Cross-Country Growth Comparison: Theory to Empirics

by

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January 2000

*I thank the British Academy, the ESRC, and the Andrew Mellon Foundation for financial support. This paper draws on a range of ideas jointly developed in earlier collaboration with Steven Durlauf and with Louise Keely. Tony Atkinson, Gavin Cameron, Stephen Redding, and seminar participants at the Reserve Bank of Australia provided helpful comments. I alone, however, am responsible for (mis) interpretations and errors in the paper. I used tSrF to perform all the calculations.

Nontechnical Summary

This lecture, delivered at the International Economic Association World Congress in Buenos Aires, August 1999, describes some empirical regularities in cross-country patterns of aggregate economic growth, and discusses how theoretical reasoning has guided their analysis.

It uses three themes. The first builds on an observation that appears, at first, obvious and perhaps trivial. This observation is that *cross-country comparisons matter*, both empirically and theoretically. By this, I do not mean the near-afterthought where a researcher looks at what happens across countries, only as a way to provide variation in a cross-country regression equation describing a representative economy. Instead, I refer to empirical and theoretical analysis that looks at why differences across, relations among, and interactions between countries matter for economic growth.

Kaldor's stylized facts is the source from which most economists first learn the empirics of growth. That list does in its last item mention the variation in economic performance across countries. But until recently, this point had not been picked up on as much as Kaldor's other enumerations—on constancies of ratios and income shares, and on the relations between aggregate variables, all within a single growing economy. Credit for this reorienting towards cross-country analyses must go to the different projects to construct, for many different countries, comparable cross-country data on macro aggregates. This then is the second theme.

Robert Summers and Alan Heston, two University of Pennsylvania economists, have provided the best-known data compilation here. As with the developers of theorems on estimators in econometrics, those authors cannot be held responsible for how their data are used or misused. But that their 1988 and 1991 papers have to date seen 900 citations in scholarly economics publications is surely testament to how they have shifted the debate since Kaldor. (According to the Social Science Citation Index, by May 1999 these two papers had been cited 840 times. This is, moreover, almost surely an undercount as the *Summers-Heston* data have reached a notoriety where they are

sometimes referred to and used without explicit citation.)

There is a final, third theme in this lecture—actually more subtext and spin than a theme proper. That is *technology*. By this, I mean not just a factor that shifts production functions. Instead, I refer more to knowledge in the form of ideas, blueprints, and design.

Sure, knowledge perturbs production technologies. Accumulating knowledge shifts out the production possibilities frontier. It has done so since at least the Industrial Revolution of the late 18th century. But of at least equal concern, I believe, when we discuss growth relations across countries is the 'nonrivalry' of knowledge (or what Thomas Jefferson called its 'infinite expansibility'), and the healthy disrespect that knowledge shows for physical geography, the political boundaries of nation states, and other artificial barriers constructed by economic agents. Some of these provide key insight into so-called "endogenous growth". But other implications for economic performance follow as well.

Many have remarked how knowledge cannot be exchanged as a standard Arrow-Debreu commodity. But we have other ways of modelling its production and dissemination. By happy coincidence, the same economics that helps us analyze these is useful also for thinking about other, in my view, exclusively modern (and therefore post-Kaldor) features of economic performance. Those features acquire ever greater prominence when progressively more of aggregate economic value is generated in commodities like computer software, communications technology, biotechnology and genetic databases, and Internet-mediated activity. What is significant now and different from earlier times is that the economic concerns surrounding technology do not center exclusively on technical developments in the shipbuilding dock or airplane hanger, on the shopfloor or manufacturing assembly line, or in the R&D cleanroom or engineering laboratory. Instead, the interest in information, knowledge, and technology centers on their direct impact on and immediacy to consumers. It is irrelevant whether one regards to be scientific knowledge software such as Windows 95 or cryptography algorithms, or for that matter, a video game. These commodities happen to have *all* the essential properties of scientific knowledge—infinite expansibility, disrespect for geography, and so on. In this view, knowledge is no longer only something produced in R&D labs through Schumpeterian competition. Instead, commodities that behave like knowledge have now been taken out of the domain of scientists and engineers, and brought upfront to the final consumer. How does this influence patterns of economic growth from here on out?

These last changes I have just described do not yet have enough of a data presence that I can discuss their cross-country growth empirics. However, acknowledging them helps explain why my subsequent discussion is structured the way it is.

New growth theory is a branch of analysis that has had some critics suggesting its development arises from an internal dynamic, that in improvement in economists' mathematical tools. This lecture argues that the professional success of new growth theory has not arisen solely from that. While it is true ever more intricate models have now become tractable to analysis, that itself is an endogenous outcome that is explained by or jointly emergent with yet other developments. Successful development of growth theory has only proceeded in step and simultaneous with the concerns of empirical research and topical policy.

By the last, I mean simply acknowledging the increasingly important roles of information, knowledge, and high technology in everyday economic life, and government responses to that growing recognition. Those changes are highlighted by, for instance, much-debated and economically significant legal decisions being made on Internet and operating system technology—words that had no meaning in the 1950s and 1960s, but are now common currency among consumers.

Before the early 1990s, the demands of empirical research and topical policy—in their current forms—were never as visible nor as pressing. And it is this, in my estimation, that accounts for the resonance and appeal of recent research in both theoretical and empirical analyses of economic growth. At the same time, however, this shift also comes with a warning: "traditional" growth models that emphasize endogenous technology on the production side of the economy might not provide the sharpest insights for how technology matters in the economy now.

