903 (0.08)	1.5712 (0.02)	1.5656 (0.02)
$\ln(h_{it})$	-	0.8947 (0.08) @	1.0770 (0.06) @
PATENTINDEX	-	-	0.0591 (0.04)
Time period	1995-2010	1995-2010	1995-2010
No. of observations	84	84	92
No. of groups	21	21	23
No. of instruments	10	14	16
F-test (5, 79)	79.93 (0.00)	64.80 (0.00)	69.33 (0.00)
Instruments used for GMM estimation	*POLITY2*, *LINDEX*	*POLITY2*, *LINDEX*	*PATENTINDEX*, *CG*, *GOVSIZE*, *REGLABOR*
Sargan test of overidentifying restrictions	2.21 (0.82)	7.60 (0.47)	13.93 (0.18)
Sargan test excluding group	0.03 (0.98)	1.10 (0.58)	7.63 (0.11)
Allerano-Bond test for AR(2)	0.49 (0.62)	1.04 (0.30)	1.08 (0.28)
Speed of convergence	0.0465	0.0713	0.1197

Notes: Please see Table 2. @ *h* (human capital) refers to average years of primary schooling. Instruments used: *POLITY2*, *LINDEX* (log of *INDEX*), *CG*: please see Table 2. *GOVSIZE* is index measuring size of government (Gwartney, Lawson, and Hall 2013). A lower value for the index represents larger government size. *REGLABOR* is an index covering labour hiring regulations, hiring and firing regulations, etc. (Gwartney, Lawson, and Hall 2013). A higher value indicates less rigid regulations related to labour.

Source: Author's calculations.

Equation (5.1) in Table 3 shows that the role of investment ($\ln s_{it}$) in the growth process of HIC is not very important with the coefficient not being significant. The coefficient of the rate of growth population $\ln(n_{it} + \delta + g)$ is, contrary to expectation, positive though significant only at 8% level. In general, the equation shows results contrary to what is expected from a Solow model. The speed of convergence is, however, much higher for this group at 0.0465. Adding in the human capital variable, while keeping the rate of change of TFP uniform, results in the population variable becoming strongly significant at the 2% level. The rate of convergence becomes even more rapid at 0.0713. Finally, I introduce TFP variable (*PATENTINDEX*). The impact of the human capital variable becomes stronger in the presence of varying rate of change of TFP while *PATENTINDEX* itself is significant at the 4% level. The importance of patent protection in spurring TFP leading to a positive impact on growth is clearly seen. The speed of convergence increases substantially to 0.1197. Once again, it is worth pointing out that the convergence rates I have obtained clearly exceed those obtained by Barro (2015). When I introduce patent protection as a proxy for TFP into the equation there is a significant impact on growth and raises the rate of convergence to steady state incomes substantially. This result is in broad agreement with Kim et al. (2012) that high income countries are able to take better advantage of stronger patent protection. It may be noted that the average of *PATENTINDEX* for HIC for the year 2010 was 4.41 as compared 2.75 for low income countries, 3.32 for middle income countries and 3.57 for countries which had changed their income category. With the help of these strong patent regimes, richer countries are able to restrict availability of new knowledge about TFP change to other countries. With the temporary monopoly that these patents confer, high income countries are able to encourage much faster TFP. The benefit of this in the form of higher productivity is able to enhance growth in these countries leading to a much faster convergence to steady state incomes.

5. Empirical Results: Middle Income Countries (MIC)

This section focuses on middle income countries of which there are 20 in the group. Table 4 reports the estimated equations for this group.

In Equation (6.1) of Table 4, the role of investment ($\ln s_{it}$) in the growth process is seen to be very important with the coefficient being positive and significant. The coefficient of the rate of growth population $\ln(n_{it} + \delta + g)$ is negative though significant only at 7%. In general, even though the population variable is not significant, the equation shows results in keeping with what is expected of a Solow model. The speed of convergence is seen to be 0.0392. The introduction of the human capital variable in Equation (6.2) improves the rate of convergence to 0.0584, though the variable itself is not significant. The introduction of the TFP variable (*PATENTINDEX*) in Equation (6.3) brings about a sudden slowing down of the rate of convergence to 0.0204. As far as the individual variables are concerned, the investment variable remains positive but is now significant only at 6% level. The population variable and the human capital variable are seen to be non-significant. However, unlike in the case of HIC, the coefficient of *PATENTINDEX* is negative and not significant. This shows that offering patent protection does not have a positive impact on growth. In fact, the adverse effect of patent protection is clearly visible in the speed of convergence which has reduced

