Convergence by Parts*

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Abstract

This paper investigates Quah's finding that the cross country distribution of per capita income is moving toward a twin peaked distribution, that is, a state with a group of countries with low incomes, a group of countries with high incomes and few countries in between. This finding has supported and encouraged a large theoretical literature on development traps which produce twin peaks through physical and human capital accumulation. Contrary to these models, physical and human capital are found to be moving toward single peaked distributions. The productivity residual is moving toward a twin peaked distribution which mirrors that of per capita income. It is therefore concluded that Quah's result is driven by productivity differences rather than factor accumulation. This result mirrors recent work by Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) which emphasize the importance of productivity differences. A further examination uncovers dynamic externalities from factor accumulation and openness to productivity. Low levels of human capital and lack of openness to trade are potential causes of the lower peak in productivity.

Introduction

The persistence of extreme poverty in much of the world is one of the most vexing problems facing students of economic growth. Output per worker in the poorest nations is less than 5% that of the United States. Unfortunately, there is little evidence that the group of poor countries is getting smaller over time. In fact, there is some evidence that it may be getting larger.

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Quah (1993b) concludes that world income is moving toward a twin peaked distribution, with a cluster of rich countries and a cluster of poor countries.[1] Countries in the middle of the distribution appear to be transitioning to one of the extreme groups in the long run. The upper and lower income clusters of countries are commonly referred to as convergence clubs.[2] Understanding the nature of the low income "club" is crucially important if we wish to develop strategies to eliminate it.

There is a large theoretical literature which both anticipates and draws support from Quah's finding. This literature focuses on models where per capita income has multiple, locally stable steady states. A low income steady state is often referred to as a development or poverty trap. In these models it is possible for two countries with identical preferences and identical production technologies to end up in very different long run steady states due to different initial conditions. This is consistent with Quah's finding.

There are three distinct classes of models of development traps that can be identified in the theoretical literature: physical capital models, human capital models, and productivity models. All three classes of models can potentially explain Quah's twin peaks in per capita output.[3]

The first two types of development trap models rely on differences in rates of factor accumulation. The first class of models finds multiple equilibria in physical capital accumulation. Suppose, for example, that fertility and income are endogenously related so that rich countries have low fertility and poor countries have high fertility. It is easy to show that this can produce two steady states in physical capital accumulation. There is one stable steady state with a high level of physical capital and low fertility and another with a low level of physical capital and high fertility. The second class of model similarly produces multiple steady states in the level of human capital. Through a production function, multiple steady states in physical and human capital translate into multiple steady states in per capita output.

The third class of development trap models rely on productivity differences to produce convergence clubs in output. In some models, multiple steady states are generated through productive externalities to capital accumulation. In others, explicit modeling of technological spillovers can results in a low technology trap that is unconnected to factor accumulation.

This paper will look at the connection between the theoretical literature on

[1] Durlauf and Johnson (1995), using a regression tree analysis, also find empirical support for the existence of convergence clubs

[2] The phrase "convergence club" seems to make its first appearance in the literature in Baumol (1986).

[3] This breakdown between the two accumulable factors of production and productivity mirrors the development accounting work of Hall and Jones (1999) and Klenow and Rodriguez-Clare (1997).

development traps and Quah's twin peaks. I will exploit the fact that the central implication for each of the three types of development trap models is not twin peaks in per capita output, but twin peaks in physical capital, human capital, or productivity. Using the techniques suggested by Quah, I examine the distributions of physical capital and human capital unmediated by a production function. Following a development accounting approach similar to the cross sectional work of Hall and Jones (1999), I calculate a productivity residual for each country over time and examine its distribution.

My results suggest that the distributions of physical and human capital are moving toward single peaked distributions. The technological residual is found to be moving toward a twin peaked distribution like that found by Quah in per capita output.[4] It therefore appears that productivity differences are driving Quah's twin peaked result.

The finding that productivity is at the root of the twin peaks in per capita income mirrors recent empirical work emphasizing the importance of productivity in explaining cross country income differences. In contrast to Mankiw, Romer and Weil (1992), Klenow and Rodriguez-Clare (1997) conclude that productivity differences account for 70% of cross country income differences.

These results suggest that discovering the root causes of productivity differences is essential to understanding convergence clubs. This does not necessarily mean that we should ignore factor accumulation altogether. The theoretical models of convergence clubs tend to be monocausal and the origins of convergence clubs may lie in the interactions between factor accumulation and productivity differences.

Many factors which have been identified as important in determining productivity differences between countries. The productive environment in different countries varies enormously. As noted by Hall and Jones (1999) and others government institutions, language, and geography all play a large part in determining relative productivity levels. However, these factors all tend to change slowly over time and may not be particularly useful in explaining the distributional dynamics exhibited by the productivity residual.

It may be useful to think about productivity changes for most countries in the world as a process of adopting productive technologies developed at the technological frontier. Factor accumulation may play an important role in the ability of countries to take advantage of technological spillovers.

[4] In the language of the convergence literature, there is β convergence if a variable is tending toward the same long run level in all countries and there is σ convergence if the distribution of a variable is narrowing. This paper will show that there is β and σ convergence in the ratio of physical capital to output and in human capital. The productivity residual exhibits β divergence.

To this end, I examine the joint distributions of (physical and human) capital and productivity. If there are linkages between factors and productivity this should become evident in the evolution of the joint distributions. The results suggest that factor accumulation may have important dynamic effects on productivity. In the long run, countries with high human capital end up in the upper peak in productivity and countries with low levels of human capital cluster at the low productivity peak. The interaction between human capital and productivity may be causing the lower peak in productivity.

This results is potentially hopeful, because the examination of the human capital distribution indicates movement out of the low human capital ranges. The joint distributions seem to indicate that the low peak in productivity will disappear as the number of low human capital countries diminishes. The low peak in productivity may therefore be a transitory phenomenon. Causality, however, is a potential problem as a similar result is found for openness to trade.

Section 1 of the paper explains the twin peaked result for output per capita and reviews the literature on development traps. Section 2 examines the evolution of the distributions for physical capital, human capital, and productivity. Section 3 looks at static and dynamic externalities to factor accumulations through the marginal distributions of productivity with respect to physical and human capital. Section 4 examines the dynamic effects of openness on productivity.

1 Development Traps and Twin Peaks

The following analysis is based on the examination of the long run distribution of per capita income in Quah (1996b). Quah finds that, in the long run, per capita income is moving toward a twin peaked distribution. That is, the world distribution of income per capita is moving toward a state where there is a significant group of poor countries and a group of wealthy countries with few countries in the middle.

The evolution of the world distribution of income per capita is modeled as a first order Markov process. Let λ_t represent a measure of the distribution of income per capita across countries at time t. The distribution evolves according to

$$\lambda_{t+1} = M * \lambda_t \tag{1}$$

where M is a stochastic kernel that maps the distribution at time t into the distribution at time $t+1$. The simplest and most tractable way to construct a measure of the distribution, λ_t is to divide the distribution into discrete blocks. Given the distribution at time t it is possible to iterate (1) to estimate the distribution at any future time $t + s$

$$\lambda_{t+s} = M^s * \lambda_t \tag{2}$$

Taking the limit of (2) as $s \to \infty$ yields the long run, or ergodic, distribution implied by the transition matrix. The ergodic distribution, λ_E, has the property that

$$\lambda_E = M * \lambda_E \tag{3}$$

The analysis will be based on a comparison of the ergodic distribution with the observed distribution of the data.

In order to generate a discrete distribution of real GDP per capita, I divide the ratio of RGDPC to the world average into five bins divided by relative RGDPC levels 0.24, 0.50, 0.85, and 2.02.[5] These values were chosen because it divides the data into equal groups. With a discrete λ_t, M is simply a matrix of transition probabilities. Table 1 is an estimate of the transition matrix for real GDP per capita between 1970 and 1989. The first column represents real GDP per capita at time t relative to the world mean. Each column to the right represents the probability that real GDP per capita will be at a particular level relative to the world average at time $t + 1$ given the time t state from the first column. The final column is the distribution of initial values, 20% for each range.