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ABSTRACT

This paper reviews the cross-country record of economic growth, using as organizing framework how economic theory has guided that empirical analysis. The paper argues that recent studies of economic growth—both empirical and theoretical—distinguish from previous work in three distinct ways: 1. An explicit focus on cross-country growth and development experiences; 2. Improved, more extensive cross-country data; 3. A heightened need, driven by real-world topicality, for understanding the role of knowledge and technology in economic growth.

Keywords: convergence, cross-section regression, distribution dynamics, endogenous growth, knowledge, neoclassical growth, technology, twin peaks, panel data

JEL Classification: C21, C22, C23, D30, E13, O30, O41

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1 INTRODUCTION

In this lecture I describe some empirical regularities in cross-country patterns of aggregate economic growth, and discuss how theoretical reasoning has guided their analysis.

Those longtime participants in this audience already know the lead role in these topics that the IEA has taken for almost its entire history. The well-known Kaldor stylized facts on growth—so well-known they are now no longer given a proper citation—were first set down explicitly in the Proceedings volume of an IEA Conference forty years ago (Kaldor, 1961). This focus on and interest in economic growth has been maintained through all the IEA meetings since—quickly established by looking through the series of World Congress published volumes.

How then can I say anything that might surprise, or in any way approach something post-Kaldor?

I will use three themes in addressing the topic I mentioned at the beginning of this lecture. The first builds on an observation in the literature that appears, at first, obvious and perhaps trivial. This observation is that *cross-country comparisons matter*, both empirically and theoretically. By this, I do not mean the near-afterthought where a researcher looks at what happens across countries, only as a way to provide variation in a cross-country regression equation describing a representative economy. Instead, I refer to empirical and theoretical analysis that looks at why differences across, relations among, and interactions between countries matter for economic growth.

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[2] Arrow (1962) provides an early formalization and technical discussion of these properties. That many empirical studies have found knowledge spillovers geographically localized presents a puzzle to resolve, not a fundamental shift of principle. Those findings might suggest, say, that in certain economic activities, tacit knowledge transmitted only through specific kinds of interactions matter more than do generally-broadcasted codifiable knowledge. Nonetheless, however, the latter can remain the more important and significant for understanding cross-country patterns of growth.

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2 GROWTH AND DEVELOPMENT ACROSS COUNTRIES

In a key paper re-igniting professional interest in economic growth, Robert Lucas (1988, p. 3) described the question to address as follows:

> "By the problem of economic development I mean simply the problem of accounting for the observed pattern, across countries and across time, in levels and rates of growth of per capita income. This may seem too narrow a definition, and perhaps it is, but thinking about income patterns will necessarily involve us in thinking about many other aspects of societies too, so I would suggest that we withold judgment on the scope of this definition until we have a clearer idea of where it leads us."

Lucas quickly concedes that for some, his definition has too much a hard-nosed, mainstream economics focus on only per capita income.[3] However, Debraj Ray's excellent textbook on development economics, among others, notes that while a broader, multi-faceted view is, in principle, the appropriate perspective, per capita income is a pretty good proxy for many of the important dimensions to development (Ray, 1998, p. 29).

This 1988 statement of Lucas's usefully contrasts with a comparable one from 1969: Stiglitz and Uzawa, eds (1969, p. 3) introduced the then-modern theory of economic growth as follows:

> "The primary objective of the modern theory of economic growth is to explain, on the one hand, the movements in the output, employment, and capital stock of a growing economy and the inter-relations among these variables, and on the other hand, to explain the movements in the distribution of income among the factors of production."

[3] Composite indexes for, say, "physical quality of life" or "human development" might take into account indicators such as infant mortality, life expectancy, educational attainment, per capita incomes downweighting higher values, literacy rates, and so on.

Per capita income in national economies	times world per capita income **1960–64**	**1985–89**
10th %-ile	0.22 × (26.0% world popn.)	0.15 × (3.3% world popn.)
90th %-ile	2.70 × (12.5% world popn.)	3.08 × (9.3% world popn.)
(25th-15th) %-iles	0.13 ×	0.06 ×
(95th-85th) %-iles	0.98 ×	0.59 ×

Table 1: Evolution of country per capita incomes

The difference between the two positions can be simply stated. Stiglitz and Uzawa were concerned with explaining conditions *within* a single economy through time. Lucas's evocative statement, on the other hand, removed the limits confining that analysis to within national boundaries and asked, Can we understand what is happening over time to the entire cross section of countries?

Earlier growth theorists and empiricists might simply have confined themselves to within-country studies because they thought different countries were, well, different. Researchers have long known about the biases and omissions in developing-country national income accounts. Comparison of those data with the data of developed countries can be unreliable even when within-country analysis over time for a given economy is perfectly sensible. That Switzerland's per capita income is 400 times Tanzania's at official exchange rates probably does not mean the same thing as Bill Gates's being 400 times wealthier than the 95th-percentile household in the US. But this excuse for excess caution in cross-country comparison has lost some of its punch with World Bank, UN, and Summers-Heston efforts at purchasing power parity corrections in aggregate income data across countries. Such adjustments cannot remove all problems in cross-country comparisons, but the obvious analytical difficulties are now minimized.

