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David Mayer-Foulkes

CONVERGENCE CLUBS IN CROSS-COUNTRY LIFE EXPECTANCY DYNAMICS

Abstract

I model life expectancy in terms of physical and human capital and technology, the fundamental economic variables described by economic growth theories. For concreteness, the Solow model and a convergence club growth model by Howitt and Mayer (2001) are used as examples. I discuss how a multiple convergence club structure can be used to define states of development and show that it must be reflected in the life expectancy dynamics. I then show by visual examination and by using mis-specification tests on levels and on convergence properties that the empirical cross-country distribution of life expectancy for the period 1960-1997 is best described using a convergence club structure. This gives strong empirical evidence that only growth theories involving convergence clubs can explain the process of development.

Resumen

Se modela la esperanza de vida como función del capital físico y humano y de la tecnología, las variables económicas fundamentales descritas por la teoría de crecimiento económico. Como ejemplos concretos se toman, el modelo de crecimiento de Solow y un modelo de clubes de convergencia de Howitt y Mayer (2001). Se discute cómo la estructura de clubes de convergencia puede utilizarse para definir estados de desarrollo y se muestra que la misma debe de reflejarse en la dinámica de la esperanza de vida. Se muestra por medio del examen visual de histogramas, y utilizando pruebas de especificación sobre sus niveles y sus propiedades de convergencia, que la distribución empírica de la esperanza de vida durante el periodo 1962-1997 se describe mejor como un proceso con clubes de convergencia que como un proceso homogéneo. Esto proporciona evidencia empírica fuerte de que solamente las teorías técnicas de crecimiento que involucren clubes de convergencia pueden explicar adecuadamente el proceso de desarrollo.

Introduction

Can 'development' and 'underdevelopment' be defined as specific economic states? Is it possible that whole sets of countries find themselves in particular types of dynamic equilibria that determine the type and extent of their growth? This is the kind of question that was addressed when development theory originated. However, the difficulties faced by development policy in practice led to the current focus on poverty and on 'sound' macroeconomics, trade and investment policies. Although it is hoped that these policies will lead to growth and lift billions out of misery, they are not really based on a theory of development, but on general recommendations dealing with poverty and growth that in principle apply to any country.

The basic reason for this uniformity of policy is that neoclassical growth theory, on which most current policy recommendations are based, tends to consider growth to be a uniform process, leading of its own towards the convergence of income levels, particularly if policies allowing the markets to function are applied.

Recent empirical work, however, questions the neoclassical theory by stressing role that productivity differences play in explaining income differentials level between countries (Klenow and Rodriguez-Clare,1997; Hall and Jones, 1999). Howitt and Aghion (1998) develop a theory of growth that goes beyond Solow in that it gives an endogenous account of technological change. Howitt (2000) develops a multi-country model that accounts for the endogenous nature of technological change. Howitt and Mayer (2001)[1] extend this model to explain the divergence in per-capita income that took place between countries during the 20th Century (documented by Pritchett, 1997), as well as the convergence that took place between the richest countries during the second half of the century. Their model implies the existence of three convergence clubs. Those in the highest club will converge to an R&D steady state, while those in the intermediate club will converge to an implementation steady state. Countries in both of these clubs will grow at the same rate in the long run, as a result of technology transfer, but inequality of per-capita income between the two clubs will increase during the transition to the steady state. Countries in the lowest club will stagnate, with relative incomes that fall asymptotically to zero. Once R&D has been introduced, a country may have only a finite window of opportunity in which to introduce the institutions that support R&D, after which it will remain trapped in an implementation or stagnation equilibrium. The model implies that a series of factors known to slow growth, such as ineffective property rights, excessive taxes, weak financial and monetary institutions, corruption and lack of public services (Easterly, 2001), can determine a countries continued permanence in a stagnation or implementation steady state.

Broadly speaking, this and other growth models with multiple steady states – and therefore convergence clubs – present a paradigm allowing for the definition of *states of development.* In the Howitt and Mayer (2001) model developed countries are those carrying out R&D, and there are two kinds of underdeveloped countries: those implementing current technological advances and those in stagnation. Finer subdivisions are possible with models incorporating other relevant economic phenomena such as trade, or other sources of multiple steady states, for instance in human capital dynamics (Azariadis and Drazen, 1990; Benabou, 1996; Durlauf, 1993, 1996; Galor and Zeira, 1993; Galor and Tsiddon, 1997; Tsiddon, 1992). In the language of dynamics, countries can be defined to be in a specific state of development if their growth dynamics lie in the basin of attraction of a specific configuration of economic of growth. Conversely, empirical evidence that growth dynamics posses convergence clubs implies that growth is occurring though a process involving multiple steady states. A fuller knowledge of the underlying economics can lead to policies specifically aimed at dissolving technological and other traps and therefore at *changing states of development.*

A budding literature exists on convergence clubs. In cross-country studies of income distribution dynamics, Quah (1996, 1997) finds little convergence. Instead, he finds persistence, immobility, polarization and an emerging twin-peaked income distribution since the 1980's. Here, we find twin peaks in the life expectancy distribution since 1962, implying that a preexisting convergence club structure may be the antecedent of the later divergence in incomes found by Quah. Desdoigts (1999) finds cross-country evidence for a non-linear association of higher stages of development with higher stages of growth. Engelbrecht and Kelsen (1999) find that the APEC countries have distinct convergence properties from the OECD and European Union groups of economies. Andrés and Bosca (2000) find evidence for convergence clubs within the OECD. There are also some country specific studies showing, for instance that Ireland (O'Rourke and Grada, 1994) and New Zealand (Greasley and Oxley, 2000) do not grow as well as groups of countries thought to be their natural convergence partners.

Convergence clubs may be at the root of the evolution of income inequality, because most income inequality is between countries and thus depends on relative growth (Quah, 2001), and growth in turn tends to increase incomes within country proportionally (Dollar and Kraay, 2001a, 2001b).

Establishing the existence of convergence clubs empirically may thus play a crucial role in understanding the problems and setting out the appropriate policies for development. The purpose of this paper is to address this issue using of the cross-country pattern of changes in life expectancy during the period 1962-1997. I first show that life expectancy dynamics can be modeled using the theories of economic growth, and that they must reflect the convergence club structure of any underlying theory. Then I show that the data supports the existence of at least three large-scale convergence clubs. The first has very low levels of life expectancy to this day and thus roughly corresponds to the concept of stagnating countries. The second had very low levels of life expectancy in 1962, which nevertheless rose quickly and thus consists of countries implementing basic technologies for the population as a whole. The third consists of countries that already had relatively high life expectancies in 1962. This includes the developed and a top layer of underdeveloped countries that still invites further subdivision into an the R&D and a second implementation club at a higher technological level.

Life expectancy is one of the best widely available indicators of population welfare. In fact, its five-yearly data is more complete than that of either income or education. Life expectancy results from the general availability of private and public goods and services covering basic needs and providing the technological inputs and social organization for health. Since freedom from disease and premature death are amongst the main human aims at both the individual and social levels (Sen, 1999), life expectancy attainment is an excellent indicator of population-wide development. Its importance has been recognized by its inclusion in the Human Development Index (also including education and income).