Table 1: Transition Matrix for RGDPC, 1970-1989

	$RGDPC_{t+1}$					
$RGDPC_t$	<24%	24-50%	50-85%	85-202%	>202%	freq
<24%	0.97	0.03				0.20
24-50%	0.04	0.92	0.04			0.20
50-85%		0.04	0.92	0.04		0.20
85-202%			0.04	0.94	0.02	0.20
>202%				0.02	0.98	0.20
Ergodic	0.23	0.15	0.15	0.18	0.28	
stderr	(0.09)	(0.05)	(0.05)	(0.06)	(0.15)	

RGDPC is expressed as a percentage of the within period mean, OBS = 1710

From bootstrap: $P\{(Q_1 + Q_5) > 0.4\} = 94.0\%$

[5]This differs slightly from Quah for the sake of consistency between RGDPC and the other variables. Quah uses 1/4, 1/2,1, and 2, a set of even numbers which come close to generating an equal distribution of data points for RGDPC. Because I will be comparing the ergodic distribution of RGDPC with other variables it seemed reasonable to generate all the discrete distributions in the same way.

In the ergodic distribution, 23% of countries have less than 24% of the world average for per capita GDP compared to only 20% in the data. Similarly, 28% of the countries in the ergodic distribution have greater than 202% of the world average compared to only 20% in the data. For each of the three central groups, the ergodic distribution contains less countries than observed in the data. This movement of the distribution away from the central groups and into the lowest and highest groups characterizes the twin peaked result.

Quah presents his results without standard errors and without a discussion of the significance of the results, an omission which makes it difficult to interpret the results. I will attempt to improve upon this situation by using a bootstrap procedure. The original data was resampled 10000 times and a transition matrix and ergodic vector were calculated in each case. The standard deviation for each element of the ergodic vector is reported. The standard errors are admittedly quite large, so no strong inferences can be made about any individual element. However, the interesting feature of the ergodic vector is not any individual element, but the shrinking of the center of the distribution relative to the tails. Let Q_1 through Q_5 represent the five values of the ergodic distribution, one for each quintile. The null hypotheses is that the tails of the distribution are smaller or equal to the 40% found in the data:

$$H_0 : Q_1 + Q_5 \leq 0.40 \tag{4}$$

An examination of the bootstrap repetitions shows that $Q_1 + Q_5 \leq 0.40$ in only 6% of the cases. On this basis I reject the null hypothesis and conclude that the movement of the distribution toward the tails is significant.[6] Other evaluations of the bootstrap repetitions also suggest the significance of the twin peaked result. For each repetition, the locations of peaks in the ergodic vector were identified.[7] Only 1.2% of the repetitions were found to have a single peak located at one of the three central ranges.

[6] One objection to this characterization of twin peaks is that distributions with a large density on Q_1 or Q_5 will show an emptying of the middle even though they are by no means twin peaked. An examination of the bootstrap repetitions shows that only 5% are characterized by a single peak at either end.

[7] A peak is defined as an element of the ergodic distribution with smaller elements on either side. The end points are considered to be a peak if the single adjacent point is lower. Somewhat more formally, Q_i is a peak if $Q_i > Q_{i+1}$ and $Q_i > Q_{i-1}$ for $i = 2, 3, 4$. Q_5 is a peak if $Q_5 > Q_4$. Q_1 is a peak if $Q_1 > Q_2$.

1.1 Development Traps

The Quah result has supported and encouraged a large theoretical literature on development traps. If we assume a general production function taking physical capital, human capital, productivity as arguments, we would expect that the emerging twin peak result in output per capita will be mirrored in the distribution of one (or more) of the inputs. This is indeed the approach that the theoretical literature takes. The majority of models generate twin peaks in output by modeling twin peaks in one of the factors.

With regard to physical capital, there is some question as to the appropriateness of focusing on capital per worker. This paper's examination of physical capital will focus on the ratio of physical capital to output.[8] This formulation is valuable because it is independent of shocks to productivity. To see this we start with a simple Solow model with neutral technological progress:

$$y_{i,t} = A_{i,t}\ f(k_{i,t}) \tag{5}$$

$$\dot{k}_{i,t} = s_i A_{i,t} f(k_{i,t}) - (n_i + \delta) k_{i,t} \tag{6}$$

where $f(k_{i,t})$ is a neoclassical production function with decreasing returns to capital per worker, $A_{i,t}$ is an exogenous productivity parameter, $k_{i,t}$ is capital per worker, n_i is population growth, and δ is depreciation. We can state the requirements for a steady state where $\dot{k}_{i,t} = 0$.

$$(n_i + \delta)\ k^*_{i,t} = A_{i,t}\ f(k^*_{i,t})\ s_i \tag{7}$$

It can be shown that the steady state level of capital per worker, $k^*_{i,t}$ is an increasing function of the productivity level $A_{i,t}$. A shock to productivity will therefore produce an increase in the steady state level of capital per worker. On the other hand, the steady state level of the capital-output ratio,

$$\left(\frac{K}{Y}\right)^*_{i,t} = \frac{k^*_{i,t}}{A_{i,t}\ f(k^*_{i,t})} = \frac{s_i}{n_i + \delta} \tag{8}$$

is not a function of the productivity level. If twin peaks in capital per worker are being driven by endogenous fertility or endogenous saving rates, we should see twin peaks in the capital-output ratio as well as capital per worker. On the other hand, if there are twin peaks in productivity, we would expect to see twin peaks in capital per worker, but *not* in the physical capital-output ratio.

[8] This approach follows Hall and Jones (1999) and Klenow and Rodriguez-Clare (1997)

Becker, Murphy and Tamura (1990), Galor and Weil (1996), Becker and Barro (1989), Murphy, Shleifer and Vishny (1989) and many others find development traps in physical capital accumulation.[9] These models share the feature that there can be multiple, history dependent equilibria in physical capital per worker *and* in the ratio of physical capital to output. If any of these models are to explain convergence clubs, the long run distribution of the physical capital-output ratio should display twin peaked characteristics.[10]

Azariadis and Drazen (1990), Durlauf (1993), Benabou (1996), Durlauf (1996), Durlauf (1993), Galor and Zeira (1993), Galor and Tsiddon (1997), Tsiddon (1992) and others similarly find that development traps can cause low levels of human capital accumulation.[11] These models share the feature that there can be multiple, history dependent equilibria in human capital per worker. If any of these models are to explain convergence clubs, the long run distribution of human capital should display twin peaked characteristics.

An additional possibility is that there are twin peaks in income per capita caused solely by productivity differences. Models of this sort are less common and more recent. Howitt (2000) presents a model where countries which engage in no R&D remain in a low productivity trap while R&D producing countries experience positive productivity growth. This model has the potential to generate twin peaks in productivity alone.

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[9] Physical capital development traps have a long history which predates convergence clubs. Nelson (1956) model capital traps related to endogenous fertility. Kuznets (1966) and others identify physical capital traps associated with impatience. The modern era of economic growth theory has provided a wealth of theoretical mechanisms for producing capital traps. Becker and Barro (1989), Becker et al. (1990), and Galor and Weil (1996) find capital traps caused by endogenous fertility. Murphy et al. (1989) produce physical capital traps in a multiple sector model with increasing returns in the manufacturing sector.

[10] Azariadis and Drazen (1990) present a simple model where the productivity level is a function of the level of capital per worker. This model will produce twin peaks in capital per worker and productivity, but not in the capital-output ratio. Any models which rely on productive externalities to physical capital accumulation will produce similar results. By focusing on the capital-output ratio, I am implicitly classifying these models as productivity driven. The same does not hold true for human capital. Because the analysis looks as human capital per worker, productive externalities to human capital will results in twin peaks for both human capital and productivity.

[11] Development traps relying on human capital are a more recent, but quite active area of research. Azariadis and Drazen (1990) finds that increasing returns to human capital accumulation can produce multiple equilibria. Galor and Zeira (1993) rely on imperfections in capital markets. Benabou (1996), Durlauf (1996) and Galor and Tsiddon (1997) explore the role of parental and local effects. Becker et al. (1990) rely on non-convexities in the production function of human capital. This list of references is hardly exhaustive. Azariadis (1996) and Galor (1996) survey the development trap literature in more depth

1.2 An Example

This section describes a model with multiple equilibria in physical capital. Suppose that each economy in the world is described by a modified version of the Solow model with a simple endogenous fertility setup. Output is produced in each country with an identical neoclassical technology that satisfies the standard Inada conditions. The saving and depreciation rates are exogenous. The rate of population growth is a function of the level of capital per worker.

$$y_{i,t} = f(k_{i,t}) \tag{9}$$

$$\dot{k}_{i,t} = sf(k_{i,t}) - (n_{i,t} + \delta)k_{i,t} \tag{10}$$

$$n_{i,t} = \begin{cases} n_1 & : \quad k_{i,t} < \bar{k} \\ n_2 & : \quad k_{i,t} > \bar{k} \end{cases} \tag{11}$$

$$n_1 > n_2$$

Countries below the threshold level of capital per worker, $\bar{k}$, have high levels of fertility while countries with a level of capital per worker above the threshold have low fertility. This roughly corresponds to the observed patterns of fertility in the world. Poor countries have higher fertility than rich countries. Figure 1 graphs equation (10) and shows a case where there are two stable equilibria.[12]

For any given country the eventual equilibrium is determined by the initial conditions. Countries which start with capital intensities below $\bar{k}$ converge to the lower equilibrium, while countries with initial capital intensities above $\bar{k}$ converge to the upper equilibrium. Through the production function, capital per worker translates directly into output per worker.