Between 1960 and 1990, average per capita income in the world grew by 2.25% per annum. Individual country performance fluctuated around this worldwide average growth path. Table 1 shows the evolution of country per capita incomes over this period. The figures take countries as the basic unit of observation and are relative to world average per capita income. Thus, the first entry in the Table shows that over the five-year period 1960–1964 the 10th percentile country had per capita income only 22% of the world average. The ratio of the 90th percentile per capita income to the 10th percentile averaged over 1960–1964 was 12. By the beginning of the 1990s, this ratio had increased to 21, a 67% increase over 25 years. That rise in disparities came from both a relative decline at the bottom of the cross-country income distribution *and* a relative increase at the top end.

Table 1 also shows the fraction of the world's population contained in the top and bottom deciles of countries. We see a remarkable decline in population share of the bottom decile from 26% to 3%. This, however, is due to a single economy, China, exiting the group of very poorest countries. Taking out China, the modified Table 1 (not presented here) says two things. First, the richest countries are usually larger, and the poorer countries smaller. Second, over time, the share of the world's population living in the very richest countries has declined, while that in the very poorest has increased.

What I have just described suggests to me that if one is interested in the worldwide distribution of incomes across people—not just that across countries—additional insights are available by looking directly at the distribution of incomes across people within these countries, and then merging that information with the data underlying Table 1. It will take us too much out of the way to go into that discussion here, but some quick comments are in order. China's transition out of the bottom decile of countries has been associated with an increase in its personal income inequality. Thus, it might seem misleading to suggest that only 3.3% of the world's population remained in the bottom decile by the end of the 1980s. Of course, Table 1 does not actually say that, but, regardless, we also know that the increase in within-country inequality in China did not stop hundreds of millions of Chinese from becoming markedly better off over this 25-year period. In a simple accounting sense, China's growth in per capita income *did* remove a significant fraction of the world's population from poverty. On this, therefore, Table 1 does not mislead.

Calculations show that the flavor of this conclusion carries more generally.[4] Inequality within countries has certainly changed through time. But the magnitude of those variations is dwarfed by that of changes in per capita incomes due to aggregate economic growth. Thus, to understand the distribution dynamics of worldwide individual incomes, not just of cross-country economic performance, Table 1 does a pretty good job representing the salient facts.

The final two rows of the Table show a progressive narrowing of income distance between the ten percentile points centred on the 10th and 90th percentiles respectively. This indicates a clustering of observations around those two distinct points on the cross-country income distribution.

An alternative depiction of the message of Table 1 is shown in the *emerging twin peaks* of Fig. 1. The Figure illustrates the evolution of the cross-country per capita income distribution, using an estimated model of distribution dynamics. Fig. 2 shows the actual cross-country distributions in 1960 and 1988, with the incipient rise of the two modes. To understand the mechanics of the emerging twin peaks in Fig. 1, turn to Fig. 3: This shows likelihoods of transiting over time from one part of the income distribution to another. Contour plots of the graph on the left of Fig. 3 show probability mass clustering around distinct parts of the diagonal, and thus greater likelihoods, relatively, of remaining in those parts of the income space upon entry there. Trace through the dynamics of the system by repeatedly applying the estimated stochastic kernel in Fig. 3 to Fig. 2. (Quah, 1997, gives details on this procedure).

[4] For further details, the reader might wish to consult Heston and Summers (1999), Milanovic (1999), and Quah (1999a).

3 GROWTH THEORY AND EMPIRICS

What do growth models say about Figs. 1–3?

The answer I want to give is, an unsatisfactory combination of "a great deal" and "not a lot" simultaneously. To see why, it suffices to consider the simplest version of the Solow (1956) growth model. The conclusions I will draw relevant for Figs. 1–3 will follow from many other models as well.

The model is standard, and the very brief exposition that follows is mostly to establish notation. Let Y be total output, N be the workforce, and K be the total capital stock. Denote per worker quantities in lower case:

$$y \stackrel{\text{def}}{=} Y/N \qquad k \stackrel{\text{def}}{=} K/N. \tag{1}$$

Output depends on K, N, and technology A through a standard smooth neoclassical production function. Assume technology A enters the production function multiplicatively in N so that output per worker can then be written as

$$y = Af(k/A), \quad f' > 0,\ f'' < 0,\ \lim_{k\to\infty} f(k)k^{-1} = 0. \tag{2}$$

Technology and the workforce evolve exogenously at constant growth rates

$$\dot{A}/A = \xi \geq 0, \quad A(0) > 0 \tag{3}$$
$$\dot{N}/N = \nu \geq 0. \quad N(0) > 0 \tag{4}$$

Capital depreciates at a constant rate δ and accumulates through savings equal to fraction τ of total income Y:

$$\dot{K} = \tau Y - \delta K, \quad \tau \text{ in } (0,1) \text{ and } \delta > 0. \tag{5}$$

Combining (1) through (5) gives the dynamic equation for capital per worker:

$$\dot{k}/k - \dot{A}/A = \tau \frac{f(k/A)}{k/A} - (\delta + \nu + \xi) \tag{6}$$

The right side of this equation has the graph given in Fig. 4. Under the standard curvature assumptions on f given in (2), equation (6) has a unique steady-state value $[k/A]^*$.