Recent research has found that the links between life expectancy and income are indeed very close. In a cross-country study, Preston (1975) showed that life expectancy is positively correlated with income, with higher levels of life expectancy achieved for equivalent levels of income in later periods. Pritchett and Summers (1996) carefully corroborate by means of instrumental variable techniques that countries with higher incomes enjoy higher health, suggesting, as Anand and Ravallion (1993) find, that the main causal channels of this relationship are the income levels of the poor and public expenditure in health care. There is also a causal relation from health to income. Fogel (1994) finds that increased nutrition and health account for up to a third of the economic growth in Great Britain during the last 200 years. Macroeconomic studies of economic growth such as Barro's (1991) have found life expectancy to be an important predictor of economic growth. In more recent work, Mayer (2001) shows that health indicators are associated with a long-term impact on economic growth in Latin America during the period 1950-1990. Arora (2001) finds cointegration between economic growth and health in 100-125 year time series for seven advanced countries, with growth responding to the changes in health and not vice versa. There has also been intense microeconomic research on the role of health and nutrition investment and returns (Schultz, 1992, 1997, 1999, Thomas, Schoeni and Strauss, 1997; Strauss and Thomas, 1998; Savedoff and Schultz, 2000, amongst many others), although the magnitudes found for the health impacts tend to be smaller than those measured macroeconomically. Height and weight, as indicators of population health, have been established as standard of living indicators that rival aggregate measures of income (e.g. Steckel, 1995). These are well know to be causally interlinked with life expectancy (Fogel, 1994).

Life expectancy is thus an excellent measure of the standard of living. As a measure of population welfare it is probably better than income. It is more sensitive to inequality (the longevity of the rich is less than proportional to their wealth), and its production requires, in addition to capital, a richer mix of public services and technology. In contrast, important proportions of the income of many underdeveloped countries have tended to be associated with a small number of sectors applying a limited spectrum of technologies.[2] Health may thus index the fundamentals of development better than income per capita, explaining why the macroeconomic causal impact of health indicators on income is found to be larger than the corresponding microeconomic relationships.

Based on the close association of health with income and growth, I take the theoretical viewpoint, in the cross-country context, that life expectancy can be modeled in terms of the theories of economic growth. I model health as a function of the main underlying economic variables, namely capital and technology, much like income is. For concreteness I use both the Solow (1957) model and the Howitt and Mayer (2001) endogenous technology convergence club model. Expressed in these models as a function of capital per capita and technology, life expectancy thus provides an indirect measure of the underlying variables. It will follow that when an economy converges to a steady state, life expectancy will tend to a corresponding trajectory, and that if several steady states exist, then several such life expectancy trajectories will exist. In addition, if relative convergence holds among economies tending to the same steady state, life expectancy will inherit the same property. Thus, each of these two theories of growth, as well as any other to which life expectancy could be similarly added, predicts a qualitative property of life expectancy dynamics.

I argue below that the parameters of these models are single-peaked. Under these conditions the Solow model predicts a single convergence club, while the Howitt and Mayer model predicts multiple convergence clubs. Thus, testing life expectancy dynamics for convergence clubs is in effect a test of the qualitative predictions of these growth models. Finding that life expectancy dynamics exhibit convergence clubs implies that only growth models predicting convergence clubs can hold.

Our *qualitative* test of the Solow and Howitt and Mayer models (which applies to most growth models) thus consists of a test of the *descriptive* properties of life expectancy dynamics.

The empirical study uses the cross-country life expectancy database by Easterly and Sewadeh that is available on the World Bank web page.[3] A complete five-yearly panel is available for the period 1962-1997 for 159 countries. I first invite the reader to a visual examination of the life expectancy histograms for each of the years in the panel. A changing two-peaked pattern is clearly apparent. In 1962, half of the countries formed a low peak and the other half a high peak. By 1997, half of the countries in the low peak had migrated to the high peak, and the peak structure had shifted about 5 years to the right along the life expectancy axis (Figure 1). On the basis of these histograms I define three sets of countries, according to their life expectancy trajectories: 'Low-Low' (LL), 'Low-High' (LH), 'High-High' (HH). I then propose these three sets as possible convergence clubs and proceed to analyze the trajectories' levels and their convergence properties. First I show by means of a series of summary statistics and graphs that this subdivision reflects different development processes, and does not result from multi-peakedness of the birth rate, an important parameter in growth models. To analyze the levels we show, using and F-test applied to quadratic estimates of log life expectancy, that a three clubs model is much better than the single club model. To analyze the convergence properties I use a sequence of nested F-tests, showing that a three clubs model admitting both time effects and separate coefficients for each group of countries fits the data better than any simpler model. The visual and statistical examination of the data clearly shows that the process of life expectancy improvement in these three groups of countries was quite different, and that each subdivision of the sample enjoys the properties of a convergence club.

Section 2 contains the theory, section 3 the empirical work, and section 4 the conclusions.

Growth Theories and Life Expectancy

As was mentioned above, there is strong evidence that life expectancy rises with income, and that, as a result of technological progress, higher life expectancies have been obtained at later dates for the same income. Besides, there is evidence that health itself increases productivity, through a series of mechanisms including increased labor, educational and household productivity, and female economic participation. This and other research on health has led to the concept of ***health capital*** as an extension of human capital mainly consisting of education.

For our Solow model, we may broaden the notion of capital to include physical, human and health capital. We can then write the Solow model of economic growth with exogenous technological change for each country as:

$$k' = s\Phi k^{\alpha} - (n + \delta + g)k, \qquad (1)$$

$$A_{World}' = g\, A_{World}, \qquad (2)$$

where k is capital per *effective* worker, s is the saving rate, Φ is a country-specific fixed productivity factor, α is the elasticity of a Cobb-Douglass production function[4], n is the population growth rate, δ is the depreciation rate and g is the rate of growth of A_{World}, the globally available level of technology. We now suppose that health (which shall be measured by life expectancy) is given by

$$v = \Psi k^{\theta} A^{\varphi} \qquad (3)$$

(v for vitality), where $\theta \geq 0$, $\varphi \geq 0$ and $\theta + \varphi < 1$ to obtain the property that life expectancy increases less than proportionally to income. Ψ represents a country-specific factor expressing how much health is produced at given levels of capital and technology. It includes such factors as preferences for heath, inequities in the distribution of income, and the equity, level and efficiency of public policy. Note that income is given by Ak^{α}, so that v can be viewed as partly or wholly a function of income. The expression for v would arise under Cobb-Douglass preferences if these imply that a constant proportion of income is spent on health and if health is a homogeneous function of order $\theta + \varphi$ of expenditure on health.

The Howitt and Mayer model is based on the premise that a new method for creating technological change, "research and development," was introduced early in the 20th Century. In order to take advantage of this method a country must have (i) an appropriate set of supporting institutions and (ii) at least a threshold level of human capital that depends on the technological frontier. Countries that do not fulfill both of these requirements can only create new technologies through an older method, "implementation." Here I do not report the fairly complex framework used to model technological change, but only state the closed form equations that hold about each steady state:

$$h' = s\Phi h^{\beta} - (n + \delta + \pi_{+}(\psi,h,\lambda)(a^{-1} - 1))h, \tag{4}$$

$$a' = \pi_{+}(\psi,h,\lambda)(1 - a) - ag_{World}, \tag{5}$$

where h is human capital per effective worker, ψ is a country-specific index for the incentives to innovation, $\pi(\psi,h,\lambda)$ is the intensity of successful innovation, an increasing function of ψ, h and of λ, the productivity of the innovation technology characterizing the stationary state, either R&D or implementation. If the incentives for innovation are too small, as in the case for stagnation, π may be negative and is replaced by $\pi_{+} = \max[\pi,0]$. In this model $a = A/A_{World}$ is the relative technological level of each country, defined with respect to the global leading edge technological parameter A_{World}. A is the average technological level of the intermediate goods industries. A_{World} is the maximum of the country-specific A's and grows at a rate g_{World} given by the technological spillovers of world-wide innovation through R&D and implementation. As mentioned above, R&D is possible only if the per-capita level of human capital is above a certain threshold that rises with the leading technological edge A_{Max}. Thus the productivity of innovation is

$$\lambda = \lambda_{R\&D} \text{ for } ha \geq \eta, \text{ and } \lambda = \lambda_{Imp} \text{ for } ha < \eta, \tag{6}$$

where η is the *innovation effective* human capital threshold and $\lambda_{R\&D} > \lambda_{Imp}$, stating that innovation is more productive through R&D than through implementation.

