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TWIN PEAKS: GROWTH AND CONVERGENCE IN MODELS OF DISTRIBUTION DYNAMICS

Danny T. Quah

Convergence concerns poor economies catching up with rich ones. At issue is what happens to the cross sectional distribution of economies, not whether a single economy tends towards its own steady state. It is the latter, however, that has preoccupied the traditional approach to convergence analysis. This paper describes a body of research that overcomes this shortcoming in the traditional approach. The new findings – on persistence and stratification; on the formation of convergence clubs; and on the distribution polarising into twin peaks of rich and poor – suggest the relevance of a class of theoretical ideas, different from the production-function accounting traditionally favoured.

Conventional analyses of economic growth and convergence address one natural set of questions. What is the contribution of physical capital to output? Knowing this allows us to understand or explain patterns of growth by pointing to rates of capital accumulation. How quickly can poor countries catch up with richer ones? What factors aid this convergence? Appreciating these gives us perspective on the relative levels of development that we observe across different countries, and insight into how poor countries can improve their circumstances.

There is a traditional approach to answering such questions: estimate a cross-section regression of growth rates on income levels, possibly including other variables on the right hand side of that regression. In this reasoning, the levels coefficient informs on both capital's contribution to output and the rate at which poor economies catch up with those richer. (Whether this catch up occurs is known as the *convergence hypothesis*.) Such an equation relating growth rates and levels takes on added significance when we recall that it can be derived from theoretical growth models. This traditional approach thus seems doubly blessed. It sheds light on important economic questions; it dovetails neatly with theoretical reasoning. This is the standard that all empirical analysis strives for; what, in this traditional approach, could be controversial?

This paper argues that conventional analyses miss altogether key aspects of economic growth and convergence. The reason is the following. One dimension of growth is the mechanism by which agents in an economy push back technological and capacity constraints; this increases aggregate output. When the mechanism works spectacularly well, we consider the economy a growth success. Such economic progress is germane to rich countries, just as it is to poor ones – there need be no distinction between them. A different dimension of growth, however, is the mechanism that determines the relative performance of rich and poor economies: does growth in poorer economies lead to their catching up with the richer ones? Here, one wants to know if economic progress occurs differently in poorer economies than it does in richer ones.

The two mechanisms – pushing back and catching up – are related, but logically distinct: one can occur without the other. For brevity, I will refer to

the first as a *growth* mechanism, and the second as a *convergence* mechanism. As with all such taxonomies, the distinction is imperfect, but, we will see, is better than nothing. Taking the distinction seriously means, temporarily, divorcing the convergence hypothesis from issues of any one country's productivity performance. What is important for convergence is how economies perform relative to each other, not how a single economy performs relative to its own history. Obviously, both growth and convergence mechanisms matter: to make progress in understanding, however, the details of one are usefully abstracted away to focus on the other.

This paper argues that a key shortcoming of the traditional approach is that it fails to distinguish these two dimensions of economic growth. Theoretical and empirical statements made about one are taken, inappropriately, to apply to the other. Consequently, theoretical insights recognising the distinction are unavailable in the standard approach.

I will describe below a body of newer empirical research that repairs this shortcoming. This work models directly the dynamics of the cross-section distribution of countries. In doing so, it uncovers regularities fundamentally different from those in conventional analyses. This research provides evidence on persistence and stratification; on the formation of convergence clubs; and on the cross section distribution polarising into twin peaks of rich and poor.

Such regularities raise intriguing questions. What economic structures produce these dynamics? What mechanisms determine club formation and membership? Is it only those already-rich economies that converge towards each other, leaving the poor to form a different convergence club? What features of cross-country interaction generate polarisation and stratification? When physical capital flows more freely from one part of the world to another, does that lead to a spreading out of the distribution – so that the rich get richer and the poor, poorer? Or, does the opposite happen, and the poor have opportunity to become richer than those previously rich? In addressing these questions, the researcher is led to draw on fresh theoretical ideas, in ways hidden to the traditional approach. Thus, these distribution dynamics empirics not only repair the failure in the traditional approach to represent reality accurately, they also generate new theories on economic growth and convergence.