Taking together equations (2), (3), and (6) then gives observable dynamics for labor productivity:

$$\log y(t) = \Gamma_0 + \xi \cdot t + [\log y(0) - \Gamma_0]e^{\lambda t}, \tag{7}$$

where

$$\begin{aligned} \Gamma_0 &= \log f\left([k/A]^*\right) + \log A(0) \\ &= g\left([\delta + \nu + \xi]^{-1}\tau\right) + \log A(0), \quad \text{with } g' > 0, \\ \text{and } \lambda &= \lambda(f, (\delta + \nu + \xi), \tau) < 0. \end{aligned}$$

These dynamics are illustrated in Fig. 5. For any single economy, say with output per worker y_1, economic history is the transition from its initial level to a specific steady-state path. However, the Figure also shows that the cross section of economies, having different underlying steady-state paths varying with Γ_0, displays a wide range of possible behaviors. Economies 2 and 3 diverge away from each other, criss-crossing along the way although they began close together at a middle-income level. Economies like 1 begin and remain rich; those like 4 begin and remain poor. If the number of countries exceeds that of underlying steady-state paths, then a clustering in the cross section distribution, as in the emerging twin peaks in Fig. 1 could well arise.[5]

The cross section therefore shows great diversity. Despite that, the average economy (or, for that matter, *each* economy taken in isolation) shows a straightforward relentless monotone convergence to its unique underlying steady-state growth path. The behavior of the cross-section distribution and that of the individual, while each consistent with the other, send markedly different messages about what

[5] More subtle analysis on this same point, within a representative economy framework, appear in Azariadis and Drazen (1990), De Castro (1999), Durlauf and Johnson (1995), and Solow (1997).

is quantitatively important. Indeed, a researcher might well conclude he has a good understanding of economic growth after successfully calibrating the dynamic performance of a single economy, but, at the same time, leaving completely at odds the situation for the entire cross section.

In this accounting, understanding the behavior of a representative economy entails understanding the economics in ξ and λ. Understanding the disparities in the cross section means clarifying the sources of differences in Γ_0. Of course, the economics in equations (2) through (5) does not separate cleanly these two sets of factors. Any single economic analysis will usually have implications for both. Knowledge on and guesses about the magnitudes of different elasticities will be needed to isolate what matters more for which.

Here I will pursue technology A, as the key force underlying Γ_0. That technology matters, even within a single economy and for the first fifty years of the twentieth century (much less now), is a point already made as early as Solow (1957): the increase in output per worker from \$0.62 per worker-hour in 1900 to \$1.28 in 1949 has only 12.6% explained by k; the rest, an overwhelming 87.4%, is due to A.

(I mention these earliest growth-accounting estimates here, rather than later ones that, say, correct for changes in quality of the factors of production. It might well be that upon proper quality-adjustment, these Solow (1957) results can be amended until nothing remains in A. However, my hunch is that that economic reasoning used for understanding A is also the best reasoning available for understanding the economics of the new ideas that improve quality in factors of production. Put another way, what else is it but technology that improves factors of production?)

We can assess A's cross-section importance by asking what we should observe if it were absent or, equivalently for our purposes, identical across countries. A US/India comparison is instructive here. In the Summers-Heston data, for the forty years from 1950 through 1990, the ratio of US to Indian output per worker averaged 14.6. Over the same period, US output per worker grew at 1.5% per year while Indian output per worker grew at 2.3% per year. Output per worker varies from year to year, and while long-run growth rates in the two countries have differed—so that a trend change has occurred—the variation is certainly not monotone.

If we assume that in equation (2), f is derived from a Cobb-Douglas production function,

$$y = A \times (k/A)^{\alpha},$$

and capital's income share α is taken to be 0.4—roughly what it is calculated to be in many countries—then the ratio of physical capital's rate of return in India to that in the US should be 56! That worldwide capital flows do not wipe out this huge differential means something other than just differences in k must be responsible for the variation in income levels across the rich and poor countries.

Noting that India while poorer is also growing faster, we can perform one further calculation. Maintaining the just-used assumptions, we obtain from equations (2) and (6) an explicit expression for how growth rates, in the transition to steady state, vary as a function of observable variables:

$$\dot{y}/y = [\xi - (\delta + \nu + \xi)\alpha] + \left(\alpha A^{\frac{1}{\alpha}-1}\right) \times \tau y^{1-\frac{1}{\alpha}}$$

If the term in square brackets on the right of this equation is approximately equal across countries, then to explain how growth rates and income levels differ across US and India, the savings rate in the US must be more than 35 times that in India!

These calculations, where I have simply replicated arguments in Lucas (1990) and Romer (1994), show, in my estimation, the importance of technology A in explaining the large cross-sectional variation in economic performance across countries. This can be put alternatively as follows. Suppose one uses as organizing framework the growth model (1)–(5). How much of the plight of poor countries is due to shortage of material resources like physical capital? The answer suggested by the calculations just presented is, Very little.