Table 4 Estimating Growth Equations: Middle Income Countries

Variables	Equation (6.1)	Equation (6.2)	Equation (6.3)
$\ln(y_{i,\,t-1})$	0.8222 (0.00)	0.7468 (0.00)	0.9030 (0.00)
$\ln(s_{it})$	0.4112 (0.00)	0.2298 (0.07)	0.3042 (0.06)
$\ln(n_{it} + \delta + g)$	-1.0898 (0.07)	-0.5552 (0.41)	-1.2289 (0.33)
$\ln(h_{it})$	-	0.1601 (0.30)	-0.0130 (0.96)
PATENTINDEX	-	-	-0.0172 (0.75)
Time period	1995-2010	1995-2010	1995-2010
No. of observations	68	68	68
No. of groups	17	17	17
No. of instruments	10	14	14
F-test (4, 64)	48.89 (0.00)	46.79 (0.00)	29.07
Instruments used for GMM estimation	*POLITY2, LINDEX*	*POLITY2, POP*	*POLITY2, LINDEX*
Sargan test of overidentifying restrictions	4.14 (0.66)	15.41 (0.08)	11.23 (0.19)
Sargan test excluding group	0.76 (0.69)	1.71 (0.43)	0.97 (0.62)
Allerano-Bond test for AR(2)	-0.37 (0.71)	-0.22) (0.82)	-0.32 (0.75)
Speed of convergence	0.0392	0.0584	0.0204

Notes: Please note to Table 2. @ *h* (human capital) refers to average years of primary schooling.

Source: Author's calculations.

by more than half as compared to Equation (6.2). Our results are in line with those of Rod Falvey, Neil Foster, and David Greenaway (2006) who state that patent protection by strengthening intellectual property rights (IPR) protection may not benefit MIC since these countries engage in imitative technological development which is prevented by strong IPR protection. In the absence of a strong patent regime, the public goods property of technological knowledge comes to the fore. Middle income countries are able to free-ride on the TFP change in high income countries but this externality is severely restricted with strong patent laws and all the benefits of TFP progress are internalised by HIC with very little spillovers to MIC.

6. Empirical Results: Low Income Countries (LIC)

The next group to be considered is that of low income countries of which there are 28. Table 5 reports the estimated equations for this group.

The Solow equations for LIC are seen to be similar to those of MIC in that the investment variable is positive and significant and the population variable is not significant. The speed of convergence in Equation (7.1) is extremely slow at just 0.0021. Equation (7.2) introduces the human capital variable into the model. The population variable is positive but still not significant at conventional levels of significance though the *p*-value is down to 0.10. The investment variable remains positive and significant. The human capital variable is seen to be significant only at 8% indicating some contribution of the variable to the growth process. However, the speed of convergence rises to 0.0159. The TFP variable is introduced in Equation (7.3) and is seen to be positive (unlike in the case of MIC but similar to the results obtained for HIC) but is not significant. Nonetheless, the speed of convergence improves substantially to 0.0232. This shows that the effect of varying TFP change for LIC is quite different from the effect seen for MIC. It is noteworthy that our result in this regard runs counter