The discussion below concentrates on income distributions across countries. It directly applies, however, to convergence and growth in other economic units as well. Thus, the criticisms of the traditional approach extend readily. They imply that the traditional approach cannot at all address the concerns of policy-makers interested in regional development, economic and geographical redistribution, and comparative economic performance. Instead, revealing analysis must be found elsewhere – possibly in extensions of the models of distribution dynamics described below.

The goal of the rest of this paper is to flesh out the points just made. The paper is not intended as a broad survey of all possible criticisms of the traditional approach. Rather, the coverage is selective. Section I highlights those aspects of conventional analyses relevant to the current discussion.

Section II describes that class of newer empirical findings that use distribution dynamics, and indicates the theoretical issues raised in such work. Section III concludes.

I. THE TRADITIONAL APPROACH

Traditional empirical analyses of growth and convergence derive from an elegant theoretical insight. This is that, in many growth models, equilibrium growth rates can be shown to be related to income levels through physical capital's relative contribution to national income (Barro and Sala-i-Martin, 1992; Romer, 1994; Sala-i-Martin, 1995; 1996). Developed explicitly, this insight gives a 'convergence equation' with growth on the left-hand side, explained by – among other things – income levels on the right.

In this reasoning, the cross-country correlation between growth rates and income levels is doubly interesting. It sheds light on the rate at which poor economies catch up with rich ones. Simultaneously, it informs on physical capital's importance for growth. Estimated on a wide range of data, this correlation implies a stable uniform rate of convergence equal to 2% a year. Thus, while the poor do eventually catch up with the rich, the speed with which this happens is low: only half the gap between rich and poor is closed in 35 years. Moreover, the implied contribution of physical capital to aggregate output is high – much higher than suggested by factor income shares in national income accounts.

The second of these implications raises a puzzle: if it is physical capital that is driving growth, why is it not being properly compensated by the market? This basic question has motivated research on externalities and endogenous technological progress (Romer, 1990). Such research seeks to explain the observed empirical regularities on convergence rates and capital's factor income share. At the same time, it resolves deep theoretical subtleties in the theory of economic equilibrium with non-rival commodities.

In the taxonomy given earlier, such analyses provide powerful insights on the growth mechanism. However, whether they help us understand the convergence mechanisms hinges on auxiliary assumptions. What is the nature of interaction across different countries? Are currently leading economies always the first to push back technology frontiers, and does new technology then always filter passively to poorer economies? Are there costs of adoption that lead to leap-frogging, where it is the temporarily follower economies that jump to being leader, because they find it easier to exploit new discoveries? Or, do persistent advantages accrue to the leader, richer countries, simply by virtue of their already being leader and richer? Do poorer economies need to overcome poverty-trap barriers before they can hope to catch up with richer ones?

Traditional cross-section regressions on the 'convergence equation' can address none of these issues. That they are revealing to the coefficient of physical capital in a production function is just that, no more and no less. Such exercises, while using dynamic information creatively, are part of a time-honoured practice in production-function accounting, and might be usefully compared to empirical analyses like those in Griliches and Ringstad (1971).

However, in the absence of auxiliary assumptions, they give no insight on whether poor countries are catching up with rich ones.

I show below that all the different possibilities relating rich and poor, described two paragraphs above, are consistent with a 'stable uniform 2% rate of convergence' – as estimated from the traditional convergence equation. Thus, a negative correlation between growth rates and levels says nothing about the poor catching up with the rich.[1] Contrary to claims made elsewhere, traditional empirics are completely silent on the important convergence dimension in economic growth.

To see this, I need to make explicit some ideas – empirical and theoretical – on the dynamics of large cross sections. We turn to this next.

II. DISTRIBUTION DYNAMICS

This section develops models of distribution dynamics to study the convergence hypothesis.[2]

Fix a year – say t – and consider the then-extant empirical distribution of *per capita* incomes across countries. Suppose that the density of that distribution is as plotted, at time t, in Fig. 1. That density shows some rich countries in the upper part of the distribution; a majority of middle-income countries in the middle part of the distribution; and some poor countries, in the lower.