There are a range of possibilities how one proceeds from here. A researcher might calculate regressions with measured per capita income growth on the left side and a variety of ad hoc conditioning variables on the right. This is done with the view that that wide range of conditioning variables can then potentially explain growth in A. Ideally, these regressions should describe the steady-state paths in Fig. 5 while *convergence* regressions describe transitions to those steady states. A large literature, following a line of reasoning given in Barro (1997), has taken exactly this route. Some of these regressions can be informative, others not easily interpretable, most fragile, and a considerable fraction what some have called "a blaze of mediocre sociology"—Durlauf and Quah (1999) tabulate over one hundred such equations estimated in the literature.[6]

The empirical analysis can also adopt more intricate methods. An argument is sometimes made that because the data studied in cross-country growth comparisons vary in both cross-section and time-series dimensions, a panel-data analysis is appropriate and informative. Fig. 5 suggests the opposite. To appreciate this, recall that panel-data analysis typically conditions out (or "corrects for") individual heterogeneities—the so-called *fixed effects* or *random effects*. Being able to do this, in many microeconometric panel-data studies, is a virtue. In cross-country growth comparisons, however, it is a defect. As represented in Fig. 5, the variation we are concerned with is precisely that in the underlying country-specific heterogeneities. This variation occupies center stage in interest—it is exactly what underlies why some countries are rich, and others poor. Conditioning it out as statistical nuisance parameters—fixed or random effects, or more generally as unobservable individual heterogeneities—is, in my view, exactly the opposite of what one should do.[7]

[6] The informativeness of such regressions been discussed many times elsewere; see, e.g., Durlauf (1996), Quah (1996), and Sala-i-Martin (1996).

[7] In some cases (e.g., fixed-effects averaging), a researcher can recover what might appear to be estimates of the underlying individual heterogeneities. It is, however, unclear whether those are useful for the current cross-country growth application. To see this, recall that most sophisticated panel-data techniques are specifically designed to estimate a low-dimensioned parameter vector, without requiring or achieving consistent estimation of the individual heterogeneities. This

A reasoned view on these growth regressions—cross-section or panel—is that the researchers concerned have simply given up on the idea that A represents technology. Instead, A could be anything or everything in a list that includes income inequality, political stability, democracy, property rights regimes, climate, geography, openness of the economy, financial depth, ethno-linguistic fractionalization, and many others. No theory exists that says these variables should *not* affect economic performance somehow. Casual observation suggests they likely do. However, once we step outside a technology interpretation for A, all these different alternatives amount to believing that societies act in such a way that the resulting outcome falls strictly inside the production possibilities frontier.

On the other hand, even hewing (over-conservatively perhaps but with a scientific discipline) to the simple growth theory laid out in (1) –(5), it remains that one has not yet completely exhausted understanding of the possibilities when A is technology. Why flit to another lode of ore when so much is still to be clarified? Moreover, a technology-based approach is firmly both old growth theory and new growth theory: The extremes agree on the importance of technology; it's those in the middle that diverge.

To be sure, some might argue that the partition between k and A in my discussion is artificial, and that the two, in reality, develop in tandem. This is doubtless true, and interesting research (e.g., Howitt and Aghion, 1996) has formalized this argument further.

In this lecture I want to abstract from such conceptual multicollinearity in k and A. I ask instead, What determines the distribution of A across countries? This is a question in the economics of technology and knowledge dissemination. Analyzing it reveals a discipline for what would otherwise simply be behavior leading to outcomes strictly within the production possibilities frontier.

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is why such methods are so remarkable—doing the last-mentioned is typically impossible as the dimensionality of individual effects is comparable to sample size. But then it is almost accidental (and perhaps unfortunate) that things looking like estimates of individual effects can be obtained, even when statistically meaningless.

4 TECHNOLOGY ACROSS COUNTRIES

To motivate the theoretical and empirical modelling choices here, a useful first observation is that the important interactions leading to A's dissemination have to lie outside conventional market exchange. Because A is infinitely expansible or nonrival, its free trade would lead to the zero-price, market-failure outcome identified in Arrow (1962). Even if regimes for intellectual property rights (IPRs)—patents, copyrights, trade secrets—putatively enforce monopolistic outcomes in the development and provision of A, such systems are contrivances that societies have come to construct and that natural competitive forces seek to circumvent.[8] IPRs are neither primitive nor intrinsic to the problem of technology and idea dissemination (David, 1993).

We can organize relevant analysis into two broad categories, as described by the duality in Fig. 6. The Figure's left panel represents one category, by far the larger in the literature. This analysis takes as given the set of possible follower and leader countries: it then models the rate—fast or slow—of possible catchup in technology levels, and considers the possibility of overtaking. Empirical examples of such analyses include Bernard and Jones (1996), Coe and Helpman (1995), and Cameron, Proudman and Redding (1998). The right panel of Fig. 6 shows the other category, much smaller, that takes the set of economy identities not as given but as objects to be determined. It asks, Which are the economies that turn out to be followers and leaders in which (joint) subgroups; what forces determine who gets included in what clusters? This analysis is relatively new, and includes Keely (1999)and Quah (1997, 1999b) in cross-country growth, although the theoretical ideas and tools useful here are also only seeing recent development (e.g., Bloch, 1996; Ray and Vohra, 1997, 1999; Yi, 1997).

The analysis in Cameron, Proudman and Redding (1998) well represents the concepts and results in the first strand of literature.

[8] Software and Internet development provide powerful real-world examples of how the forces Arrow (1962) identified will re-route around artificial barriers like intellectual property rights.

Consider two economies 0 and j, where 0 indexes the initial leader and j a representative follower. Write A dissemination as:

$$\dot{A}_j/A_j = \xi_j - \beta_j \times \left(\frac{A_j - \psi_j A_0}{A_0}\right), \qquad A_j(0),\ \beta_j,\ \xi_j \geq 0;\ \psi_j \in [0,1]. \tag{8}$$

This adds a layer of complication over the leader country's assumed behavior, taken from equation (3):

$$\dot{A}_0/A_0 = \xi_0 = \xi \geq 0, \quad A_0(0) > 0.$$

In (8), the constants ξ_j, β_j, and ψ_j are interpreted, respectively, as j's own natural growth rate, j's rate of technology catchup, and the fraction of A_0 potentially transferable to j.

