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ON THE MECHANICS OF ECONOMIC DEVELOPMENT*

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This paper considers the prospects for constructing a neoclassical theory of growth and international trade that is consistent with some of the main features of economic development. Three models are considered and compared to evidence: a model emphasizing physical capital accumulation and technological change, a model emphasizing human capital accumulation through schooling, and a model emphasizing specialized human capital accumulation through learning-by-doing.

1. Introduction

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

The main features of levels and rates of growth of national incomes are well enough known to all of us, but I want to begin with a few numbers, so as to set a quantitative tone and to keep us from getting mired in the wrong kind of details. Unless I say otherwise, all figures are from the World Bank's *World Development Report* of 1983.

The diversity across countries in measured per capita income levels is literally too great to be believed. Compared to the 1980 average for what the World Bank calls the 'industrial market economies' (Ireland up through Switzerland) of U.S. $10,000, India's per capita income is $240, Haiti's is $270,

*This paper was originally written for the Marshall Lectures, given at Cambridge University in 1985. I am very grateful to the Cambridge faculty for this honor, and also for the invitation's long lead time, which gave me the opportunity to think through a new topic with the stimulus of so distinguished an audience in prospect. Since then, versions of this lecture have been given as the David Horowitz Lectures in Israel, the W.A. Mackintosh Lecture at Queens University, the Carl Snyder Memorial Lecture at the University of California at Santa Barbara, the Chung-Hua Lecture in Taipei, the Nancy Schwartz Lecture at Northwestern University, and the Lionel McKenzie Lecture at the University of Rochester. I have also based several seminars on various parts of this material.

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and so on for the rest of the very poorest countries. This is a difference of a factor of 40 in living standards! These latter figures are too low to sustain life in, say, England or the United States, so they cannot be taken at face value and I will avoid hanging too much on their exact magnitudes. But I do not think anyone will argue that there is not enormous diversity in living standards.[1]

Rates of growth of real per capita GNP are also diverse, even over sustained periods. For 1960–80 we observe, for example: India, 1.4% per year: Egypt, 3.4%; South Korea, 7.0%; Japan, 7.1%; the United States, 2.3%; the industrial economies averaged 3.6%. To obtain from growth rates the number of years it takes for incomes to double, divide these numbers into 69 (the log of 2 times 100). Then Indian incomes will double every 50 years; Korean every 10. An Indian will, on average, be twice as well off as his grandfather; a Korean 32 times. These differences are at least as striking as differences in income levels, and in some respects more trustworthy, since within-country income comparisons are easier to draw than across-country comparisons.

I have not calculated a correlation across countries between income levels and rates of growth, but it would not be far from zero. (The poorest countries tend to have the lowest growth; the wealthiest next; the 'middle-income' countries highest.) The generalizations that strike the eye have to do with variability within these broad groups: the rich countries show little diversity (Japan excepted – else it would not have been classed as a rich country in 1980 at all). Within the poor countries (low and middle income) there is enormous variability.[2]

Within the advanced countries, growth rates tend to be very stable over long periods of time, provided one averages over periods long enough to eliminate business-cycle effects (or corrects for short-term fluctuations in some other way). For poorer countries, however, there are many examples of sudden, large changes in growth rates, both up and down. Some of these changes are no doubt due to political or military disruption: Angola's total GDP growth fell from 4.8 in the 60s to −9.2 in the 70s; Iran's fell from 11.3 to 2.5, comparing the same two periods. I do not think we need to look to economic theory for an account of either of *these* declines. There are also some striking examples

[1] The income estimates reported in Summers and Heston (1984) are more satisfactory than those in the World Development Reports. In 1975 U.S. dollars, these authors estimate 1980 U.S. real GDP per capita at $8000, and for the industrialized economies as a group, $5900. The comparable figures for India and Haiti are $460 and $500, respectively. Income differences of a factor of 16 are certainly smaller, and I think more accurate, than a factor of 40, but I think they are still fairly described as exhibiting 'enormous diversity'.