There is a density for each year: Fig. 1 plots, at $t+s$, the density at some date in the future from t. As drawn, two suggestive classes of features of Fig. 1 should be noted. The first class constitutes the *location*, *shape*, and other external characteristics of the distributions at different times: these can, in general, fluctuate. The second comprises the *intra-distribution* dynamics, or churning-like behaviour – indicated by arrows in Fig. 1 – when individual economies transit from one part of the distribution to another. We consider these different features in turn.

Fig. 1 has drawn the income distribution at $t+s$ to be bimodal or twin-peaked: in the picture, there is a group of the rich, collecting together; a group of the poor, collecting together; and a middle-income class, vanishing.[3] There is no *a priori* reason for this. The $t+s$ distribution might well have been unimodal, and tightly concentrated at a single point: then, the researcher could, with some confidence, say the originally poor at t had, by $t+s$, attained equal footing with the originally rich. The researcher might even want to call that catching up.[4]

[1] Sometimes, evidence on that negative correlation comes only with additional conditioning, hence the term '*conditional convergence*.' Sometimes, in the traditional approach, that evidence is buttressed also with evidence on cross-sectional standard deviations. While this last is marginally helpful, it remains potentially misleading: the next section shows why. As for conditional convergence, even in the best of all possible scenarios, all it could show is whether each country converges to its own steady state, different from that of other countries. It is a complete puzzle to me how this can be interesting for whether the poor are catching up with the rich.

[2] Emphases on the empirics of distribution characteristics and dynamics appeared earlier in the personal income distribution literature, e.g., Atkinson (1970) and Shorrocks (1978).

[3] Why say 'twin peaks' rather than just 'bimodal', or make up the word 'twin-peakedness' rather than simply use 'bimodality'? Despite having more letters, the former contain fewer syllables.

[4] Something like this must be what European Commission policy makers have in mind when they talk about achieving cohesion or equity across rich and poor regions in Europe.

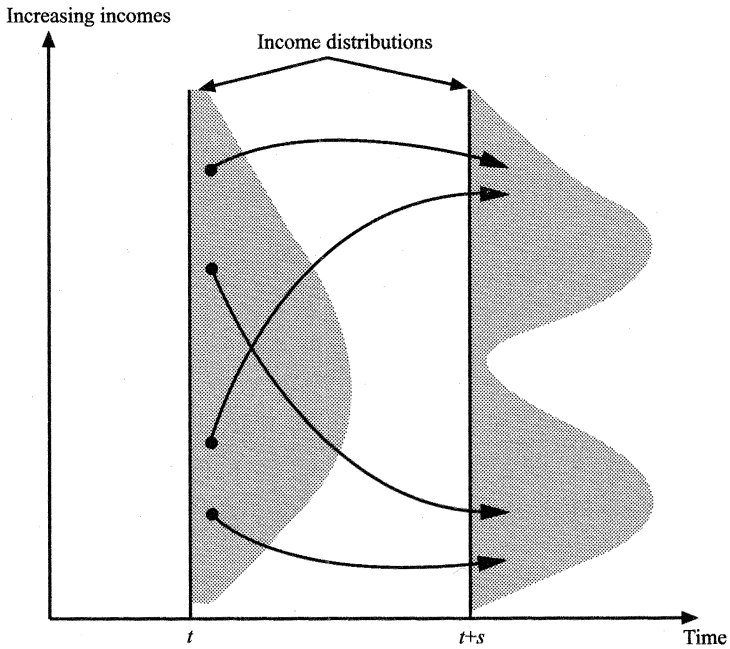

Fig. 1. Twin-peaks distribution dynamics.

If time $t+s$ is within the researcher's data sample, then a hypothesised tendency towards twin-peakedness can be examined directly from observed data. If, however, time $t+s$ is beyond the available sample, then a model is needed before the researcher can reach a conclusion on this.