We suppose as before that health is given by

$$v = \Psi h^{\theta} A^{\varphi}. \tag{7}$$

Physical capital, which has been excluded for simplicity, can be added to this model. The convergence club structure is retained, although steady state levels may depend on whether the economy is open or closed. Note that equation (1) in the Solow model is analogous to equation (4) in the Howitt and Mayer model, with the rate of technological growth replaced by the endogenous rate $\pi_{+}(\psi,h,\lambda)(a^{-1} - 1)$.

Each of the steady states of these two models has the property that as trajectories approach the steady states they do so at an exponential rate given by the absolute value of some largest eigenvalue, $-\mu$, which is negative, depends on the parameters of the model and may be steady-state specific. Using the same arguments as Barro and Sala i Martin (1990), a log-linearization at each steady state implies that the normalization

$$\underline{v} = v/(A_{World})^{\varphi} = \Psi h^{\theta} a^{\varphi} \text{ or } \Psi k^{\theta} a^{\varphi} \tag{8}$$

converges exponentially to its steady state $\underline{v}^*$. Hence

$$\log[\underline{v}(t)] = \log[\underline{v}(0)] \exp(-\mu t) + \log(\underline{v}^*) [1 - \exp(-\mu t)]. \tag{9}$$

This implies that the non-normalized quantity v satisfies

$$(1/T) \log[v(t_0+T)/v(t_0)] = \varphi g + (1/T) [1 - \exp(-\mu t)] [\log(\underline{v}^*) - \log(\underline{v}(t_0))]$$

$$= \varphi g + (1/T) [1 - \exp(-\mu t)] [\log(\underline{v}^*) - \{\log(v(t_0)) + \log(A_{World}(0))$$

$$+ g t_0\}]. \tag{10}$$

(with g replaced by g_{World} in the case of the Howitt and Mayer model). This is the basic equation describing relative convergence that we estimate. The convergence coefficient is $-(1/T)[1 - \exp(-\mu t)]$. A term involving time appears because of the dependence of v on the leading technological edge.

In expression (10) $\underline{v}^*$ is an unknown quantity that depends on the parameters s, Φ, α or β, n, δ, Ψ, θ, φ, ψ, λ and g or g_{World}. λ is a steady state specific parameter, while g and g_{World} are global parameters. The technology parameters α, β, θ, φ, δ are usually thought of as global. The remaining parameters s, Φ, n, Ψ, ψ are country-specific. Except for the population growth rate n, I assume that their cross-country distributions are single-peaked, assuming that the multiple-peakedness of life expectancy is overridingly an economic phenomenon. The only conceivable exception could be the country-specific health factor Ψ, if it were true that some regions of the world are dramatically unhealthier than others, independently of achieved technological levels, something I find unlikely.[5] It is verified below that the population growth distribution n is single-peaked and thus does not have an important qualitative effect on the choice of subsamples. Under these assumptions, the cross-country distribution of $\underline{v}^*$ is single-peaked at each steady state. Once the mean is removed, this is the error term in the econometric version of equation (10).

Equation (10) is steady-state specific. If data from several steady states are pooled together, the resulting convergence coefficient will still be negative. If a data set is partitioned into several subsamples, a better estimate of equation (10) may result if the subsamples contain countries belonging to different steady states for which equation (10) has different coefficients. However, the boundaries of these subsamples may be imprecise and further subdivision may still be possible. Note that when referring to relative convergence the assumption of a single club is usually made. Here I am explicit about the number of clubs and regard relative convergence as a *club-specific property*.

We now have two models of life expectancy based on the dynamics of the fundamental economic variables, as given by the Solow or the Howitt and Mayer models of economic growth. Life expectancy works as an indicator of each country's economic state.[6] It is quite clear that the arguments above are applicable to most if not all other dynamic models of capital and technology. Ramsey type growth models lead to convergence equations such as (10). Two-sector models with physical capital and human capital (representing knowledge rater than skill) also exhibit convergence to their steady states, so that life expectancy expressed as a function of capital and knowledge would similarly converge to a steady state trajectory. Thus the model for the convergence of life expectancy – to one or to several steady states – is quite general. I concentrate on comparing the hypothesis that there is a single or that there are several convergence clubs, each possessing the property of relative convergence. In the examination of life expectancy dynamics I find that ignoring the existence of a club structure either in a description of the levels or in a relative convergence test, involves a very significant specification error that is detected by omitted variables tests.

Empirical Dynamics of Life Expectancy

The life expectancy data consists of a five-yearly panel of data over the period 1962-1997 that is complete for 159 countries, available on the World Bank web page mentioned above. By comparison, the 1960-1995 GNP panel is complete for only 122 countries; even less educational data is available.

I conduct the descriptive study of this data as follows. First I examine the five-yearly histograms for life expectancy. These clearly exhibit a changing twin-peaked structure with three groups of countries: those originally in the high peak, those originally in the low peak shifting to the high peak and those remaining in the low peak. The histograms also exhibit a slow shift towards higher life expectancy.

The dynamic structure that the histograms exhibit naturally gives rise to a subdivision of countries into three groups, LL, LH and HH. I next show, by means of several summary statistics to give additional evidence that this subdivision distinguishes between different types of dynamics, and that it is not unduly influenced by the population growth rate.

Finally, I examine the levels and the convergence properties followed by life expectancy dynamics, to see to what extent these slow and fast moving peaks correspond to convergence clubs.

Life Expectancy Histograms

Figure 1 shows the distribution of life expectancy across the 159 countries for which a balanced panel is available. In 1962 and 1997 these histograms have a well defined twin-peaked structure. However, the size of these peaks is different. As can be ascertained by observing the full sequence of histograms, a group of countries has traveled from the lower to the higher peak. Also, both peaks have shifted about five years to the right. In 1962 about half the countries in the sample were in the lower peak. The median life expectancy of 54.865 years lies right in between the two peaks. By 1997 about half of the countries in the lower peak had moved beyond this reference level.[7]

The histogram motivates the definition of the subsamples LL, LH and HH as follows. LL is the set of countries with life expectancy less than the median 54.865 in 1962 and also less than this level in 1997. LH are those countries that were below this level in 1962 and above it in 1997. The HH countries were above this level at both dates. Table I shows the composition of the three subsamples by regions.

Examination of these groups shows that the LL countries are located mainly in Sub Saharan Africa, LH belong to the rest of the underdeveloped world, and HH includes Europe and North America as well as 13 countries in East Asia Pacific and 21 countries in Latin America and the Caribbean. Thus HH picks up the developed world as well as an upper layer of underdeveloped countries.[8]

The mean life expectancy for LL countries is 39.5 in 1962, rising to 48.2 by 1997. These countries had very low income and technology levels in the sixties, improving only very slowly through the thirty five year period. LH countries improved much more rapidly from an initial 46.9 to 64.6 years of life expectancy. The initial life expectancy is still at a very low level corresponding to low income and technology levels, but the final level can only be attained on the basis of sufficient private and public health inputs. HH countries improved from 65.4 to 74.1 years, indicating a high technological level throughout.