To clarify what a specification like (8) delivers, define *relative technology* $a_j \stackrel{\text{def}}{=} A_j/A_0$. Then (8) implies a steady state value a_j^* and transition dynamics:

$$a_j^* = (\xi_j - \xi_0)\beta_j^{-1} + \psi_j$$
$$\dot{a}_j/a_j = -\beta_j \times (a_j - a_j^*)$$

These relations deliver a simple quantification of convergence, divergence, or persistent stagnation, depending on where the value a_j^* lies relative to 1, and on the value of β_j. Except when ξ_j is the same as ξ_0, steady-state relative technology depends on more than just ψ_j.

It is easy in concept, moreover, to justify and estimate the dependence of ξ_j, β_j, and ψ_j on variables such as openness, R&D expenditure, or human capital. As just one empirical example, the estimates in Cameron, Proudman and Redding (1998), combining a range of such indicators, suggest that for the UK relative to the US, a_j^* is, for different industries, between 53% and 92%.

Such empirical analyses are useful for pointing the way forwards and establishing what matters empirically. However, the authors themselves have no illusion about the reduced-form nature of the work thus far. It remains unclear, also, whether such analyses can lead usefully to conclusions about the dynamics of the entire cross section, or will be restricted to pairwise comparisons.

Empirical analysis in the second category is in even earlier stages. Calculations in Quah (1997) suggested that patterns of trade—who trades with whom—rather than just openness, say, matters importantly for the patterns of clusterings that emerge in the cross section of countries. The theoretical counterparts to that empirical work remain to be studied: A reasonable conjecture is that theories of coalition formation—for idea- and technology-sharing clusters, implicit or explicit—will figure prominently. The key economic consideration is, How does it serve the self-interest of the putative leader—the source of the frontier technology—to have specific hangers-on taking advantage of and learning that technology? What do potential followers bring to the interaction between them that benefits the economy having the current technological lead?

5 CONCLUSIONS

In their lecture to the Tenth IEA World Congress in Moscow in 1992, Aghion and Howitt (1995) reviewed the issues and content in new growth theory. They observed economics was "experiencing the second post-war wave of neoclassical growth theory".

At the same time, however, they noted that much of the substance and many of the ideas in the theory of economic growth had, for decades if not longer, already seen serious work by the most penetrating, analytical minds in the profession. For Aghion and Howitt, no "grand new insights into the workings of market economies" could explain the remarkable rapid development of endogenous growth theory. They were, therefore, led to ask (Aghion and Howitt, 1995, p. 102):

> "What, then, accounts for the phenomenal success of a theory with no fundamentally new ideas on a subject that has been studied for centuries?"

We know their question had to be in part rhetorical if not downright disingenuous and mischievous (especially the "no fundamentally new ideas" phrasing) as Aghion and Howitt have been among the new theory's most prolific developers.

Their answer, similar to that given in Romer (1994), is the technical progress in tools and concepts that economists can now apply in equilibrium analysis. In particular, dynamic general equilibrium analysis with increasing returns—of which endogenous technology is a special case—is now routine.

Among other things, my goal in this paper has been to suggest how Aghion and Howitt (1995) and Romer (1994) have been overly modest. A more complete explanation, in my view, includes at least the following:

1. Cross-country focus on development and growth, more broadly construed;
2. Improvement in data availability;
3. The topicality of high technology, now taken out of R&D labs and the narrow domain of scientists and engineers.

These points are not entirely distinct. The first two of these obviously interact with each other. And, they feed directly into this paper's main topic, What is the cross-country growth record, and how has economic theory helped design its empirical analysis? This lecture has described how looking across countries is important and how doing so signals which models—theoretical and empirical—should be the ones to provide further quantitatively important insights.

Items 1.–3., in my view, temper Aghion and Howitt's suggestion that the accomplishments of recent research in endogenous growth have been "more a matter of form than substance", that "endogenous growth theory has succeeded mainly because of its technical progress" (i.e., in the tools that equilibrium theory now affords), and that "technique has come to dominate new ideas as the determinant of professional success".

In this lecture, I have argued the opposite. The professional success of the theory has not arisen solely from technological change in practitioners. While it is true ever more intricate models have now become tractable to analysis, that itself is an endogenous outcome that is explained by or jointly emergent with yet other developments.

Successful development of growth theory has only proceeded in step and simultaneous with the concerns of empirical research and topical policy.

By the last, I mean simply acknowledging the increasingly important roles of information, knowledge, and high technology in everyday economic life, and government responses to that growing recognition.[9] What is significant now and different from earlier times is that the economic concerns surrounding technology do not center on technical developments in the shipbuilding dock or airplane hanger, on the shopfloor or manufacturing assembly line, or in the R&D cleanroom or engineering laboratory. Instead, the interest in information, knowledge, and technology centers on their direct impact on and immediacy to consumers.[10] Those changes are highlighted by much-debated and economically significant legal decisions being made on Internet and operating system technology—words that had no meaning in the 1950s and 1960s, but are now common currency among consumers.