Is the twin-peakedness drawn in Fig. 1 more than just whimsy and artistic licence? Below, I describe empirical techniques to study this. The quick answer is that the world cross-section of countries does show such tendencies. There is even evidence that twin-peakedness can already be observed for $t+s$ within current data samples. However, twin-peakedness will certainly not be seen if all the researcher does is calculate means, standard deviations, third moments, and so on, of the cross-section distributions.

Turn now to intra-distribution dynamics. It does not take a high-tech econometrician to note that, in the world, there are some rich countries that have remained rich for long periods of time, and, similarly, that there are some poor countries that have remained poor. Casual observation also readily comes up with examples of rich countries that have transited to being relatively poor; poor countries, to relatively rich; and groups of countries, beginning at similar levels of development, eventually diverging, with some becoming richer, and others, poorer. (Korea and the Philippines are the usual examples for the last.) Put briefly, one sees a broad range of intra-distribution dynamics.

Next consider the intra-distribution arrows drawn in Fig. 1. Just as cross-sectional standard deviations give no insight on potential twin-peakedness in the distribution, they say nothing either about churning within the cross section. Understanding these intra-distribution dynamics, however, would

inform on the dynamics of the poor catching up with the rich. It would inform on the poor stagnating within poverty traps; on the poor overtaking those previously rich; and on convergence club dynamics – sub-groups or clubs forming, with member countries converging towards each other, and diverging away from different clubs. It would shed light on possibilities for the poorest 5 % of the cross section catching up with the richest 5 %; and on whether global development takes multi-tier forms. Intra-distribution dynamics include information on switches in ranks – the leading country falling to seventeenth position, or *vice versa* – but, more than that, they also include information on the distance traversed when such switches happen.

I have just described some characteristics of (cross-country income) distribution dynamics that will be of interest in discussing convergence. Formalising this description offers two payoffs: first, precise statistical quantification; second, theoretical analysis based on economic ideas.

The simplest useful model of distribution dynamics is one where a stochastic difference equation describes the evolution of the sequence of distributions. Let F_t denote the time t cross-country income distribution. Associated with each F_t is a probability measure λ_t, where

$$\forall y \in \mathbb{R}\colon \lambda_t((-\infty, y]) = F_t(y).$$

A stochastic difference equation describing distribution dynamics is then

$$\lambda_t = T^*(\lambda_{t-1}, u_t), \quad \text{integer } t, \tag{1}$$

where $\{u_t\colon \text{integer } t\}$ is a sequence of disturbances, and T^* is an operator mapping the Cartesian product of probability measures with disturbances to probability measures. (Needless to say, the first-order specification in (1) is just a convenience for the discussion. Nothing substantive hinges on it, and the model easily generalises to higher-order dynamics.)

Since our concerns include intra-distribution dynamics, (1) has to record more than just means and standard deviations – or more generally – of a finite set of moments of the distribution sequence $\{F_0, F_1, \ldots\}$. Equation (1) takes values that are measures, rather than just scalars or finite-dimensioned vectors, and thus differs from the typical time-series model.

The structure of T^* reveals if dynamics like those in Fig. 1 occur. Estimated from observed data, T^* allows empirical quantification of those dynamics. Economic hypotheses restrict T^* in particular ways: they therefore provide predictions on how λ_t, and thus the distributions F_t, can evolve over time.

Just as in time-series analysis, the researcher might seek to understand T^* by its 'impulse response function': set the disturbances u to zero, and run the difference equation forwards.

$$\begin{aligned} T^*(\lambda_{t+s-1}, 0) &= T^*(T^*(\lambda_{t+s-2}, 0), 0) \\ &\vdots \\ &= T^*(T^*(T \ldots (T^*(\lambda_t, 0), 0) \ldots 0), 0), \end{aligned} \tag{2}$$

with the result being a proxy for λ_{t+s}. Then, convergence in country incomes to equality might be represented by (2) tending, as $s \to \infty$, towards a

degenerate point mass. Alternatively, the world polarising into rich and poor might be represented by (2) tending towards a two-point measure: the implied limit distribution F_{t+s}, $s \to \infty$, would then be bimodal or twin-peaked. More generally, stratification into different convergence clubs might manifest in (2) tending towards a multi-point, discrete measure, or equivalently, a multi-modal distribution. How quickly a given initial distribution, F_0, evolves into the limiting distribution, F_{t+s}, $s \to \infty$, can be read off T^*'s (spectral) structure.