[2] Baumol (1986) summarizes evidence, mainly from Maddison (1982) indicating apparent convergence during this century to a common path of the income levels of the wealthiest countries. But De Long (1987) shows that this effect is entirely due to 'selection bias': If one examines the countries with the highest income levels at the *beginning* of the century (as opposed to currently, as in Maddison's 'sample') the data show apparent *divergence*!

of sharp increases in growth rates. The four East Asian 'miracles' of South Korea, Taiwan, Hong Kong and Singapore are the most familiar: for the 1960–80 period, per capita income in these economies grew at rates of 7.0, 6.5, 6.8 and 7.5, respectively, compared to much lower rates in the 1950's and earlier.[3,4] Between the 60s and the 70s, Indonesia's GDP growth increased from 3.9 to 7.5; Syria's from 4.6 to 10.0.

I do not see how one can look at figures like these without seeing them as representing *possibilities*. Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia's or Egypt's? If so, *what*, exactly? If not, what is it about the 'nature of India' that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else.

This is what we need a theory of economic development *for*: to provide some kind of framework for organizing facts like these, for judging which represent opportunities and which necessities. But the term 'theory' is used in so many different ways, even within economics, that if I do not clarify what I mean by it early on, the gap between what I think I am saying and what you think you are hearing will grow too wide for us to have a serious discussion. I prefer to use the term 'theory' in a very narrow sense, to refer to an explicit dynamic system, something that can be put on a computer and *run*. This is what I mean by the 'mechanics' of economic development – the construction of a mechanical, artificial world, populated by the interacting robots that economics typically studies, that is capable of exhibiting behavior the gross features of which resemble those of the actual world that I have just described. My lectures will be occupied with one such construction, and it will take some work: It is easy to set out models of economic growth based on reasonable-looking axioms that predict the cessation of growth in a few decades, or that predict the rapid convergence of the living standards of different economies to a common level, or that otherwise produce logically possible outcomes that bear no resemblance to the outcomes produced by actual economic systems. On the other hand, there is no doubt that there must be mechanics other than the ones I will describe that would fit the facts about as well as mine. This is why I have titled the lectures '*On* the Mechanics ...' rather than simply '*The* Mechanics of Economic Development'. At some point, then, the study of development will need to involve working out the implications of competing theories for data other than those they were constructed to fit, and testing these implications against observation. But this is getting far ahead of the

[3]The World Bank no longer transmits data for Taiwan. The figure 6.5 in the text is from Harberger (1984, table 1, p. 9).

[4]According to Heston and Summers (1984), Taiwan's per-capita GDP growth rate in the 1950s was 3.6. South Korea's was 1.7 from 1953 to 1960.

story I have to tell, which will involve leaving many important questions open even at the purely theoretical level and will touch upon questions of empirical testing hardly at all.

My plan is as follows. I will begin with an application of a now-standard neoclassical model to the study of twentieth century U.S. growth, closely following the work of Robert Solow, Edward Denison and many others. I will then ask, somewhat unfairly, whether this model *as it stands* is an adequate model of economic development, concluding that it is not. Next, I will consider two adaptations of this standard model to include the effects of human capital accumulation. The first retains the one-sector character of the original model and focuses on the interaction of physical and human capital accumulation. The second examines a two-good system that admits specialized human capital of different kinds and offers interesting possibilities for the interaction of trade and development. Finally, I will turn to a discussion of what has been arrived at and of what is yet to be done.

In general, I will be focusing on various aspects of what economists, using the term very broadly, call the 'technology'. I will be abstracting altogether from the economics of demography, taking population growth as a given throughout. This is a serious omission, for which I can only offer the excuse that a serious discussion of demographic issues would be at least as difficult as the issues I will be discussing and I have neither the time nor the knowledge to do both. I hope the interactions between these topics are not such that they cannot usefully be considered separately, at least in a preliminary way.[5]

I will also be abstracting from all monetary matters, treating all exchange as though it involved goods-for-goods. In general I believe that the importance of financial matters is very badly over-stressed in popular and even much professional discussion and so am not inclined to be apologetic for going to the other extreme. Yet insofar as the development of financial institutions is a limiting factor in development more generally conceived I will be falsifying the picture, and I have no clear idea as to how badly. But one cannot theorize about everything at once. I had better get on with what I do have to say.

2. Neoclassical growth theory: Review

The example, or model, of a successful theory that I will try to build on is the theory of economic growth that Robert Solow and Edward Denison developed and applied to twentieth century U.S. experience. This theory will serve as a basis for further discussion in three ways: as an example of the *form* that I believe useful aggregative theories must take, as an opportunity to

[5]Becker and Barro (1985) is the first attempt known to me to analyze fertility and capital accumulation decisions *simultaneously* within a general equilibrium framework. Tamura (1986) contains further results along this line.

explain exactly what theories of this form can tell us that other kinds of theories cannot, and as a possible theory of economic development. In this third capacity, the theory will be seen to fail badly, but also suggestively. Following up on these suggestions will occupy the remainder of the lectures.