Some issues on the choice of subsamples

Changes in life expectancy over the period 1962-1997 can be seen in Figure 2, which examines these changes by countries and by continents, and also shows where the LL, LH and HH subsamples lie. It is quite clear that the full sample does not consist of a simple single-humped distribution. I have not attempted to subdivide the HH group into convergence clubs, considering that other data or methods may be required. Before examining the dynamics of these subsamples we discuss some issues regarding their choice.[9]

The division of the sample of countries into low and high life expectancy groups in 1962 is not too arbitrary because the distribution is double-peaked and the median lies right in between the peaks, especially as shown in a more finely subdivided histogram. On the other hand the boundaries between the LL and LH groups may seem somewhat arbitrary. It may appear that its choice introduces selection bias in the level analysis, because these groups are defined on the basis of their ex-post performance in life expectancy improvement. However, the main point is that the life expectancy of countries starting at a low level *diverges*. Figures 3.1 and 3.2 show the life expectancy histograms for the LL and LH groups in 1962 and

1997. The two distributions clearly diverge,[10] something that does not depend on the exact location of the boundary. If anything, some of the lower LH countries should be classified as LL countries, making the divergence between the two subsamples even larger. Further evidence of the differences between the samples is found in Figures 4.1 and 4.2, which show the average evolution of life expectancy for the full sample and for the three subsamples.[11] Figure 4.1 shows that life expectancy improvements have diminished through the years. However, as can be seen in Figure 4.2, this cannot be explained simply by diminishing returns to expenditure in health. For example, LH countries improved their life expectancy more in 1962-1967 than LL countries did in 1992-1997 at very similar life expectancy levels, even after 30 years of technological improvements! It is also apparent that the experience of each group of countries does not lie in the neighborhood of the average cross-country performance.

Another issue that must be considered is whether the distribution of population growth may be behind the several-peaked nature of the full sample. However, as can been seen in Figure 5, the distribution of population growth was single peaked in 1960. A growing number of countries experienced low population growths, but mostly in the HH group (Figures 6.1 and 6.2). Figure 6.1 shows that the population growth histogram for the HH countries was twin-peaked, a piece of evidence for the existence of convergence clubs within this subsample. However, the distributions for the LL and LH countries are not very different, so that they do not originate the distinction between these groups. Nevertheless, the demographic transition was more advanced in the LH countries: they had a higher population growth in 1960 (which would imply slower economic growth!) and a lower one in 1997, confirming that these groups of countries were indeed on different development trajectories.

Its is clear that life expectancy and the population growth rate were not direct determinants of the divergence between the LL and LH groups noted above. Suppose that these groups of countries correspond to convergence clubs. According to the Howitt and Mayer (2001) model, the most likely determinant of membership would be the initial level of technology, because the human capital level, as indicated by life expectancy, is similar. Fixed factors such as institutional quality, productivity and incentives to innovation may affect membership, but countries similar in these respects may nevertheless belong to different convergence clubs for reasons lying in the past. I show with a probit regression some correlates of whether a country belonged to the LH rather than the LL group. The probit regression, run on the LL and LH countries, is the following (z-statistics in parenthesis):[12]

$$I_{LH} = \underset{(-2.648)}{-42.06} + \underset{(2.386)}{9.677} \log(LE1962) + \underset{(2.637)}{1.608} (SECONDARY1960 > 5\%) +$$

$$\underset{(-0.376)}{-0.010\, URBAN1960} + \underset{(1.817)}{1.112 \log(RGDP1960)} \underset{(-1.818)}{- 1.879\, N1960}$$

The significant indicators (all at better than 7%) of belonging to LH rather than LL all reflect levels of capital and technology, except for the population growth rate, which appears as well.[13]

One or several convergence clubs: levels

I now test whether the life expectancy dynamics are better modeled by taking these three subsamples as clubs than by considering the full sample as the only club. First I look at the levels followed by the trajectories. For this purpose I use quadratic models of log life expectancy as follows.

Model L1. Single club:

$$\log(LE_t) = c_1 + c_2 TIME_t + c_3 TIME^2_t + u_t$$

Model L2. Three clubs:

$$\log(LE_t) = c_1 LL + c_2 LH + c_3 HH + (c_4 LL + c_5 LH + c_6 HH)TIME_t$$

$$+ (c_7 LL + c_8 LH + c_9 HH)TIME^2_t + u_t$$

The results are shown in the first two columns of Table II. The coefficients of all terms containing $TIME^2_t$ are significant and negative as expected. The three clubs model has a much higher R^2 of 0.866 rather then 0.094, and is supported by an F-test value of 1233.9 (probability equal to 0). Figure 7.1 shows that the residuals remain twin-peaked in the single club model, but are single-peaked in the three clubs model. The Durbin-Watson test shows as expected, however, that the errors u_t have positive autocorrelation. This problem disappears in the relative convergence regressions.

Figure 8 shows the results of the three clubs model in graphical form, showing a ±3 standard deviation band for the estimated mean log life expectancy of each subsample (transformed back into years). The results confirm the life expectancy trends of the three subsamples that are visually evident in the sequence of histograms (Figure 1).

One or several convergence clubs: relative convergence

I estimate the following relative convergence models, each based on equation (10).

Model RC1. Single club, autonomous:

$$(1/5)(\log(LE_{t+5}) - \log(LE_t)) = c_1 + c_2 \log(LE_t) + u_t$$

Model RC2. Three clubs, autonomous:

$$(1/5)(\log(LE_{t+5}) - \log(LE_t)) = c_1 LL + c_2 LH + c_3 HH +$$

$$+ (c_4LL + c_5LH + c_6HH)\log(LE_t) + u_t$$

Model RC3. Single club, time dependent:

$$(1/5)(\log(LE_{t+5}) - \log(LE_t)) = c_1 + c_2\, TIME_t + (c_3 + c_4\, TIME_t)\log(LE_t) + u_t$$

Model RC4. Three clubs, partially time dependent:

$$(1/5)(\log(LE_{t+5}) - \log(LE_t)) = c_1LL + c_2LH + c_3HH +$$

$$+ (c_4LL + c_5LH + c_6HH)\log(LE_t) + c_7\, TIME_t + c_8\, TIME_t\, \log(LE_t) + u_t$$

Model RC5. Three clubs, time dependent:

$$(1/5)(\log(LE_{t+5}) - \log(LE_t)) = c_1LL + c_2LH + c_3HH +$$

$$+ (c_4LL + c_5LH + c_6HH)\log(LE_t) + (c_7LL + c_8LH + c_9HH)TIME_t$$

$$+ (c_{10}LL + c_{11}LH + c_{12}HH)TIME_t\, \log(LE_t) + u_t$$

These models estimate convergence equation (10). The error term u_t corresponds with the country-specific steady state levels $\underline{y}^*$, means removed. We confirmed above that the population growth rate n has a single-peaked distribution, and we also argued that the other model parameters are single-peaked, so $\underline{y}^*$ has a single-peaked distribution. For simplicity it is assumed that the distribution is normal and OLS regressions are carried out. Figure 7 shows that the residuals for Models 1 and 2 are indeed single-peaked. Although they are not quite normal, their similarity shows that it is not any multi-peakedness of the residuals that is running the results. It is worth nothing that since what is under examination is a *descriptive* feature, the problem of endogeneity does not arise. On the other hand, heterogeneity is precisely what is being tested.

Convergence equation (10) predicts the presence of a time dependence term. However, some of the parameters, such as the population growth rate or productivity factors reflecting institutional quality, may change endogenously with time. Thus the sign of the coefficients for $TIME_t$ (measured in quinquenia from 1 to 7, while t is in years) may be ambiguous.