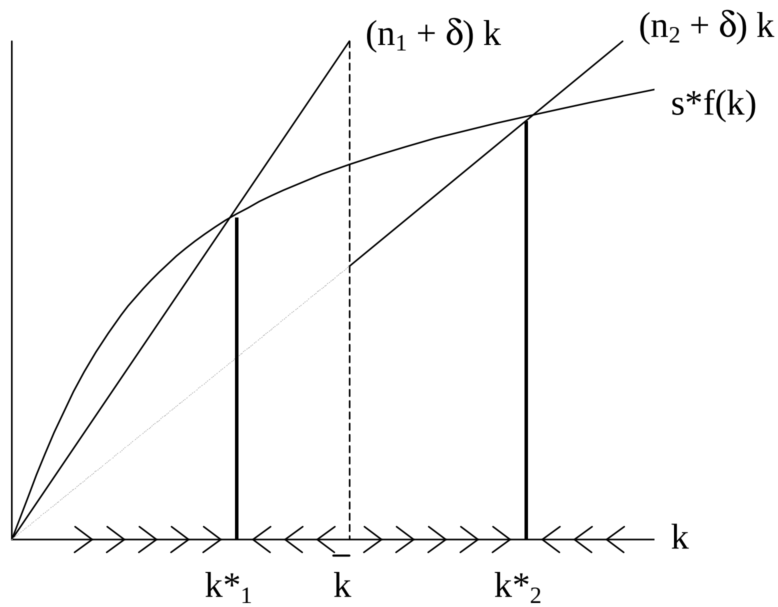
While this model is deliberately simple, it provides a possible explanation for Quah's result. The previously cited factor accumulation papers use more complex models with explicit microfoundations, but all share the feature that there are multiple, history dependent equilibria in (physical or human) capital per worker which can translate directly into twin peaks in per capita income.

2 The Evolution of the Distributions

The next two sections will examine the long run distributions of physical and human capital. This examination relies entirely on the data and does not rely on any specific production function. The results will be used to determine the validity of factor

[12] There is an additional, unstable equilibrium at $k = 0$.

Figure 1: Multiple Equilibria Due to Endogenous Fertility



accumulation models of development traps. I will then assume a particular form for the production function to calculate a productivity residual and evaluate its long run distribution.

2.1 Physical Capital

The examination of physical capital will focus on the ratio of physical capital to output. Physical capital stocks are taken from Easterly and Levine (2000).[13] Output is taken from the Penn World Tables. Table 2 is an estimate of the transition matrix for K/Y. The endpoints of the ranges are chosen so that approximately 20% of the observations fall into each range.

The ergodic vector indicates that the distribution of the capital-output ratio is moving toward a single peak centered between the third and fourth groups. In the data 40% of the observations are in these two groups (with between 83% and 147% of the world average for K/Y). This number increases to 51% in the ergodic distribution. There is also clear movement out of the lowest K/Y range (from 20% to 12%). There are no indications that K/Y is moving toward a twin peaked distribution.

Again, I examine the significance of the ergodic vector by using a bootstrap

[13] Their calculations, in turn, are based on the Penn World Tables 5.6. Both are available from the World Bank website (http://www.wordbank.org/research/growth)

Table 2: Transition Matrix for Physical Capital, 1970-1989

	$(K/Y)_{t+1}$					
$(K/Y)_t$	<55%	55-83%	83-111%	111-147%	>147%	freq
<55%	0.96	0.04				0.20
55-83%	0.03	0.89	0.08			0.20
83-111%		0.06	0.86	0.09		0.20
111-147%			0.08	0.86	0.06	0.20
>147%				0.08	0.92	0.20
Ergodic	0.12	0.18	0.25	0.26	0.19	
stderr	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	

K/Y measured as a ratio to the within period world mean, OBS = 1710

From bootstrap: $P\{(Q_1 + Q_5) > 0.4\} = 4.1\%$

procedure. Based on the standard error alone the ergodic weight in quartile one is significantly away from 0.20 at the 95% level. Furthermore, in over 95% of the bootstrap repetitions, the weight on the central three elements of the distribution is larger than in the data. The movement of the distribution toward a single, centrally located peak appears to be significant.

This result may be better understood in terms of the relationship between K/Y and the marginal product of capital. Assume a Cobb-Douglas Production function,

$$Y_{i,t} = K_{i,t}^{\alpha}(A_{i,t}\ H_{i,t})^{1-\alpha} \tag{12}$$

where $Y_{i,t}$ is output, $Y_{i,t}$ is the capital stock, $H_{i,t}$ is the human capital stock, and $A_{i,t}$ represents productivity. The marginal product of capital can be expressed in terms of the capital-output ratio.

$$MPK_{i,t} = \alpha \left(\frac{Y}{K}\right)_{i,t} \tag{13}$$

According to equation (13), the observed convergence of K/Y would imply convergence of the marginal product of capital around the world. Table 3 is a transition matrix for MPK.

The ergodic vector is quite different from the distribution of MPK in the data. There is strong movement in the distribution of MPK away from the highest levels toward a single peak at the lowest range. Twenty percent of the data has MPK higher than 39% while only 4% of countries remain there in the ergodic distribution. Since the column headings represent the gross return to capital, a depreciation rate

Table 3: Transition Matrix for the Marginal Product of Capital, 1970-1989

	$(MPK)_{t+1}$					
$(MPK)_t$	<14%	14-19%	19-26%	26-39%	>39%	freq
<14%	0.94	0.06				0.20
14-19%	0.08	0.86	0.06			0.20
19-26%		0.09	0.85	0.06		0.20
26-39%			0.11	0.87	0.02	0.20
>39%				0.06	0.94	0.20
Ergodic	0.36	0.29	0.19	0.11	0.04	
stderr	(0.07)	(0.04)	(0.04)	(0.03)	(0.02)	

of 5% corresponds to a very plausible real rate of return of 9% separating the two lowest ranges. This result is highly significant. All but the central range are significantly away from 0.20 at the 95% level.

The ratio of physical capital to output is moving toward a single peak at a level that corresponds to current OECD capital-output ratio.[14] This can be seen in a simple graph of the data over time. Figures 2 and 3 graph average MPK between 1965 and 1990 for samples grouped by income and region respectively. The movement toward the OECD level of MPK is evident for all income and regional groups except the South Asian group which contains a very small sample.[15]

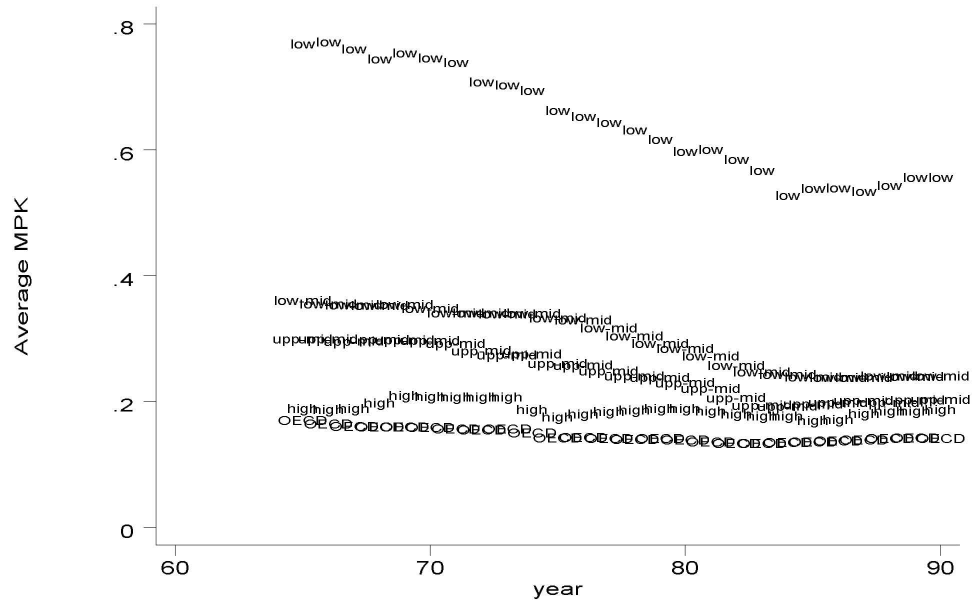
The finding of a single peaked ergodic distribution of the physical capital-output ratio is the strongest convergence result of this paper and indicates that the twin peak result in real GDP per capita is not being driven by physical capital accumulation. The strength of this result is surprising for a number of reasons. First, even in a world with perfect capital mobility, there are good reasons why the capital-output ratio (and therefore the marginal product of capital) should vary across countries. The risk of capital losses due to appropriation, natural disaster, and war should drive K/Y down in countries where these are looming threats. More importantly, if capital mobility is limited, differences in saving rates and population growth rates should be reflected in K/Y differences.[16] Of course, the convergence of K/Y described does not mean that these effects are disappearing entirely, just that they

[14] In the language of the convergence literature, there is absolute β and σ convergence in the distribution to the OECD level.