Finally, T^* also contains information on intra-distribution dynamics. Exploiting that structure, one can quantify the likelihood of the poor catching up with the rich, and characterise the (random) occurrence times for such events.

In summary, studying T^* informs on all the interesting issues in convergence analysis. What then does empirical evidence – the Summers–Heston (1991) data – tell us about T^* and Fig. 1? Desdoigts (1994), Lamo (1995), Paap and van Dijk (1994), and Quah (1993*a*, *b*; 1996*a*) take the approach of estimating – in some form – the operator T^*. Some of this work views estimating T^* as an exercise in nonparametric analysis, others, in semi-parametrics; yet others take discretisations of λ, whereupon T^* becomes just a stochastic matrix. The important insight driving these methods is not a technical one, say, of greater flexibility in estimating a 'convergence equation' regression. Rather, it is that all these methods provide a global, entire picture of what happens with incomes across countries. For cross-country data, all the research just mentioned find T^* having features that imply 'twin-peaks' dynamics.[5] Estimated T^*'s indicate that clustering or clumping together of country incomes – convergence club behaviour – occurs eventually, Estimated T^*'s reveal precise descriptions of events where economies, initially starting out close together, diverge over time towards either of the twin peaks. Thus, the empirical evidence shows all the features hypothesised in Fig. 1.

Durlauf and Johnson (1995) side-step analysing T^* directly. Instead, they estimate cross section regressions, but allow the regression to 'adapt' subsamples, depending on data realisations. This innovative empirical technique permits consistently uncovering local basins of convergence. Durlauf and Johnson find evidence for the kind of multi-modal behaviour depicted in Fig. 1. They interpret their findings as multiple regimes; in the distribution-dynamics framework here, multiple regimes and multi-modality are indistinguishable.

Bianchi (1995) takes yet a third approach to studying twin-peakedness. As in Durlauf and Jonson (1995), Bianchi eschews dealing directly with T^*. Actually, he goes even further, and considers each distribution F_t, in isolation, ignoring dynamic information. Bianchi estimates each F_t non-parametrically, and then applies to each a bootstrap test for multi-modality. He finds that in the early part of the sample (the early 1960s), the data show unimodality. However, by the end of the sample (the late 1980s) the data reject unimodality in favour of bimodality. Since Bianchi imposes less structure in his analysis –

[5] Ben-David (1994) takes a different approach, but with end results that have the same interpretation.

nowhere does he consider T^* dynamics – one can reasonably guess that his findings are more robust to possible misspecification. Here again, twin-peakedness manifests.

It is obvious that calculating standard deviations or any other moment of the cross section distribution can show nothing about twin-peaks dynamics. The cross-section correlation between growth rates and income levels reveals even less, its interpretation plagued by a version of Galton's Fallacy.[6] However, operator T^* *can* shed light on that seductive intuition – the poor growing faster and thereby catching up with the rich – that growth-on-levels regressions wish to exploit. Quah (1996*a*) calculates, from an estimated T^*, the probability density of passage times from poor parts of the income distribution to rich parts.[7] He finds that although growth miracles – the Hong Kongs, the South Koreas, and the Singapores – can happen with reasonable positive probability, the passage time from the bottom 5% percentile to the top, given the magnitude of the gap extant, averages in the hundreds of years. Thus, persistence and immobility characterise the world cross section of country incomes.

(Although their being stated with T^*-induced preciseness is new with the body of research that I have just summarised, all such empirical facts have long been used informally in work such as Lucas (1988, 1993)).

What new economic ideas do these distribution dynamics suggest? These dynamics draw attention towards the nature of cross-country interactions – although, to be clear, not entirely away from production function accounting. They suggest that an appropriate test of economic ideas about the convergence hypothesis will come from looking at implications on how the entire cross section distribution evolves, not from studying the behaviour of a single, representative economy.