The three clubs models in effect estimate equation (10) separately for each subsample, which is a proposed convergence club. However, a joint estimate is carried out. This makes it easier to perform the F tests and also Wald tests that the vector of coefficients describing the dynamics of LL is equal to the one describing LH, and so on. We use the logarithm of life expectancy because it gives consistently better results throughout.

The results are reported in Table II. The single club model has a very significant convergence coefficient with a low R2. However, the three clubs model has *larger* convergence coefficients for each subsample and a considerably higher

R2. Thus relative convergence is better detected as a club-specific phenomenon. Adding time dependence to the single club model detects a slowing convergence, increasing R2 only a little. Adding a non-club specific time dependence to the three clubs model yields insignificant results for the time variables, while adding time dependence in a club-specific way does. This underlines the club-specific nature of technological change and life expectancy improvement trends. Also, the rate of convergence is increasing for the LL (after some initial divergence) and LH samples and decreasing for the HH sample (this may be due to the presence of convergence clubs within the HH sample).

The Durbin Watson tests, which are better for the three clubs models, do not show any significant autocorrelation of the errors along time. Hence that the model is a first order system is not a significant limitation, a question that the persistency of health and health improvements could pose.

In each of the three clubs models, the Wald tests strongly reject the hypotheses that life expectancy dynamics are described by the same model for any pair of clubs, most forcefully when time dependence is taken into account.

The final step is to conduct F tests of the model extensions, in effect asking the question whether the extensions play any significant role.[14] Table III shows the results. The non-empty cells show all possible model extensions. Except for the introduction of partial time dependence in the three club models, which yields insignificant coefficients for the terms containing $TIME_t$, all of the extensions are found to be significant at the one in a million level. Of course, the confidence level may be inaccurate, for instance because the disturbance term is not quite normal. Nevertheless, it indicates that the finding that life expectancy dynamics are club-specific is quite robust. According to these tests the best of the five models is the three clubs time dependent model.

Conclusions

The econometric tests show that both the levels of life expectancy trajectories and the relative convergence phenomenon are better described as a club-specific then as a single-club phenomenon. The statistical analysis thus confirms what is evident to the eye in the sequence of histograms (Figure 1). A single-club description of levels or of convergence properties of life expectancy dynamics proves to be misspecified, and a study of the averages yields little insight of the processes occurring within each club. The three subsamples that were defined each follow quite different trajectories, yet enjoy the property of relative convergence, with parameters differing between them. The tests that were conducted give strong evidence that large-scale life expectancy and therefore economic growth convergence clubs exist. It is clear that the methods used cannot yield a firm categorization of countries. Indeed it is also quite possible that a further subdivision of the clubs would correspond closer to reality. Especially the HH group may contain further clubs, a subdivision that was not attempted.

The characteristics of the three groups of countries correspond with the convergence clubs that the Howitt and Mayer (2001) model suggests. The life expectancy of the LL countries is consistent with stagnating economics whose technological change consists of implementation that requires very little and almost costless innovation. The life expectancy improvement of LH countries, on the other hand, requires the implementation of a series of technologies. The HH group contains those countries carrying out R&D, but also contains many countries that only implement technology. As was mentioned, it can probably be subdivided into an R&D and an implementation convergence club.

It is much harder to detect convergence clubs in the income data. In this sense the life expectancy data are special in that the club structure is much more evident, and can be detected with simpler econometric methods. Life expectancy has technological requirements that cannot be eluded and may provide a better indication of technological development than income, which can result from highly specialized production, and therefore may give only a poor reflection of the state of technological development.

The model of life expectancy in terms of the underlying economic variables (capital and technology), whose dynamics are described by the theories of economic growth, implies that the descriptive properties of life expectancy dynamics provides a qualitative test of these theories. The analysis thus gives strong evidence that only theories implying convergence clubs may be valid. Such theories can explain the nature of the economic processes characterizing the steady states giving rise to the convergence clubs, for example the type of technological innovation taking place, and lead to an understanding of states of development.

The existence of convergence clubs implies that countries may remain trapped in their state of underdevelopment if only market policies are followed. Perhaps this is why market policies for globalization and growth have not been as effective as hoped for in the case of underdeveloped countries. Only the recognition and careful study of club dynamics can lead to policies that can aim at escaping poverty traps and changing states of development.

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[1] The paper can be accessed from http://www.nber.org/~confer/2001/si2001/efbdprg.html

[2] Only 24.4% of the countries that will be classified below as having low life expectancy in 1962 were classified by the 90's as diversified exporters in the World Bank data base referred to below.

[3] The address is http://www.worldbank.org/research/growth/GDNdata.htm

[4] This assumption is necessary to obtain convergence equation (10) below.

[5] It has recently been wondered if Africa and the tropics may be inherently unhealthier.

[6] This approach has been used to study chaotic dynamics. For instance, in the discrete case, Takens' theorem applied to this context shows generically that the dynamics of an m-dimensional growth model will be reproduced by the dynamics of m-histories of life expectancy ($LE_{t-(m-1)\tau}$,...LE_t), for any lag τ.

[7] Visual examination, as well as subdivision of the intervals, confirms that these features are robust to the choice of life expectancy intervals.

[8] The subsamples are the following:

Low-Low: Afghanistan, Angola, Benin, Botswana, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, The, Guinea, Guinea-Bissau, Haiti, Kenya, Lao PDR, Liberia, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Tanzania, Togo, Uganda, Yemen, Rep., Zambia and Zimbabwe.

Low-High: Algeria, Bangladesh, Bolivia, Cameroon, Cape Verde Comoros, Dominican Republic, Ecuador, Egypt, Arab Rep., El Salvador, Ghana, Guatemala, Honduras, India, Indonesia, Iran, Islamic Rep., Iraq, Lesotho, Libya, Madagascar, Maldives, Mongolia, Morocco, Myanmar, Namibia, Nepal, Nicaragua, Oman, Pakistan, Papua New Guinea, Peru, Philippines, Saudi Arabia, South Africa, Sudan, Swaziland, Syrian Arab Republic, Thailand, Tunisia, Turkey and Vietnam.

High-High: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, The, Bahrain, Barbados, Belarus, Belgium, Brazil, Brunei, Bulgaria, Canada, Chile, Colombia, Costa Rica, Cuba, Cyprus, Denmark, Estonia, Fiji, Finland, France, Germany, Greece, Guadeloupe, Guyana, Hong Kong, China, Iceland, Ireland, Israel, Italy, Jamaica, Korea, Dem. Rep., Korea, Rep., Kuwait, Latvia, Lebanon, Lithuania, Luxembourg, Macao, Malaysia, Malta, Martinique, Mauritius, Mexico, Netherlands, Netherlands Antilles, New Caledonia, New Zealand, Norway, Panama, Paraguay, Poland, Portugal, Puerto Rico, Qatar, Reunion, Romania, Singapore, Slovenia, Spain, Sri Lanka, Suriname, Sweden, Switzerland, Taiwan, China, Tajikistan, Trinidad and Tobago, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela and Yugoslavia (Serbia/Montenegro).

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[9] The histograms in Figure 1 portray a balanced sample of 159 countries. For the regressions I was slightly less stringent and included all countries for which data was available in 1962 and 1997. This added four countries that were missing a single data point (subsample and year in parentheses): China (LH, 1977), Hungary (HH, 1977), Japan (HH, 1977) and Turkmenistan (HH, 1992).

[10] See also the level regressions and Figure 8 below.

[11] Figure 4.2 is in logarithms so as to correspond with the convergence estimates.

[12] I_{LH} is an indicator function equal to 1 for LH and 0 for LL countries. LE1962, SECONDARY1960, URBAN1960, RGDP1960 and N1960 are life expectancy, the proportion of secondary school enrolment and urban population, real GDP, and five yearly average percentage population growth in the corresponding years obtained from the World Bank database. A dummy is created from SECONDARY1960 as indicated.