[15] The South Asian (SA) regional grouping contains only four countries, India, Pakistan, Bangladesh, and Sri Lanka

[16] Feldstein and Horioka (1980) bears directly on this point. If savings and investment are highly correlated and K/Y is converging, this implies that saving and population growth rates around the world are converging.

Figure 2: Average MPK by Income Group



Income groupings are low, high, upper middle, high-non OECD, and OECD

are diminishing over time.

2.2 Human Capital

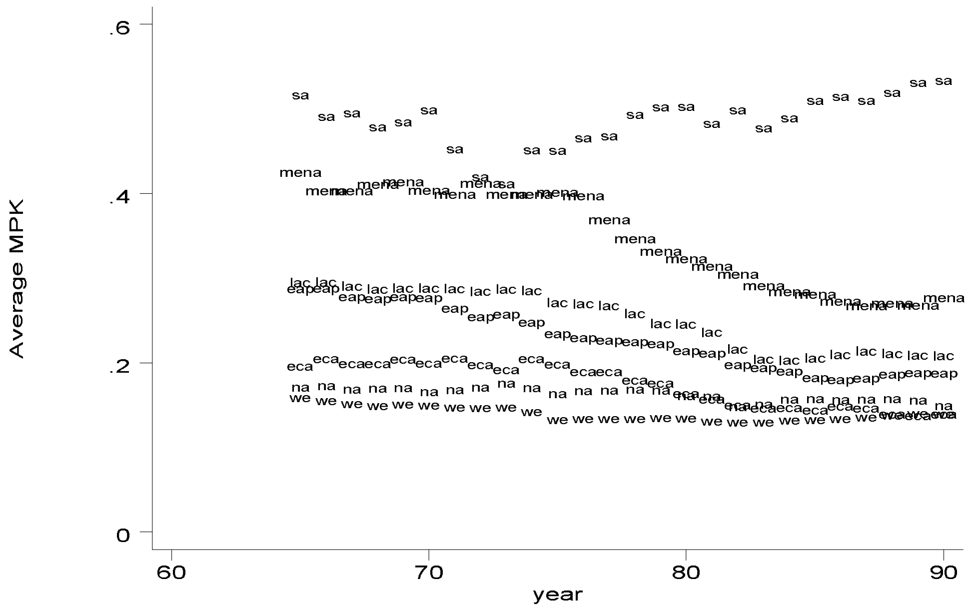
Human capital stocks are constructed following Hall and Jones (1999). Assume that the human capital production function takes on a Mincer form

$$h_{i,t} = e^{\phi(s_{i,t})} \tag{14}$$

where $\phi(s)$ is an increasing function that is assumed to be piecewise linear with decreasing returns to scale. The coefficients are taken from Psacharopoulos (1994), which surveys the literature on returns to schooling.[17] The data on schooling attainment is taken from Barro and Lee. The Barro-Lee data set is limited to 5 year intervals. In order to match schooling data to the yearly GDP and capital stock data, values were estimated using linear interpolation for the intervening years. Table 4 is an estimate of the transition matrix for the ratio of human capital to the world average.

[17]The choice of coefficients follows Hall and Jones (1999). For the first four years of schooling the return to schooling in sub-Saharan Africa, 13.4 percent, is used. For schooling from four to eight years the world average return to schooling, 10.1 percent, is used. For schooling beyond 8 years the OECD return to schooling, 6.8 percent, is used.

Figure 3: Average MPK by Region



Regional groupings are South Asia (sa), Middle East & North Africa (mena), Latin America (lac), East Asia & Pacific (eap), East Central Asia (eca), North America (na), and Western Europe (we)

Table 4: Transition Matrix for Human Capital, 1970-1989

	h_{t+1}					
h_t	<69%	69-82%	82-100%	100-129%	>129%	freq
<69%	0.98	0.02				0.20
69-82%	0.02	0.96	0.03			0.20
82-100%		0.01	0.97	0.01		0.20
100-129%			0.01	0.97	0.01	0.20
>129%				0.01	0.99	0.20
Ergodic	0.08	0.09	0.21	0.21	0.41	
stderr	(0.07)	(0.06)	(0.11)	(0.10)	(0.26)	

h measured as a ratio to the within period world mean, OBS = 1710

The ergodic distribution shows strong movement away from the lowest human capital ranges and into the highest range. There appears to be a single peak in the highest human capital range. There is no indication of a twin peaked distribution like that found for output per capita. A bootstrap analysis shows that the movement out of the lowest ranges is significant. Over 95% of the bootstrap repetitions show movement out of the bottom range. Quartile five has the highest value in 74% of the bootstrap repetitions.

This result is somewhat unsurprising for two reasons. First, for rich countries there tends to be an upper limit on the number of years an individual will spend in school.[18] This upper limit means that countries with low relative human capital have an easier time adding years to their education stocks than countries with high human capital stocks. second, because of decreasing returns, a year added in a low human capital country increases the human capital stock by more than a year added in a high human capital country. These two factors imply that we should see a compression upward in the human capital distribution which is exactly the result I find.

There are, however, several caveats. First, the result is based on limited data that is subject to significant measurement error. Second, the translation of years of education into a human capital stock is necessarily crude. There is no control for quality of education and differences in returns to education are based on generalized, aggregated findings. For this reason, the result is not particularly robust. Modest changes in the construction of human capital stocks can reduce the significance of the result.

It is worth noting that there is not a large amount of variation in levels of human capital across countries relative to the variation in world income.[19] There are no countries with less than 50% or more than 200% of the world average for human capital. For output per capita, 40% of the observations fall into these extreme categories. When you combine the overall lack of variation in human capital combined with the lack of twin peaks in the ergodic distribution, it is reasonable to conclude that human capital accumulation alone cannot explain the twin peaked result in per capital income.

2.3 The Productivity Residual

The previous two subsections show that factor accumulation cannot explain Quah's twin peaked result. Following the recent work of Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) focusing on productivity, I will calculate a productivity residual using the previously described data on physical and human capital. Unlike these papers, I will focus on the time dimension of the data to examine the long run distribution of productivity.

[18] In the extreme, the number of years of schooling is limited by life span

[19] This result is examined in more detail in Klenow and Rodriguez-Clare (1997). They find that human capital accumulation accounts for only a small portion of differences in income per capita.

The physical capital and human capital results did not require a specific form for the production function. In order to calculate the productivity residual I assume a Cobb-Douglas production function taking physical capital, human capital, and productivity as inputs.

$$y_{i,t} = k_{i,t}^{\alpha}(A_{i,t}\ h_{i,t})^{1-\alpha} \tag{15}$$

where $y_{i,t}$ is output, $k_{i,t}$ is capital per worker, $h_{i,t}$ is human capital per worker, and $A_{i,t}$ represents productivity. This can be rewritten in terms of the capital-output ratio, and solved for the productivity term.

$$A_{i,t} = \frac{y_{i,t}}{\left(\frac{K_{i,t}}{Y_{i,t}}\right)^{\frac{\alpha}{1-\alpha}} h_{i,t}} \tag{16}$$

Table 5 is an estimate of the transition matrix for the productivity residuals taken as a ratio with the world average. The ergodic vector for the productivity

Table 5: Transition Matrix for the Productivity Residual, 1970-1989

			A_{t+1}			
A_t	>53%	53-76%	76-105%	105-148%	>148%	freq
<53%	0.95	0.04				0.20
53-76%	0.08	0.85	0.08			0.20
76-105%		0.10	0.81	0.09		0.20
105-148%			0.09	0.82	0.08	0.20
>148%				0.05	0.95	0.20
Ergodic	0.30	0.18	0.15	0.15	0.23	
stderr	(0.07)	(0.04)	(0.03)	(0.03)	(0.06)	

A measured as a ratio to the within period world mean, OBS = 1710

From bootstrap: $P\{(Q_1 + Q_5) > 0.4\} = 98.8\%$

residual is remarkably similar to the ergodic vector for per capita income. There are increases in both the highest and lowest productivity ranges with movement out of the three central ranges.