Before the early 1990s, the demands of empirical research and topical policy—in their current forms—were never as visible nor as pressing. And it is this, in my estimation, that accounts for the resonance and appeal of recent research in both theoretical and empirical analyses of economic growth. At the same time, however, this shift also comes with a warning: "traditional" growth models that emphasize endogenous technology on the production side of the economy might not provide the sharpest insights for how technology matters in the economy now.

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[9] Obvious expressions of this include Industry Canada (1994), UK Department of Trade and Industry (1998), and World Bank (1998). Elsewhere, government policies in Australia, Finland, India, and Singapore—among others—are notable examples where knowledge and technology have come explicitly to the fore.

[10] Quah (1999c) documents these recent changes, draws parallels to the failure of a putative Industrial Revolution in 14th-Century China, and models how varied consumer attitudes towards sophisticated technological goods—the demand side—can lead to high or low growth in technologically-driven economies.

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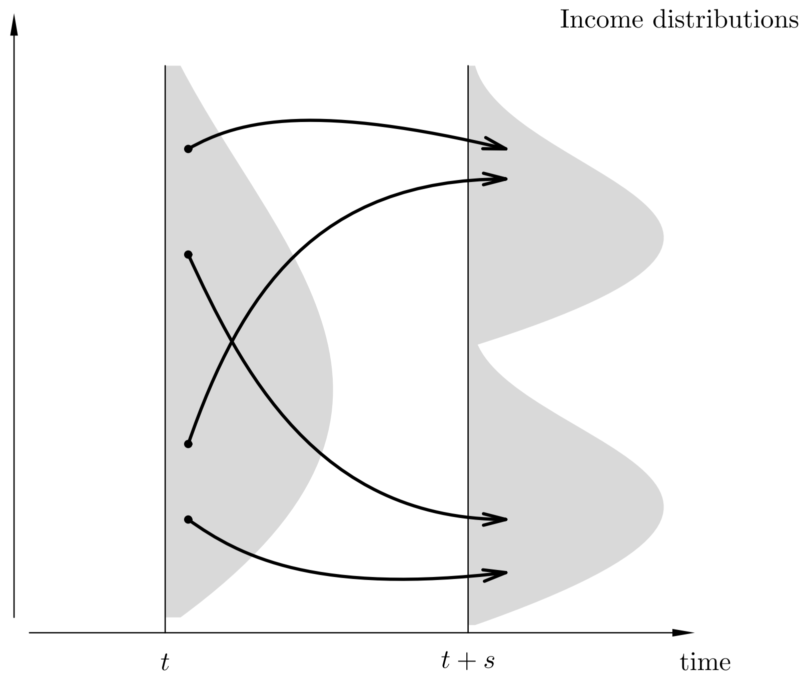
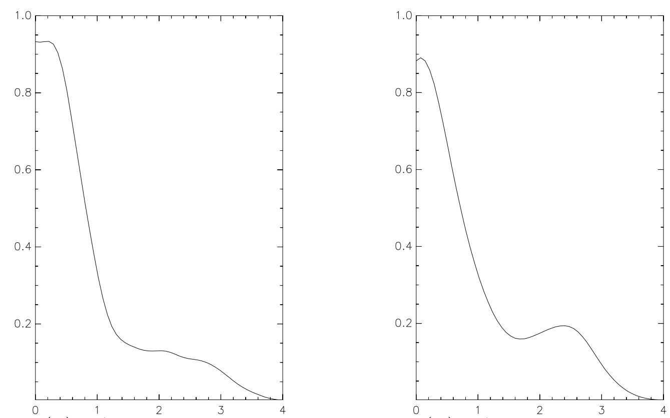
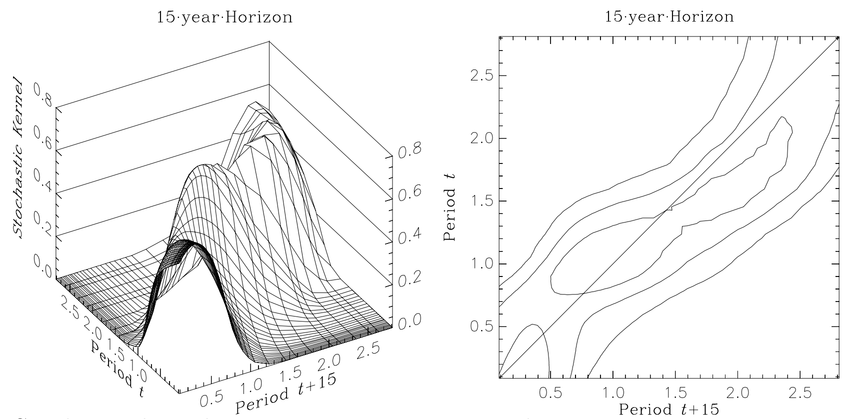


Fig. 1: Emerging twin peaks in the cross-country income distribution
Post-1960 experiences projected over 40 years for named countries are drawn to scale, relative to historical cross-country distributions.



(a): Actual 1961 (b): Actual 1988

Fig. 2: Distributions across 98 countries (Densities of relative output per worker)



Stochastic kernel Levels: 0.2, 0.4, 0.6

Fig. 3: Distribution dynamics across countries (Relative output per worker) The right panel contains contour plots of the 15-year stochastic kernel in the left panel.