[13] The differences between the means in the LH and LL samples multiplied by their coefficients yield magnitudes that put these indicators of membership in LH in order (mean difference times coefficient in parenthesis): E1962 (4.335), RGDP1960 (1.001), SECONDARY1960 (0.622) and N1960 (–0.287).

[14] To conduct these tests, LL was substituted with 1 in Models 2, 4 and 5. The hypothesis that the coefficients of the remaining variables containing LH and HH are all zero was then tested.

Figure 1. Cross-Country Life Expectancy Histograms
1962-1997

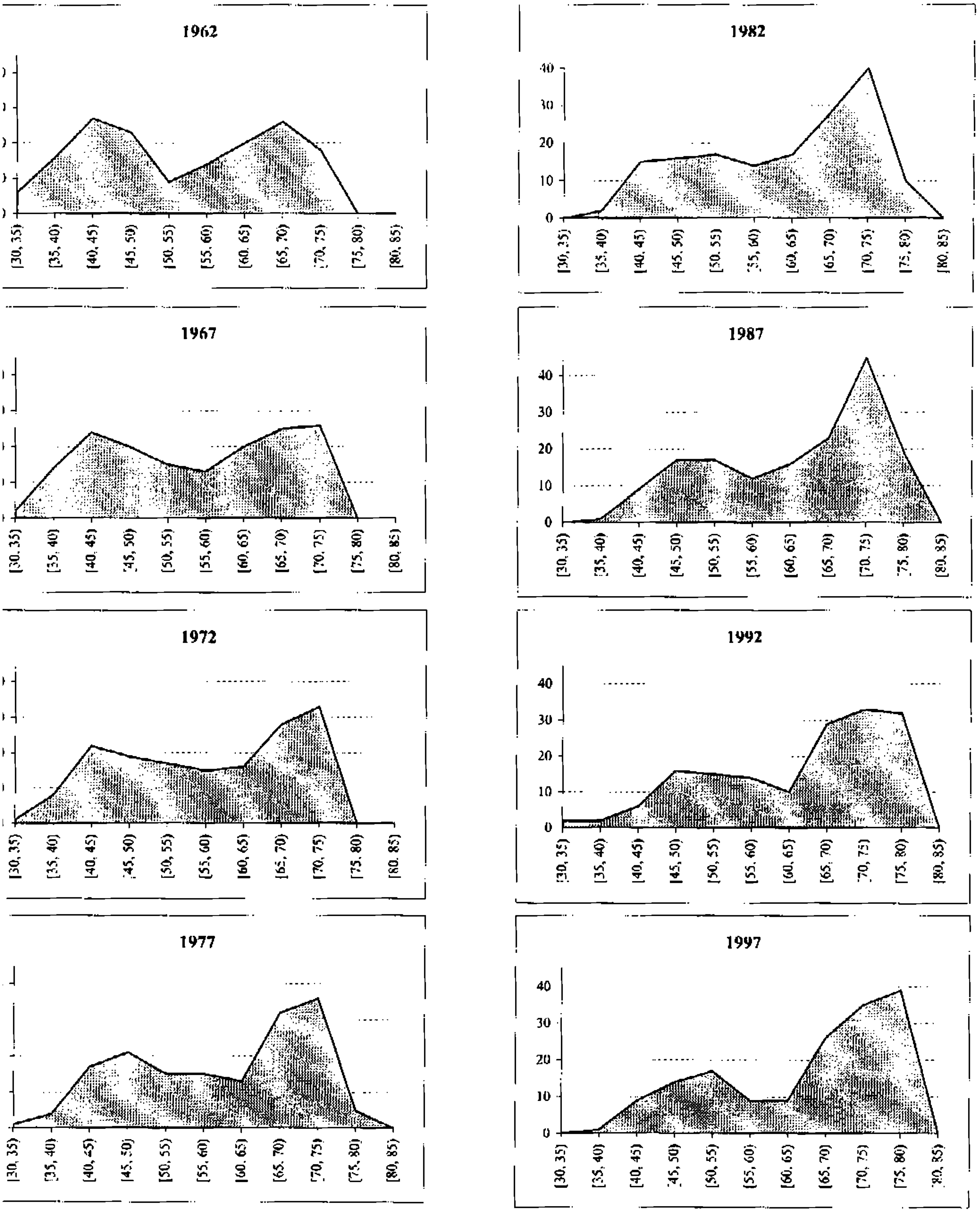


Figure 2. Life Expectancy Improvement from 1962 to 1997

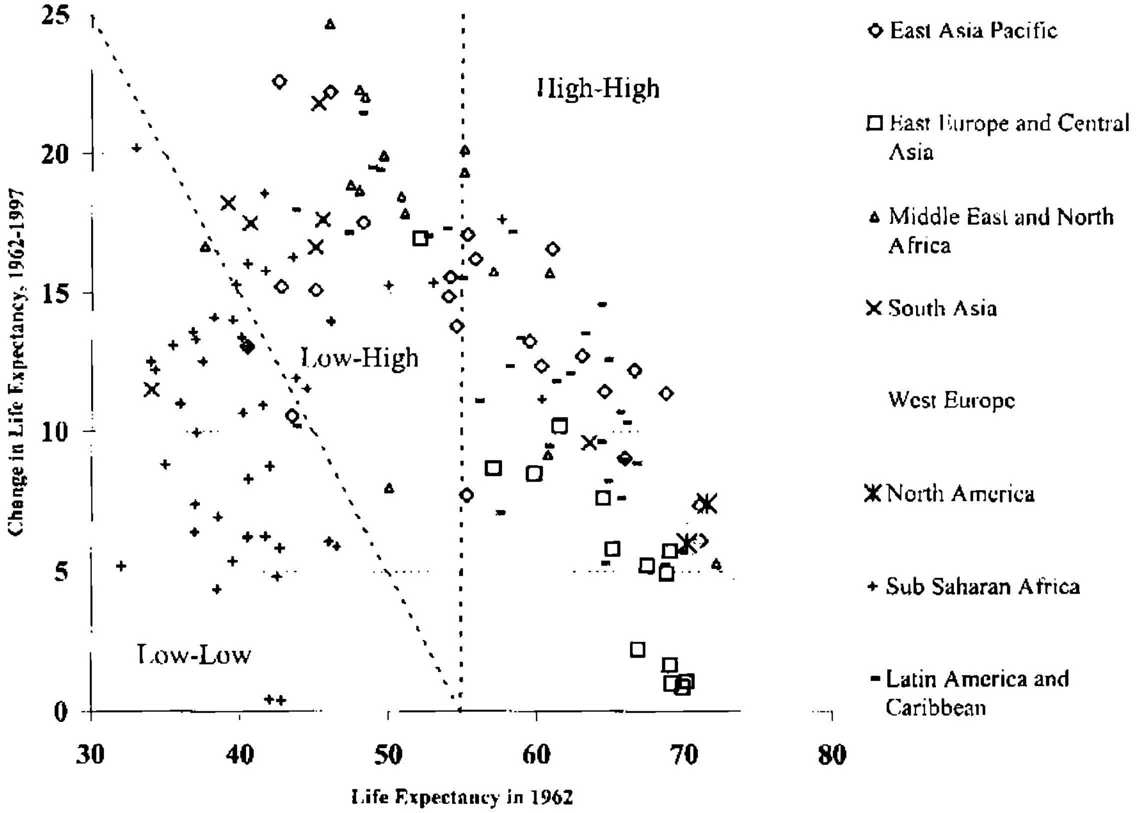
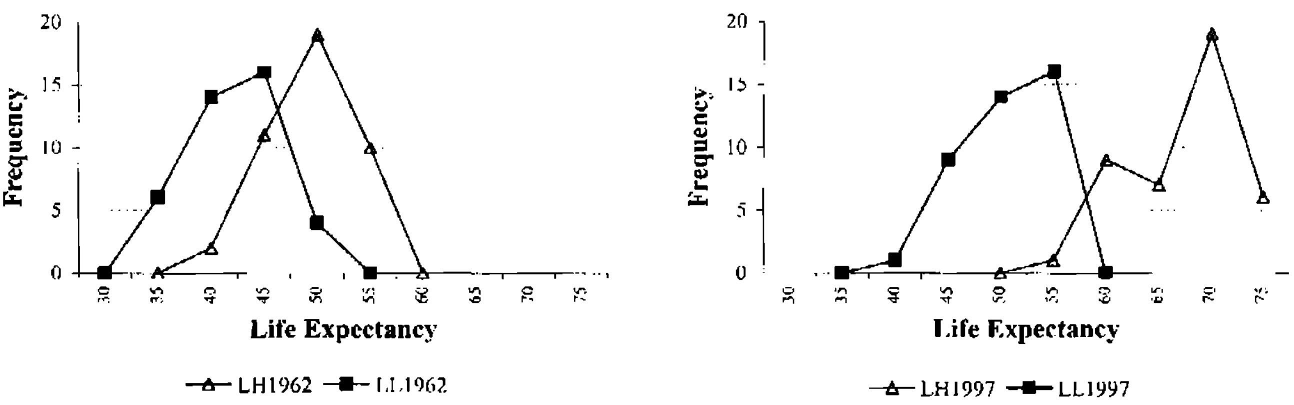