Table 5 Estimating Growth Equations: Low Income Countries

Variables	Equation (7.1)	Equation (7.2)	Equation (7.3)
$\ln(y_{i,t-1})$	0.9893 (0.00)	0.9234 (0.00)	0.8901 (0.00)
$\ln(s_{it})$	0.3501 (0.00)	0.2669 (0.00)	0.2653 (0.00)
$\ln(n_{it}+\delta+g)$	0.2339 (0.39)	0.4524 (0.09)	0.4230 (0.14)
$\ln(h_{it})$	-	0.1257 (0.08) @	0.0770 (0.62) @
PATENTINDEX	-	-	0.0313 (0.73)
Time period	1995-2010	1995-2010	1995-2010
No. of observations	84	80	80
No. of groups	21	20	20
No. of instruments	10	14	14
F-test (3, 81)	18.98 (0.00)	18.99 (0.00)	15.60 (0.00)
Instruments used for GMM estimation	*POLITY2*, *LINDEX*	*POLITY2*, *LINDEX*	*POLITY2*, *LINDEX*
Sargan test of overidentifying restrictions	4.03 (0.78)	4.97 (0.89)	5.04 (0.83)
Sargan test excluding group	0.57 (0.75)	0.44 (0.80)	0.47 (0.79)
Allerano-Bond test for AR(2)	0.43 (0.67)	0.86 (0.39)	0.81 (0.42)
Speed of convergence	0.0021	0.0159	0.0232

Notes: Please notes to Tables 2 and 3. @ *h* (human capital) refers to average years of secondary and tertiary schooling.

Source: Author's calculations.

to the result reported by Kim et al. (2012). However, one feature common to MIC and LIC is the importance of investment in the growth process. It is seen clearly that the contribution of investment is the most important among the variables included in the equation.

7. Empirical Results: Countries which Changed Income Groups (CIC)

The final estimation exercise deals with countries which changed their income group over the time period of our analysis. There are 16 such countries in the dataset. The estimated growth equations are given in Table 6.

Equation (8.1) with the investment and population variable show that the investment variable is strongly significant though the other variable is not. What is note worthy is the importance of investment in the growth process of this group of countries. This coefficient is the largest among all the groups reported so far. Clearly, growth in these countries is driven by investments. As one would expect of countries which have jumped to higher income groups over the period of our analysis, the rate of convergence is high at 0.0400. Importance of education is clearly seen in Equation (8.2) with the human capital variable being highly significant leading to a sharp rise in the rate of convergence to 0.0727. Introduction of TFP is different for this group as compared to all the others discussed so far. For this group, one-period lagged value of *PATENTINDEX* was found to be significant, which was not the case for groups discussed so far. Introduction of varying TFP change as captured by $PATENTINDEX_t$ and $PATENTINDEX_{t-1}$ in Equation (8.3) brings about a change: the human capital variable, investment variable and the population variable cease to be significant. While $PATENTINDEX_t$ is not significant, one-period lagged *PATENTINDEX* is found to be significant. Some explanation for this is in order. One clear possibility is that the ben-

Table 6 Estimating Growth Equations: Countries which Changed Income Groups

Variables	Equation (8.1)	Equation (8.2)	Equation (8.3)
$\ln(y_{i,t-1})$	0.8188 (0.00)	0.6951 (0.00)	0.4298 (0.03)
$\ln(s_{it})$	0.6767 (0.00)	0.3952 (0.03)	0.2844 (0.21)
$\ln(n_{it} + \delta + g)$	-0.5442 (0.59)	0.4973 (0.48)	1.1195 (0.19)
$\ln(h_{it})$	-	0.3124 (0.01) @	0.2143 (0.32) @
$PATENTINDEX_t$	-	-	-0.0063 (0.92)
$PATENTINDEX_{t-1}$	-	-	0.1453 (0.02)
Time period	1995-2010	1995-2010	1995-2010
No. of observations	84	84	80
No. of groups	21	21	21
No. of instruments	11	15	15
F-test (3, 81)	148.51 (0.00)	121.68 (0.00)	68.56 (0.00)#
Instruments used for GMM estimation	*POLITY2, CG, POP*	*POLITY2, CG, POP*	*POLITY2, CG, POP*
Sargan test of overidentifying restrictions	12.71 (0.12)	11.55 (0.40)	6.76 (0.66)
Sargan test excluding group	7.70 (0.05)	7.97 (0.05)	1.87 (0.93)
Allerano-Bond test for AR(2)	1.66 (0.10)	1.45 (0.15)	1.26 (0.21)
Speed of convergence	0.0400	0.0727	0.1689

Notes: Please notes to Tables 2 and 3. @ *h* (human capital) refers to average years of secondary and tertiary schooling. Degrees of freedom for *F* are (6, 74).