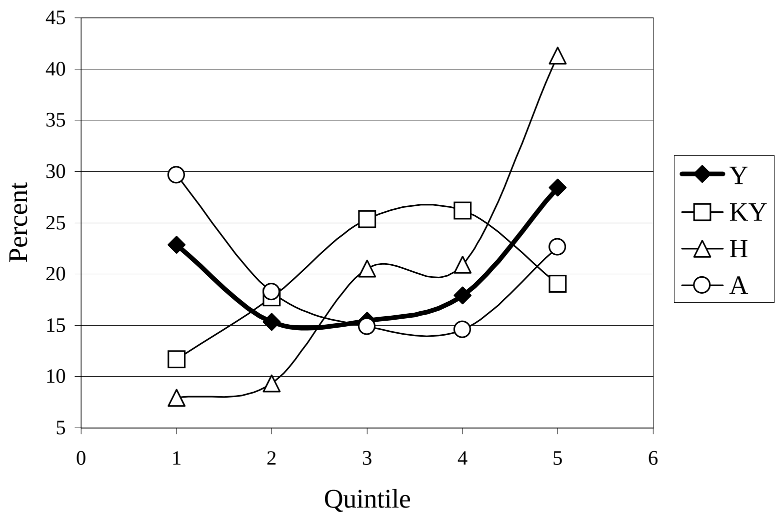
This result is highly significant. While the individual standard errors are quite large, 98.8% of the bootstrap repetitions show movement into the tails of the distribution. Less than 3% of the bootstrap repetitions were found to have a single peak. The results is also quite robust to changes in the construction of human capital.[20]

[20]Since the productivity residual is a function of human capital, the sensitivity to changes in specification exhibited by human capital could potentially infect the productivity results. This does not appear to be the case.

2.4 Implications

Figure 4 summarizes the ergodic distributions for output, physical capital, human capital, and productivity. Comparing the ergodic distributions indicates that the

Figure 4: Comparison of the Ergodic distributions



twin peaks in per capita income observed by Quah are not evident in either physical capital or human capital, but are discernible in the productivity residual term. I therefore conclude that the origin of the twin peaks result for income is a result of productivity differences and not the accumulation of the factors of production. Multiple equilibrium models which rely solely on factor accumulation appear to be unsupported by the data.

To those familiar with the empirical growth literature, the conclusion that productivity (and not the factors of production) is to blame for poverty traps will come as no surprise. In the wake of Mankiw et al. (1992) (MRW) panel studies by Islam (1995), Caselli, Esquivel and Lefort (1996), and others have shown that accounting for differences in the level of productivity across countries significantly alters the MRW conclusions and shifts the focus from factors to productivity. The relative importance of technology was given further weight by the work of Klenow and Rodriguez-Clare (1997) who concluded that productivity differences account for 70% of cross country income differences.

In order to understand the origin of the twin peaks result, more attention needs to be paid to the idea of multiple equilibria in productivity. Howitt (2000) is one example of a model of this type. Countries which engage in no R&D remain in a low productivity trap while R&D producing countries experience positive productivity growth due to spillovers of technology from other R&D producing countries.

Generalizing from Howitt's model, a possible explanation of twin peaks in productivity is that there is a group of poor countries that are incapable of enjoying the fruits of technological progress. These countries stagnate at the lower peak while the rest of the world utilizes spillovers from the technological frontier to move toward the upper peak. For this reason it may be helpful to examine some of the conditions that result in stagnant (or falling) productivity.

In the next two sections I will look at potential causes for the lower peak in productivity. First, I will turn back to physical and human capital and explore the dynamic links between factor accumulation and productivity. Second, I will explore the relationship between openness and the movement in productivity.

3 Static and Dynamic Externalities

The previous three sections examine the evolution of the distribution of each variable without concern for interaction between the distributions. This approach was reasonable for the evaluation of the existing theoretical literature, because the cited models take a monocausal view of development traps. Each of these models made a specific prediction about the evolution of one of the capital stocks independent of the other factors and productivity. This ignores the possibility that interaction between the factors of production and productivity may be the ultimate cause of twin peaks in productivity.

Table 6, a correlation table for physical capital, human capital, and productivity, shows that there is large degree of correlation between the three components of output. Recall that human capital was constructed using micro based returns to an

Table 6: Correlation Matrix, 1970-1989

	$\log(K/Y)$	$\log(h)$	$\log(A)$
$\log(K/Y)$	1.00		
$\log(h)$	0.71	1.00	
$\log(A)$	0.25	0.53	1.00

additional year of schooling. These returns reflect the private return to an additional year of schooling. If there are productive externalities to higher schooling levels, the productivity residual and schooling will be highly correlated. This appears to be the case.[21]

Similarly, the accounting procedure for physical capital (specifically, the use of the capital-output ratio rather than capital per worker) focuses on the portion of output that is affected by capital accumulation while crediting any positive externality to the productivity residual. Again, the relatively high correlation between physical capital and productivity indicates the possibility of a positive externality.

This is, of course, unsurprising. Productive externalities to factor accumulation are the basis for many endogenous growth models.[22] It is reasonable to think that higher levels of human capital are necessary for utilizing higher levels of technology. Bartel and Lichtenberg (1987) provide microeconomic evidence that more educated workers have an advantage in implementing new technologies. There may also be linkages between physical capital accumulation and productivity. Basu and Weil (1999) present a model where the level of productivity is a function of capital intensity.

Table 7 shows the percentage of observations for each possible combination of factor quartiles. For example, 7% of the observations are in the third quartile of human capital and in the second quartile of physical capital. There are very few

Table 7: Frequency of Combinations of Factor Quartiles

		h quartile				
		1	2	3	4	Total
K/Y quartile	1	17%	5%	3%	0%	25%
	2	4%	12%	7%	2%	25%
	3	3%	6%	10%	6%	25%
	4	0%	2%	6%	17%	25%
	Total	25%	25%	25%	25%	100%

countries with mismatched levels of physical and human capital. Almost 60% of observations have matching physical and human capital quartiles (hence the high numbers on the diagonal) and 90% have a mismatch of one quartile or less (the main diagonals plus the first off diagonal). There are no observations with one factor in the highest quartile and the other in the lowest. It is quite unusual to see a country

[21]The correlation is particularly strong when you consider that measurement error will induce a negative correlation between human capital and productivity. Recall that productivity is a function of output, human capital, and physical capital, $log(A) = log(y) - \frac{\alpha}{(1-\alpha)} log(\frac{K}{Y}) - log(h)$. Measurement errors in $log(h)$ will have an equal and opposite effect on $log(A)$, inducing a negative correlation. Since the data for schooling is generally thought to have large measurement errors, the strong positive correlation is surprising. The same holds true for measurement errors in K/Y

[22]Romer (1986) and other

with high human capital and low physical capital and vice versa.

Table 8 is a cross tabulation of the ratio of productivity to the world average by human capital and physical capital quartiles. There are several interesting features

Table 8: Mean Relative Productivity By Factor Quartiles.

		h quartile				
		1	2	3	4	Total
	1	0.77	0.77	1.03		0.80
K/Y	2	0.63	0.78	1.03	1.62	0.88
quartile	3	0.66	1.00	0.89	1.51	1.02
	4		0.47	1.05	1.48	1.30
	Total	0.73	0.80	0.97	1.50	1.00

Productivity is expressed as a percentage of the within period mean.

of this table. Examining the Total row and column show that higher quartiles of each factor correspond to higher relative productivity. This effect is somewhat more prominent for human capital than for physical capital, but it is clearly present in both.

A closer examination indicates that human capital is doing most of the work in this analysis. Reading across the rows shows that for a given quartile of physical capital, higher human capital translates into higher mean productivity. The same cannot be said of physical capital. Reading down the columns for a given quartile of human capital illustrates no particular relationship between a higher capital-output ratio and higher productivity. It seems that the simple correlation between the capital-output ratio and productivity is driven by their common correlation with human capital.