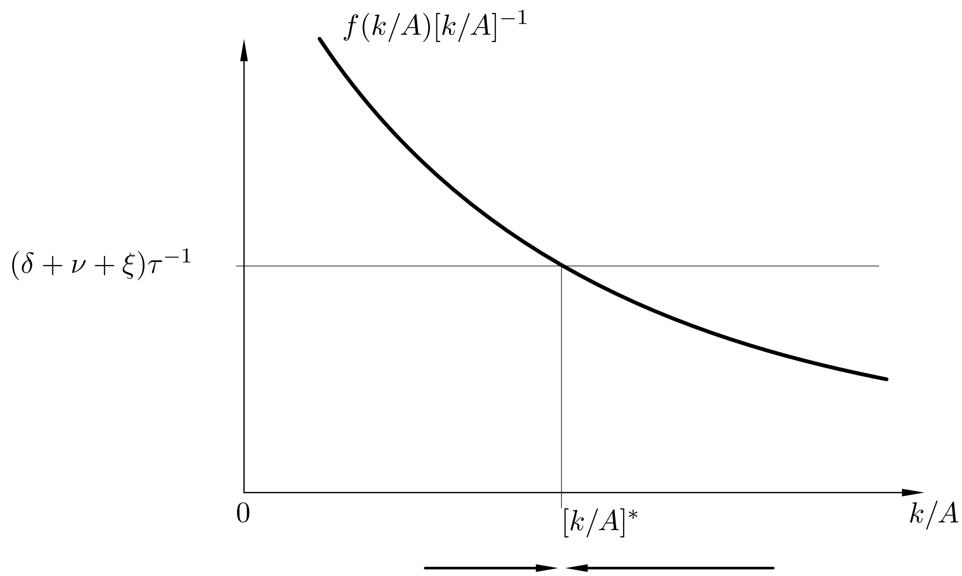


Fig. 4: k/A dynamics Convergence to steady state $[k/A]^*$ occurs for all initial values $[k/A]$.

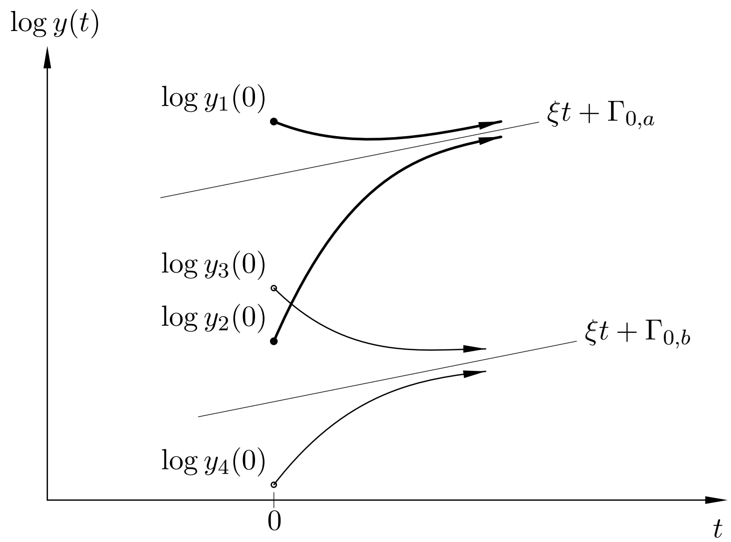


Fig. 5: Time paths across countries Each economy shows transition from its initial level to a specific steady-state path. But a cross section of economies, having different underlying steady-state paths varying with Γ_0, shows a range of possible behaviors.

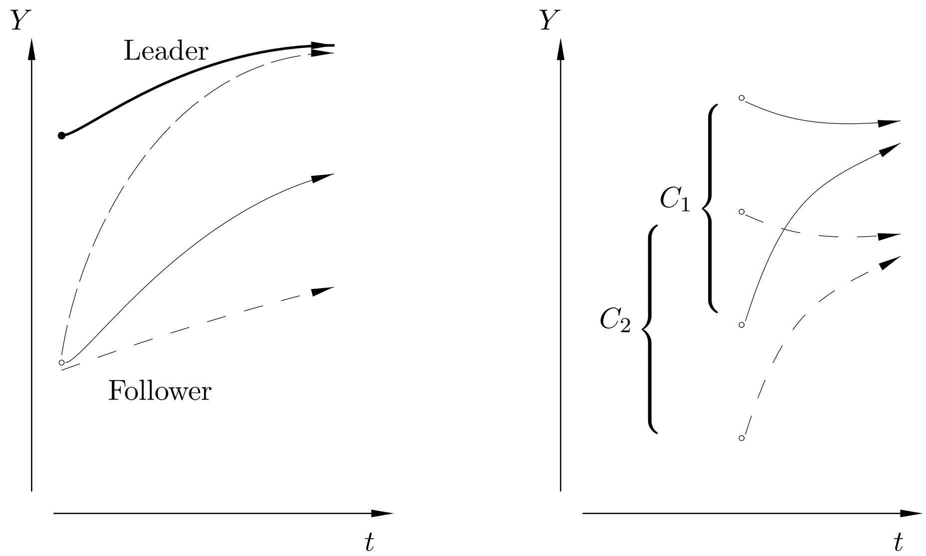


Fig. 6: Duality Modelling issue that underlies the left panel: What is the rate—fast or slow—of Follower convergence to Leader? Right panel: Which are the economies that converge, one to the other? What glue binds and separates different clusters like C_1 and C_2?