Source: Author's calculations.

efits of patents take time to benefit the economy which then results in a boost in *per capita* GDP. In this context, it is important to remember that patent protection in this group of countries is not very strong. In 1995, the average value of the patent index in this group was only 2.56 which increased to 3.56 in 2010 (Table 1). In comparison, the average of the patent index in high income countries (HIC) is almost a whole index-point higher in 2010 at 4.41. As consequence, knowledge of technological progress in the country does not remain the exclusive preserve of the patent holders and "leaks" out into the rest of the economy.

8. Conclusion

This paper has sought to extend the debate on growth equations and convergence by making a crucial change in the specification of such equation. This paper has modified the assumption of uniform rate of change of TFP (that is standard in the literature) to allow for varying rate of change of TFP across countries. This was captured by introducing the *PATENTINDEX* variable. I have found that patent protection and the consequent varying rates of TFP change across countries unambiguously benefits only the high income countries while the results for the other countries are mixed. In fact, middle income countries are likely to be adversely affected when varying rates of TFP change are assumed. The crucial question is whether varying rate of change of TFP is the correct assumption to make. Numerous authors (mentioned earlier) have argued against uniformity of TFP change across countries. If this is indeed the case, then the rates of convergence will be higher for the three groups (all countries, high income countries and low income countries) mentioned but not for the other two groups. This has important implications for growth in the MIC and CIC. If the patent regime becomes more exclusionary, knowledge of TFP progress will not become known uniformly across all countries. This is likely to thwart the progress of countries from a lower to a higher income group as seen in the case of MIC. The CIC group shows behaviour that is different from the other groups in that patents have a beneficial effect after a lag. Bearing in mind that the patent regimes in these countries is not as strong in the HIC, there is a possibility that information of technological progress becomes available throughout the economy after a brief lag thereby raising income levels.

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Appendix

Solow Growth Equation

Specifying a growth equation starts with a Cobb-Douglas production function of the following form:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}, 0 < \alpha < 1, \tag{A.1}$$

where, Y is output, K is capital, L is labour and A is the level of technology/TFP. L_t and A_t are assumed to grow exogenously as:

$$L_t = L(0)e^{nt}, \tag{A.2}$$

$$A_t = A(0)e^{gt}. \tag{A.3}$$

Mankiw, Romer, and Weil (1992) define s as a constant share of output that is invested, y as Y/AL, k as K/AL and δ as the rate of depreciation. Invoking the equation of motion of k, the steady-state value of capital stock $k*$ is written as:

$$k^* = \left[\frac{s}{(n+g+\delta)}\right]^{\frac{1}{1-\alpha}}. \tag{A.4}$$

Substituting Equation (A.2) into the production function and taking logs gives:

$$ln\left[\frac{Y_t}{L_t}\right] = ln\, A_0 + gt + \frac{\alpha}{1-\alpha} ln\, s - \frac{\alpha}{1-\alpha} ln(n + g + \delta). \tag{A.5}$$

Mankiw, Romer, and Weil (1992) show that A_0 may be specified as:

$$lnA_0 = a + \varepsilon, \tag{A.6}$$

where a is a constant and ε is a country specific shock.

The term gt in Equation (A.5) consists of g, the rate at which knowledge accumulates - which is assumed to be constant across countries and, for a single cross section, t is constant. Since gt is a constant, it can be dropped from the equation. Hence, Equation (A.5) may be written as a regression equation with an intercept and a disturbance term:

$$ln\left[\frac{Y_t}{L_t}\right] = a + \frac{\alpha}{1-\alpha} ln\, s - \frac{\alpha}{1-\alpha} ln(n + g + \delta) + \varepsilon. \tag{A.7}$$

Equation (A.7) after substituting for lnA_0 may be re-written as a growth-initial income level regression (Bond, Leblebicioglu, and Schiantarelli 2010) as in Equation (A.8). We write this equation using notation appropriate for panel data:

$$\begin{aligned} ln\, y_{it} = (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln\, s_{it} - (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha} ln(n_{it} + g + \delta) + \\ + e^{-\lambda\tau}\, ln\, y_{i,t-1} + (1 - e^{-\lambda\tau})\, ln\, A_0 + g[t - e^{-\lambda\tau}(t-1)]. \end{aligned} \tag{A.8}$$

Definitions of the variables and parameters are given in the text below Equation (6).