Even if we suppose that productivity is being driven by externalities to human and physical capital accumulation, this brings us no closer to an understanding of the lower peak in output per capita and its mirror in productivity. Since human and physical capital are not moving toward a twin peaked distribution, it cannot be the case that static externalities of the sort just described are driving the lower peak in productivity.

It is important to note that Table 8 gives an essentially static analysis of a problem that is inherently dynamic. The higher the level of human capital in a particular time period the higher the expected productivity. It is in the dynamics of the distributions that we see the twin peak phenomenon emerge. There is a group of countries experiencing falling relative productivity. Since we do not see a similar group with falling relative levels of physical or human capital, we must conclude that static externalities alone cannot explain the twin peak result.

Another possibility is that physical or human capital provide a dynamic externality to productivity. Increases in human capital might cause no immediate increase in productivity, but have an important effect on the growth of productivity through the adoption of new technologies (Bartel and Lichtenberg (1987) may be even more relevant here). Table 9 summarizes the growth rate of productivity as a function of the level of human and physical capital.

Table 9: Mean Productivity Growth By Factor Quartiles

		h quartile				
		1	2	3	4	Total
	1	-2.2	-0.6	1.7		-1.5
K/Y	2	0.1	-0.2	-0.4	2.1	-0.0
quartile	3	-0.3	1.1	-0.5	1.8	0.4
	4		-1.3	0.3	1.4	1.0
	Total	-1.5	-0.1	-0.1	1.5	-0.1

Each table entry is the average productivity growth rate.

Table 9 begins to shed some light on the dynamic externalities that may relate factor accumulation to productivity. The total row and column show that the growth rate of productivity is correlated with the levels of human and physical capital, with negative growth rates at the lowest factor quartiles and positive growth rates at the highest factor quartiles.

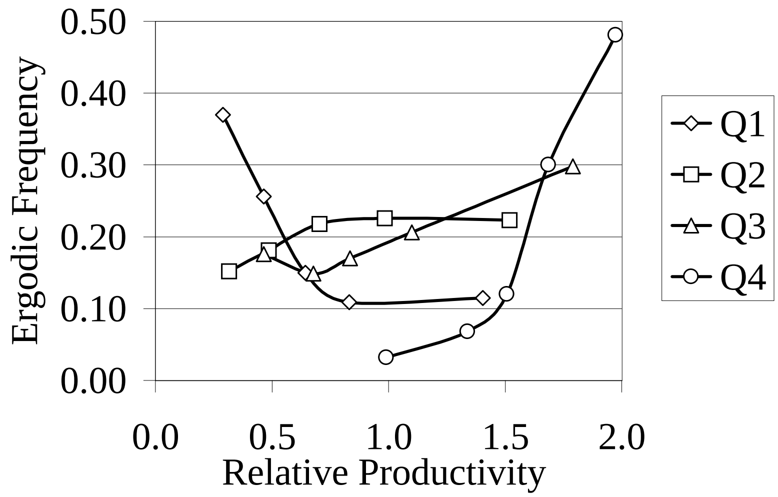
Again the human capital appears to dominate physical capital in influence. For countries in the highest quartile of human capital, average growth is positive even when physical capital is in the bottom half of the distribution. The same cannot be said for the highest quartile of physical capital. Similarly, for countries in the lowest quartile of human capital, productivity growth is negative or close to zero for all quartiles of physical capital.

Recall that the lower peak of the ergodic distribution of productivity requires that a group of countries is experiencing falling relative productivity. The upper left hand corner appears to fit this description with negative productivity growth rates for a large proportion of countries. Similarly, the lower right corner may account for the upper peak with a significant group of countries experiencing positive productivity growth. The high degree of correlation between human and physical capital levels means that over 80% of observations fall in either the upper left or lower right hand corners. The following sections will explore this in more depth.

3.1 The Marginal Distribution of A given h

In order to examine the impact of differing levels of human capital on the distribution of productivity, the data was split into quartiles sorted by the level of human capital. Tables 13 through 16 in the Appendix are estimates of transition matrices for the productivity residual, one for each quartile of human capital. These matrices represent the marginal distribution of productivity, given the level of human capital. Figure 5 summarizes the ergodic distributions for these four matrices.

Figure 5: Ergodic Distributions of Productivity by Human Capital Quartile



The position of each data point on the x-axis represents the average relative productivity for the group. The position on the y-axis represents the ergodic frequency for each group. As with the earlier transition matrices, the endpoints were chosen so that a roughly equal group of countries is in each category in the data. Points above the 0.20 line indicate movement into the group, while points below the 0.20 line represent outward movement.

The ergodic distribution for the lowest quartile of human capital shows a dramatic movement downward in the distribution. The lowest two groups are larger than in the data (they are above the 0.20 line) while the upper three groups are smaller than in the data.

The striking fact is that countries in this group have *low and falling* relative productivity. Twenty percent of the countries in the data have human capital in the lowest quartile and above average productivity. Only 9% remain in this category in the ergodic distribution. Similarly, the number of countries in the lowest productivity group (with less than 37% of the world average) doubles in the ergodic distribution. This result may explain the lower peak in productivity. Middle income countries with low human capital cannot sustain their productivity and fall from middle to low incomes.

The ergodic distributions for the middle (second and third) quartiles of human capital are unremarkable. There is very little change in either distribution. The ergodic distribution for the highest quartile of human capital is a mirror image of the distribution for the lowest quartile. Countries with high human capital begin with high productivity and there is clear movement toward the highest ranges. Thus, countries in the highest quartile of human capital have *high and rising* productivity. A middle income country with high human capital will tend to see productivity rise so that it becomes a wealthy country.

These results suggest that it is the interaction between human capital and productivity that causes the long run distribution of output to be twin peaked. Countries with low human capital have falling levels of productivity and are moving from the middle of the productivity distribution to the lower peak. Countries in the second and third quartile have unchanging levels of productivity and comprise the group remaining in the center of the distribution. Countries with relatively high human capital experience upward movement in productivity moving from the middle productivity ranges to the upper peak. There is therefore net movement out of the center of the distribution into the two ends.

One interpretation of this result is that there is some threshold level of human capital above which productivity growth is driven by spillovers from the R&D producing nations.[23] Countries below this level of human capital lack the skills to utilize overseas technologies and therefore stagnate.

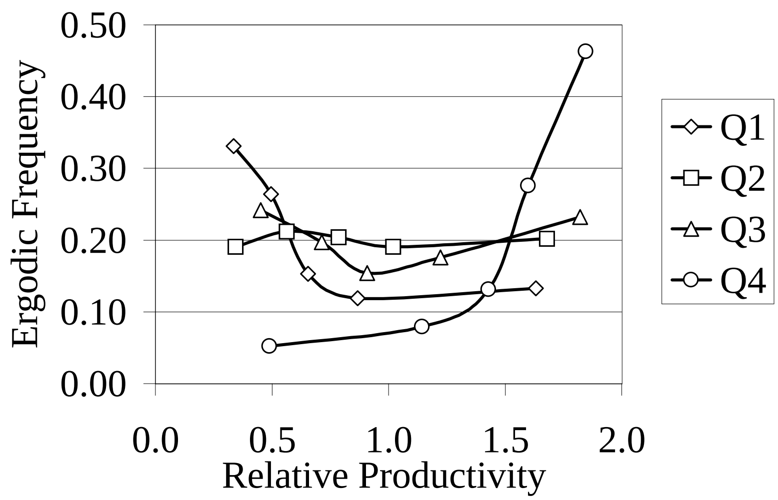
Given the ergodic distribution of human capital, this a potentially hopeful result. The marginal distributions indicate that the low peak in productivity is connected to the lowest quartile of human capital. However, the ergodic distribution of human capital seems to indicate that this group is getting smaller over time. In the long run, these two trends may combine to eliminate the lower peak in productivity.

[23]This is consistent with Howitt (2000) in that countries in the highest quartile of human capital are quite likely to be engaging in R&D while countries in the lowest quartile of human capital are unlikely to engage in R&D

3.2 The Marginal Distribution of A given K/Y

In order to complete the analysis I will also examine the impact of differing levels of physical capital on the distribution of productivity, the data was split into quartiles sorted by the level of K/Y. Tables 17 through 20 in the Appendix are estimates of transition matrices for the productivity residual for each quartile of K/Y. These matrices represent the marginal distribution of productivity, given the level of physical capital. Figure 6 summarizes the ergodic distributions for these four matrices.

Figure 6: Ergodic Distributions of Productivity by K/Y Quartile



The results are quite similar to those for human capital. Countries in the lowest quartile of K/Y see downward movement in the distribution of productivity. The second and third quartiles show less movement in the ergodic distribution. Countries in the highest quartile of K/Y have dramatic movements upward in the distribution of productivity.