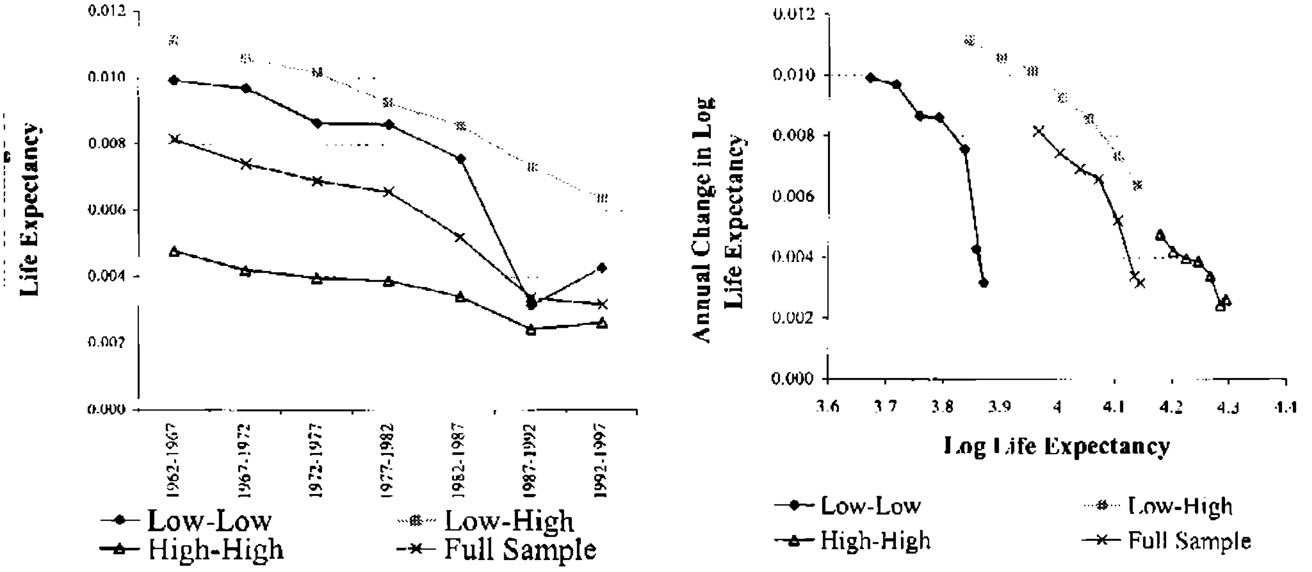
Figure 3. Life Expectancy for LH and LL Countries



3.1 Histograms for 1962

3.2 Histograms for 1997

Figure 4. Life Expectancy Dynamics 1962-1997



4.1 Average Changes in Life Expectancy for Sample and Subsamples

4.2 Phase Diagram for Sample and Subsamples

Figure 5. Quinquenial Population Growth Rate
Histograms

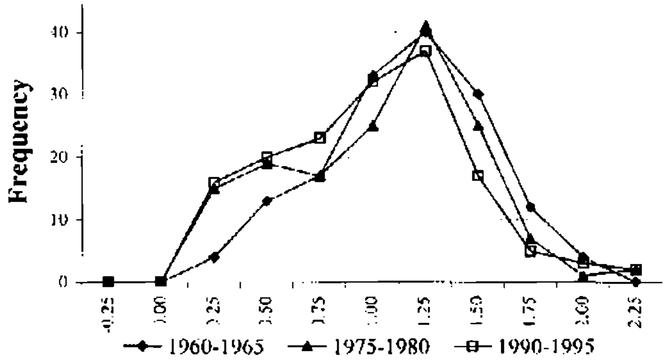
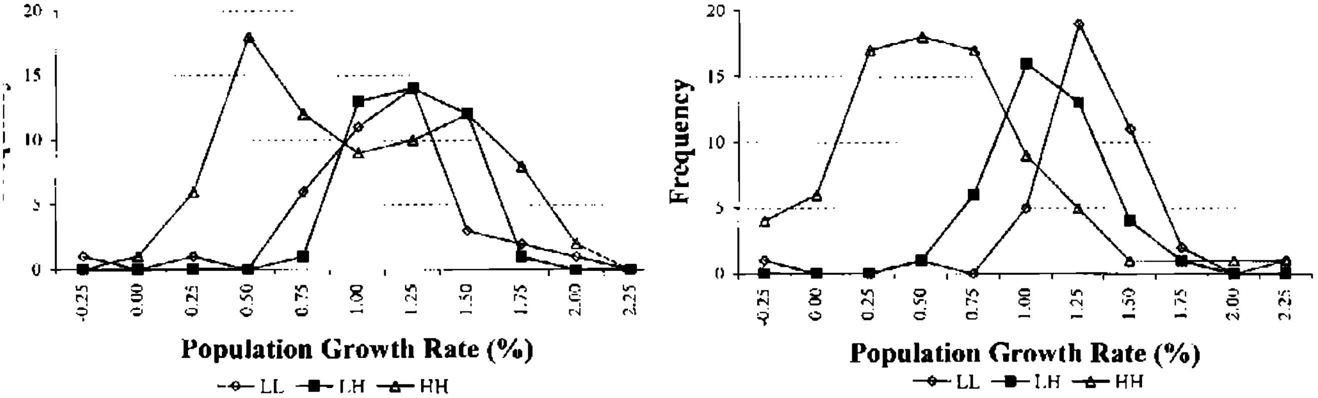
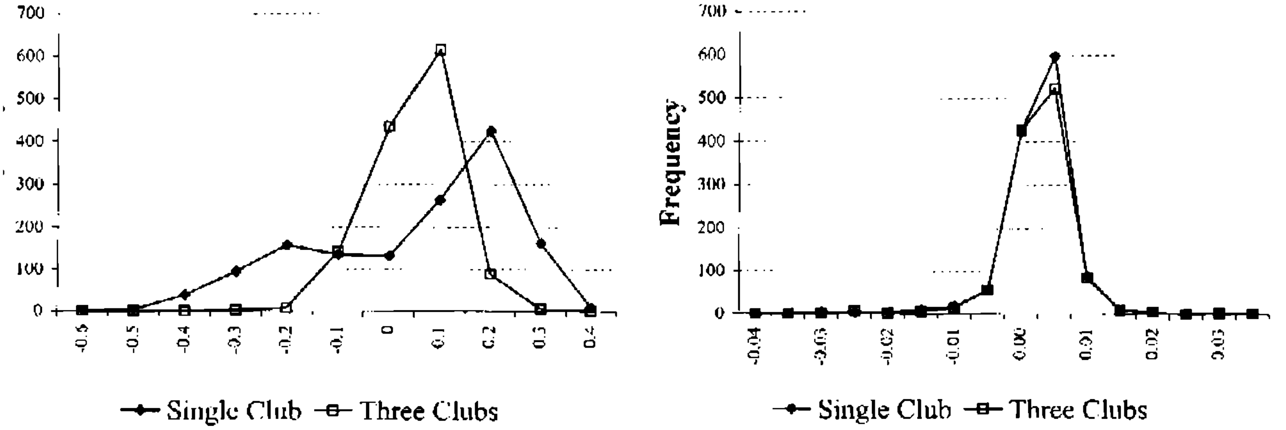