A theoretical model of distribution dynamics – in generational earnings – was developed by Loury (1981). Many of those technical modelling ideas apply here as well, although the current emphasis on clustering and coalition formation across individual elements of the distribution is novel. This focus on cross-sectional grouping does, however, mesh with recent econometric research (Brock and Durlauf, 1995; Manski, 1993).

That particular economic features – threshold externalities, capital market imperfection, heterogeneity, country size, club formation – might produce 'twin peaks' dynamics across countries can be seen in theoretical models in Azariadis and Drazen (1990), Galor and Zeira (1993), Quah (1995b, 1996a), and Tamura (1992). Quah (1995*b*, 1996*a*) most closely relates the theoretical message in these papers to empirical analysis.

The theoretical model in Quah (1995*b*) describes economic forces that determine coalition or convergence club formation. That model shows why

[6] This connection is made in Friedman (1992) and Quah (1993*b*, 1996*b*). Quah (1996*b*) also details why no combination of β-convergence and σ-convergence (in the terminology of Barro and Sala-i-Martin (1992) and Sala-i-Martin (1995, 1996)) can provide a satisfactory work-around.

[7] Durlauf and Johnson (1994) have studied similar phenomena in the dynamics of personal income distribution.

'conditional convergence' in the traditional approach can be misleading: when different convergence clubs form, factor inputs (e.g. human capital) and social characteristics (e.g., democracy) will endogenously align around values determined by each country's convergence club. Conditioning on such 'explanatory variables' leads the researcher using the traditional approach to conclude, erroneously, that it is those variables that determine a country's economic position. By contrast, in the model, it is the factors deciding club membership that determine everything. The traditional researcher never finds those, and incorrectly attributes growth and convergence to factor inputs and social characteristics. Moreover, because in that traditional approach, the researcher only estimates a cross-section regression, he sees only the behaviour of the (conditional) representative economy. He will never detect the multi-peakedness that arises in the cross-country distribution.

Similar lessons manifest in the model in Quah (1996*a*). Here, it is varying degrees of capital market imperfection that lead to twin-peaks dynamics in the model. In the traditional approach, the researcher might simply proxy the capital market imperfectness by interest rates, say. However, in the model, all countries eventually have equal rates of return for borrowing and investment. The traditional researcher, therefore, never finds out the reason why twin-peaks dynamics occur – not that he ever even realises their presence. Moreover, the model predicts that every country converges (in a univariate sense) to its own steady state at an identical rate shared by all other countries. The traditional researcher then finds exactly a globally stable, constant rate of 'convergence' in the traditional conditional convergence regression. Such a finding, however, sheds no light on the actual distribution dynamics occurring.

III. CONCLUSION

With hindsight, the key point in this paper is obvious. Convergence concerns poor economies catching up with rich ones. What one wants to know here is, what happens to the entire cross sectional distribution of economies, *not* whether a single economy is tending towards its own, individual steady state. However, it is the latter that has preoccupied the traditional approach. Proposed fixes to that approach (e.g., the increased emphasis on σ-convergence in Sala-i-Martin (1995)) continue to miss the principal important features of economic growth and convergence.

Such criticisms would be merely idle if there were no alternative empirics that appropriately address the key issues relevant to convergence analysis. This paper has described a rich and growing body of research that does exactly that. The new findings reported here – on persistence and stratification; on the formation of convergence clubs; on the distribution polarising into twin peaks of rich and poor – suggest the relevance of a class of theoretical ideas, different from the production-function accounting favoured by the traditional approach. It might, ultimately, be those factors that are important for growth, not just crudely boosting the inputs in a neoclassical production function.

Many issues remain to be researched in this alternative approach. The

empirical analyses of distribution dynamics can be substantially refined: Quah (1995*a*, *c*) explore some ways to do this. Theoretical models for cross-country, or more general social, interaction (e.g., Benabou (1995); Brock and Durlauf (1995); Quah (1995*b*), among many others) provide new insights on how economies evolve – and, in turn, generate intriguing new predictions to be studied empirically.

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