The high correlation between human capital and physical capital are likely driving the similarity between the human and physical capital results. However, physical capital may play an important role in reinforcing the dynamic externalities between human capital and productivity.

4 Openness and Twin Peaks

An additional possibility for explaining the twin peaks in productivity is that openness to trade has an important effect on productivity through technological spillovers.[24] In the following discussion, openness is defined using the binary variable of Sachs and Warner (1997).[25] Table 10 shows the percentage of observations for open and closed countries for each quartile of human capital.

Table 10: Mean Productivity By Human Capital Quartile and Openness

	h quartile				
	1	2	3	4	Total
closed	26%	17%	13%	3%	59%
open		8%	11%	22%	41%
	25%	25%	25%	25%	100%

Countries in the highest quartiles of human capital are more likely to be open, while countries in the lowest quartiles of human capital are more likely to be closed. Table 11 is a cross tabulation of mean productivity by human capital quartile and openness.

Table 11: Mean Productivity By Human Capital Quartile and Openness

	h quartile				
	1	2	3	4	Total
closed	0.71	0.78	0.92	1.14	0.79
open		0.89	1.12	1.52	1.30
Total	0.71	0.81	1.00	1.49	1.00

Productivity is expressed as a percentage of the within period mean.

Open countries are more productive than closed countries even when accounting for the level of human capital. The effect of openness, however, is most dramatic in the upper two quartiles of human capital. Higher human capital levels are again associated with higher productivity. This relationship holds for both open and closed economies. Table 12 summarizes the growth rate of productivity by human capital quartile and openness.

The dynamic effect of openness appear to be substantial. Open countries are experiencing growth in productivity regardless of their level of human capital. The

[24] Sachs and Warner (1997), Frankel and Romer (1999), Harrison (1996), and others find that trade has a positive effect on the level or growth of output

[25] Using a composite of various openness measures Sachs and Warner (1997) code countries as open or closed on a yearly basis

Table 12: Mean Productivity Growth By Human Capital Quartile and Openness.

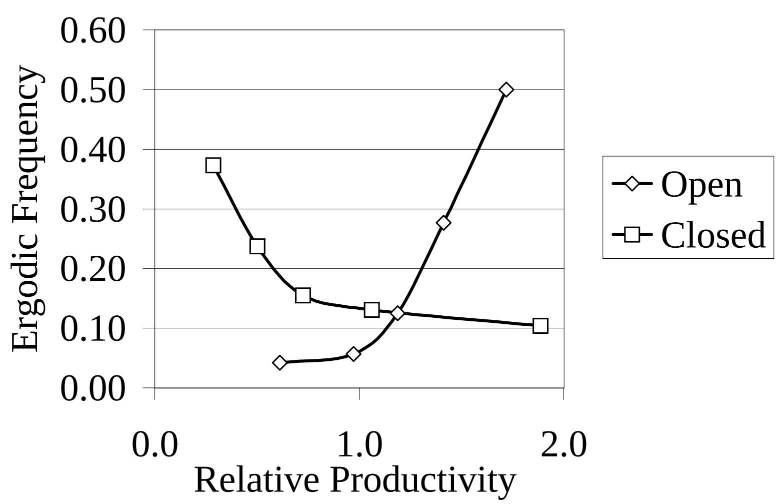
	h quartile				
	1	2	3	4	Total
closed	-1.3	-1.0	-1.8	-0.3	-1.3
open		2.0	1.9	1.6	1.7
Total	-1.3	-0.0	-0.3	1.4	-0.0

Each table entry is the mean productivity growth rate.

level of human capital has no apparent impact on the rate of productivity growth holding openness constant.

Tables 21 and 22 in the Appendix are transition matrices for the productivity residual for each group. These matrices represent the marginal distribution of productivity, given the state of openness. Figure 7 summarizes the ergodic distributions for these two matrices.

Figure 7: Ergodic Distributions of Productivity by Openness



The ergodic distribution of open economies shows dramatic movement out of the lower ranges of relative productivity and into the upper range. The ergodic distribution for closed economies does just the opposite. The groups with low productivity are larger than in the data while the groups with high productivity are much smaller. This provides an alternative to human capital in explaining the twin peaked result in productivity.

5 Summary

This paper attempts to find the origin of Quah's twin peaked distribution of per capita output. The most dramatic feature of Quah's distribution is the downward movement of a group of countries away from the world mean. Instead of converging to the income of the wealthy countries, these countries are diverging away from it.

Looking at the components of per capita output, we see that the level of K/Y is converging strongly to the OECD level and is clearly not a direct cause of the twin peaked distribution. Human capital's distribution shows some tendency toward convergence to a high level and no tendency toward a twin peaked distribution.

The productivity residual, on the other hand, shows movement very similar to the distribution of per capital-output and appears to be the proximate cause of Quah's twin peak result. This result indicates that models of development traps which rely monocausally on physical or human capital are unsupported by the data. More attention should therefore be paid to models such as Howitt (2000) which rely on development traps in productivity to create convergence clubs.

The idea that there is a threshold (in Howitt's case, some investment in R&D) which allows a country to benefit from technological spillovers seems like a sensible one. The marginal distributions of the productivity residual with respect to human capital levels shows one possible threshold. Openness to trade is another.

At a more general level, models which rely on a single factor of production to generate a twin peaked output result may be inadequate. The results presented in this paper point toward the importance of looking at the interactions between the factors of productions. Furthermore, the examination of these interactions cannot be limited to a static spillovers. Answers are likely to be found in models with both factors and technology modeled in a dynamically interactive way.

We have many models that describe the process of factor accumulation. More recently, we have developed models that describe the growth of productivity through knowledge creation. The phenomenon of twin peaks in output per capita is likely best explained by models that synthesize these two strains of the theoretical literature.

A Marginal Transition Matrices for Productivity by Human Capital Quartile

Table 13: Transition Matrix for Residuals, h in first quartile (OBS = 422)

			A_{t+1}			
A_t	0.37	0.56	0.71	0.95	∞	freq
0.37	0.91	0.09				0.19
0.56	0.12	0.79	0.07		0.01	0.19
0.71		0.14	0.78	0.08		0.21
0.95			0.13	0.81	0.06	0.20
∞				0.07	0.92	0.20
Ergodic	0.37	0.26	0.15	0.11	0.12	

Table 14: Transition Matrix for Residuals, h in second quartile (OBS = 416)

			A_{t+1}			
A_t	0.41	0.57	0.83	1.20	∞	freq
0.41	0.92	0.08				0.20
0.57	0.07	0.87	0.06			0.20
0.83		0.04	0.88	0.09		0.20
1.20		0.01	0.07	0.81	0.11	0.20
∞				0.11	0.89	0.20
Ergodic	0.15	0.18	0.22	0.23	0.22	

Table 15: Transition Matrix for Residuals, h in third quartile (OBS = 413)

			A_{t+1}			
A_t	0.60	0.75	0.95	1.33	∞	freq
0.60	0.89	0.11				0.20
0.75	0.13	0.72	0.15			0.20
0.95		0.13	0.78	0.09		0.20
1.33			0.07	0.86	0.07	0.20
∞				0.05	0.95	0.20
Ergodic	0.18	0.15	0.17	0.21	0.30	

Table 16: Transition Matrix for Residuals, h in fourth quartile (OBS = 418)

	A_{t+1}					
A_t	1.23	1.42	1.58	1.80	∞	freq
1.23	0.90	0.10				0.20
1.42	0.05	0.74	0.22			0.20
1.58		0.12	0.66	0.21		0.21
1.80			0.09	0.76	0.16	0.20
∞				0.10	0.90	0.18
Ergodic	0.03	0.07	0.12	0.30	0.48	

B Marginal Transition Matrices for Productivity by Physical Capital quartile

Table 17: Transition Matrix for Residuals, K/Y in first quartile (OBS = 405)

	A_{t+1}					
A_t	0.41	0.58	0.72	1.05	∞	
0.41	0.91	0.09				0.19
0.58	0.11	0.80	0.08	0.01		0.20
0.72		0.14	0.78	0.08		0.21
1.05			0.12	0.82	0.06	0.21
∞		0.01		0.04	0.95	0.19
Ergodic	0.33	0.26	0.15	0.12	0.13	

Table 18: Transition Matrix for Residuals, K/Y in second quartile (OBS = 382)