Figure 6. Population Growth Rate by Subsamples


6.1 Histograms for 1960

6.2 Histograms for 1990

Figure 7. Histograms of the Residuals of the Single and Three Clubs Models
(Autonomous Case)


7.1 Levels Models

7.2 Autonomous Relative Convergence Models

Figure 8. Location of Mean Life Expectancy by Subsamples
(To 3 Standard Deviations According to Model L2, see text)

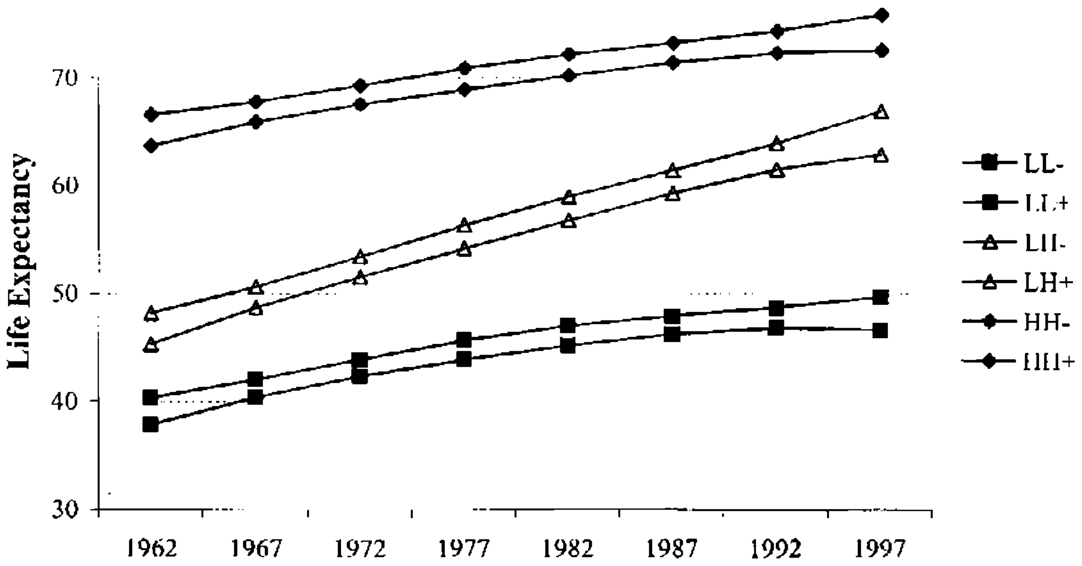


Table I. Composition of the Three Subsamples by Regions.

Subsample	East Asia Pacific	Sub Saharan Africa	Latin America and Caribbean	Europe and North America	Middle East, North Africa and South Asia	Total
Low-Low	2	35	1	0	2	**40**
Low-High	8	10	8	1	15	**42**
High-High	13	2	21	38	7	**81**
Total	**23**	**47**	**30**	**39**	**24**	**163**

Table II. Desciptive Model of Life Expectancy Dynamics

	Levels		Relative Convergence				
Model	**L1**	**L2**	**RC1**	**RC2**	**RC3**	**RC4**	**RC5**
Clubs	**Single**	**Three**	**Single**	**Three**	**Single**	**Three**	**Three**
Time dependence	**Yes**	**Yes**	**No**	**No**	**Yes**	**Partial**	**Yes**
C	3.92		0.048		0.059		
	(175.2)		(13.273)		(7.882)		
TIME	0.047				-0.005	0	
	(4.1)				(-2.565)	(0.265)	
TIME^2	-0.002						
	(-1.7)						
LOG(LE)			-0.01		-0.013		
			(-11.75)		(-6.767)		
LOG(LE)*TIME					0.001	0	
					(2.25)	(-0.395)	
LL		3.606		0.128		0.12	-0.064
		(206.8)		(11.77)		(10.249)	(-2.547)
LL*TIME		0.064					0.044
		(7.2)					(7.89)
LL*TIME^2		-0.004					
		(-4)					
LL*LOG(LE)				-0.032		-0.03	0.02
				(-11.251)		(-9.673)	(2.887)
LL*LOG(LE)*TIME							-0.012
							(-7.986)
LH		3.78		0.067		0.055	0.007
		(222)		(6.419)		(4.334)	(0.274)
LH*TIME		0.067					0.009
		(7.7)					(1.62)
LH*TIME^2		-0.002					
		(-2.4)					
LH*LOG(LE)				-0.014		-0.011	0.001
				(-5.544)		(-3.495)	(0.201)
LH*LOG(LE)*TIME							-0.002
							(-1.732)
HH		4.148		0.108		0.088	0.163
		(338.4)		(7.222)		(4.41)	(5.592)
HH*TIME		0.03					-0.018
		(4.7)					(-2.286)
HH*TIME^2		-0.001					
		(-1.8)					
HH*LOG(LE)				-0.025		-0.02	-0.038
				(-6.98)		(-4.101)	(-5.431)
HH*LOG(LE)*TIME							0.004
							(2.288)
R-squared	0.094	0.866	0.109	0.249	0.138	0.252	0.301
Adjusted R-squared	0.093	0.865	0.108	0.245	0.136	0.247	0.294
F-statistic	67.513	1038.604	138.06	74.56	60.466	54.1	43.87
Prob(F-statistic)	0	0	0	0	0	0	0
Durbin-Watson stat	0.026	0.153	1.767	1.911	1.857	1.932	1.918
Wald tests of equality for subsample coefficients							
LL = LH		170.514		93.094		69.285	47.209
		(0)		(0)		(0)	(0)
LH = HH		656.492		4.38		34.06	5.829
		(0)		(0.013)		(0)	(0)
LL = HH		1608.492		53.39		5.658	36.452
		(0)		(0)		(0.004)	(0)

Table III. F-Tests for Model Extensions

To:		Single Club	Three Clubs	Single Club	Three Clubs	Three Clubs
From:		Autonomous	Autonomous	Time Dependent	Partially Time Dependent	Time Dependent
Single Club	Autonomous		52.409 (0)	19.421 (0)	35.853 (0)	29.642 (0)
Three Clubs	Autonomous				2.466 (0.085377)	13.995 (0)
Three Clubs	Time Dependent				42.636 (0)	32.573 (0)
Three Clubs	Partially Time Dependent					19.678 (0)

F statistic, probability in parenthesis