	A_{t+1}					
A_t	0.45	0.67	0.90	1.15	∞	
0.45	0.97	0.03				0.19
0.67	0.02	0.85	0.12			0.21
0.90		0.11	0.79	0.08	0.01	0.20
1.15		0.01	0.08	0.84	0.07	0.19
∞				0.08	0.93	0.20
Ergodic	0.19	0.21	0.20	0.19	0.20	

Table 19: Transition Matrix for Residuals, K/Y in third quartile (OBS = 379)

	A_{t+1}					
A_t	0.62	0.79	1.05	1.41	∞	
0.62	0.93	0.07				0.19
0.79	0.09	0.79	0.12			0.21
1.05		0.16	0.74	0.11		0.20
1.41			0.09	0.86	0.05	0.20
∞				0.04	0.96	0.20
Ergodic	0.24	0.20	0.15	0.18	0.23	

Table 20: Transition Matrix for Residuals, K/Y in fourth quartile (OBS = 410)

	A_{t+1}					
A_t	0.86	1.35	1.51	1.70	∞	
0.86	0.96	0.04				0.20
1.35	0.02	0.83	0.15			0.20
1.51		0.09	0.73	0.18		0.22
1.70			0.08	0.76	0.16	0.20
∞				0.09	0.91	0.18
Ergodic	0.05	0.08	0.13	0.28	0.46	

C Marginal Transition Matrices for Productivity by Openness

Table 21: Transition Matrix for Productivity, Open Economies (OBS = 640)

	A_{t+1}					
A_t	0.83	1.09	1.28	1.53	∞	freq
0.83	0.90	0.10				0.20
1.09	0.05	0.80	0.14	0.01		0.21
1.28	0.01	0.06	0.79	0.14		0.20
1.53			0.06	0.78	0.16	0.20
∞				0.09	0.91	0.20
Ergodic	0.04	0.06	0.12	0.28	0.50	

Table 22: Transition Matrix for Productivity, Closed Economies (OBS = 925)

	A_{t+1}					
A_t	0.40	0.59	0.87	1.26	∞	freq
0.40	0.96	0.03	0.01			0.20
0.59	0.06	0.87	0.07			0.20
0.87		0.12	0.82	0.06		0.20
1.26		0.01	0.07	0.86	0.06	0.20
∞				0.07	0.93	0.20
Ergodic	0.37	0.24	0.15	0.13	0.10	

References

Aghion, P. and P. Howitt, *Endogenous Growth Theory*, Cambridge, MA: MIT Press, 1998.

Azariadis, Costas, "The Economics of Poverty Traps, Part One: Complete Markets," *Journal of Economic Growth*, December 1996.

—— **and Drazen**, "Threshhold Externalilities in Economic Development," *Quarterly Journal Of Economics*, May 1990, *5* (105), 501–526.

Barro, Robert J. and Jong-Wha Lee, "International measures of schooling years and schooling quality," *American Economics Review*, 1996, *86* (2), 218–23.

—— **and Xavier Sala-i-Martin**, *Economic Growth*, New York: McGraw-Hill, 1995.

Bartel, Ann and Frank Lichtenberg, "The Comparative Advantage of Educated Workers in Implementing New Technology," *Review of Economics and Statistics*, February 1987, *69.*

Basu, Susanto and David Weil, "Appropriate Technology and Growth," *Quarterly Journal Of Economics*, 1999.

Baumol, William, "Productivity Growth, Convergence, and Welfare," *American Economics Review*, December 1986, *76*, 1072–1085.

Becker and Robert J. Barro, "Fertility choice in a model of economic growth," *Econometrica*, 1989, *76*, 481–501.

—— **, Murphy, and Tamura**, "Human Capital, Fertility, and Economic Growth," *Journal of Political Economy*, October 1990, *95* (5).

Benabou, Roland, "Equity and Efficiency in human capital investment: the local connection," *Review of Economic Studies*, 1996.

Caselli, F., G. Esquivel, and F. Lefort, "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics," *Journal of Economic Growth*, September 1996, *1* (3), 363–389.

Coe, David and Elhanan Helpman, "International R&D Spillovers," *European Economic Review*, 1995, *39*, 859–887.

—— **,** —— **, and Hoffmaister**, "North-South R&D Spillovers," *Economic Journal*, 1997, *107*, 134–149.

Durlauf, Stephen N., "Nonergodic economic growth," *Review of Economic Studies*, 1993, *60*, 349–367.

——, "A theory of persistent income inequaltiy," *Journal of Economic Growth*, 1996, *1*, 75–94.

—— **and Danny Quah**, "The New Empirics of Economic Growth," *CEPR Discussion Paper*, January 1998, *384*.

—— **and P. Johnson**, "Multiple Regimes and Cross-Country Growth Behavior," *Journal of Applied Econometrics*, 1995.

Easterly, William and Ross Levine, "It's Not Factor Accumulation: Stylized Facts and Growth Models," *World Bank Working Paper*, 2000.

Efron, Bradley and Robert J. Tibshirani, *An Introduction to the Bootstrap*, New York: Chapman and Hall, 1993.

Feldstein and Horioka, "Domestic Saving and Capital Flows," *Economic Journal*, June 1980.

Frankel, Jeffrey and David Romer, "Does Trade Cause Growth?," *American Economics Review*, June 1999, *89* (3), 379–99.

Galor, Oded, "Convergence? Inferences from theoretical models," *Economic Journal*, July 1996, pp. 1056–1069.

—— **and D. Tsiddon**, "The distribution of human capital and economic growth," *Journal of Economic Growth*, March 1997, pp. 93–124.

—— **and David Weil**, "The Gender Gap, Fertility, and Growth," *American Economics Review*, June 1996.

—— **and Zeira**, "Income Distribution and Macroeconomics," *Review of Economic Studies*, 1993, pp. 35–53.

Hall, Robert and Charles I. Jones, "Why Do Some Countries Produce So Much More Output per Worker Than Others?," *Quarterly Journal Of Economics*, February 1999. An earlier version of this paper was called "The Productivity of Nations" NBER working paper 5812.

Harrison, Ann, "Openness and Growth: A Time-Series, Cross-Country Analysis for Developing Countries," *Journal of Development Economics*, March 1996, pp. 419–47.

Howitt, Peter, "Endogenous growth and cross country income differences," *mimeo*, 2000.

Islam, Nazrul, "Growth Empirics: A Panel Data Approach," *Quarterly Journal Of Economics*, November 1995, *110*, 1127–1170.

Klenow, Peter and Andres Rodriguez-Clare, "The Neoclassical Revival in Growth Economics: Has it Gone Too Far?," *NBER Macro Annual*, 1997.

Kuznets, S., *Modern Economic Growth: Rate Structure and Spread*, New Haven, CT: Yale University Press, 1966.

Mankiw, N. Gregory, David Romer, and David Weil, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal Of Economics*, 1992, *107*, 407–437.

Murphy, Shleifer, and Vishny, "Industrialization and the Big Push," *Journal of Political Economy*, October 1989, *97* (5).

Nelson, Richard, "A Theory of the Low-Level Equilibrium Trap in Underdeveloped Economies," *American Economics Review*, 1956, *46*, 894–908.

Psacharopoulos, George, "Returns to Investment in Education: A Global Update," *World Development*, 1994, p. 13251343.

Quah, Danny T, "Empirical Cross-section Dynamics in Economic Growth," *European Economic Review*, 1993, *37*, 426–434.

____ , "Galton's Fallacy and Tests of the Convergence Hypothesis," *Scandanavian Journal of Economics*, 1993, *95*, 427–443.

____ , "Convergence Empirics Across Economies with (Some) Capital Mobility," *Journal of Economic Growth*, March 1996, *1*, 95–124.

____ , "Empirics for economic growth and convergence," *European Economic Review*, 1996, *40*, 1353–1375.

____ , "Empirics for Growth and Distribution:Stratification, Polarization, and Convergence Clubs," *Journal of Economic Growth*, March 1997, *2*, 27–59.

Romer, Paul, "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, 1986, *94*, 1002–1038.

Sachs, Jeffrey and Andrew Warner, "Economic Reform and the Process of Global Integration," *Brookings Pap. Econ. Act.*, 1997, pp. 1–118.

Summers, R. and A. Heston, "The Penn World Tables Mark 5.5 (updated supplement to The Penn World Tables (Mark 5): An Expanded Set of International Comparisons 1950-1988)," *Quarterly Journal Of Economics*, May 1991, *106*, 327–368.

Tsiddon, D., "A moral hazard trap to growth," *International Economic Growth*, 1992, *33*, 299–322.