Both Solow and Denison were attempting to account for the main features of U.S. economic growth, not to provide a theory of economic development, and their work was directed at a very different set of observations from the cross-country comparisons I cited in my introduction. The most useful summary is provided in Denison's 1961 monograph, *The Sources of Economic Growth in the United States*. Unless otherwise mentioned, this is the source for the figures I will cite next.

During the 1909–57 period covered in Denison's study, U.S. real output grew at an annual rate of 2.9%, employed manhours at 1.3%, and capital stock at 2.4%. The remarkable feature of these figures, as compared to those cited earlier, is their *stability* over time. Even if one takes as a starting point the trough of the Great Depression (1933) output growth to 1957 averages only 5%. If business-cycle effects are removed in any reasonable way (say, by using peak-to-peak growth rates) U.S. output growth is within half a percentage point of 3% annually for any sizeable subperiod for which we have data.

Solow (1956) was able to account for this stability, and also for some of the relative magnitudes of these growth rates, with a very simple but also easily refineable model.[6] There are many variations of this model in print. I will set out a particularly simple one that is chosen also to serve some later purposes. I will do so without much comment on its assumed structure: There is no point in arguing over a model's assumptions until one is clear on what questions it will be used to answer.

We consider a closed economy with competitive markets, with identical, rational agents and a constant returns technology. At date t there are $N(t)$ persons or, equivalently, manhours devoted to production. The exogenously given rate of growth of $N(t)$ is λ. Real, per-capita consumption is a stream $c(t)$, $t \geq 0$, of units of a single good. Preferences over (per-capita) consumption streams are given by

$$\int_0^\infty \mathrm{e}^{-\rho t} \frac{1}{1-\sigma}\left[c(t)^{1-\sigma}-1\right] N(t)\, \mathrm{d}t, \qquad (1)$$

[6]Solow's 1956 paper stimulated a vast literature in the 1960s, exploring many variations on the original one-sector structure. See Burmeister and Dobell (1970) for an excellent introduction and survey. By putting a relatively simple version to empirical use, as I shall shortly do, I do not intend a negative comment on this body of research. On the contrary, it is exactly this kind of theoretical experimentation with alternative assumptions that is needed to give one the confidence that working with a particular, simple parameterization may, for the specific purpose at hand, be adequate.

where the discount rate ρ and the coefficient of (relative) risk aversion σ are both positive.[7]

Production per capita of the one good is divided into consumption $c(t)$ and capital accumulation. If we let $K(t)$ denote the total stock of capital, and $\dot{K}(t)$ its rate of change, then total output is $N(t)c(t)+\dot{K}(t)$. [Here $\dot{K}(t)$ is net investment and total output $N(t)c(t)+\dot{K}(t)$ is identified with net national product.] Production is assumed to depend on the levels of capital and labor inputs and on the level $A(t)$ of the 'technology', according to

$$N(t)c(t)+\dot{K}(t)=A(t)K(t)^{\beta}N(t)^{1-\beta}, \tag{2}$$

where $0<\beta<1$ and where the exogenously given rate of technical change, $\dot{A}/A$, is $\mu>0$.

The resource allocation problem faced by this simple economy is simply to choose a time path $c(t)$ for per-capita consumption. Given a path $c(t)$ and an initial capital stock $K(0)$, the technology (2) then implies a time path $K(t)$ for capital. The paths $A(t)$ and $N(t)$ are given exogenously. One way to think about this allocation problem is to think of choosing $c(t)$ at each date, given the values of $K(t)$, $A(t)$ and $N(t)$ that have been attained by that date. Evidently, it will not be optimal to choose $c(t)$ to maximize current-period utility, $N(t)[1/(1-\sigma)][c(t)-1]^{1-\sigma}$, for the choice that achieves this is to set net investment $\dot{K}(t)$ equal to zero (or, if feasible, negative): One needs to set some *value* or *price* on increments to capital. A central construct in the study of *optimal* allocations, allocations that maximize utility (1) subject to the technology (2), is the *current-value Hamiltonian* H defined by

$$H(K,\theta,c,t)=\frac{N}{1-\sigma}[c^{1-\sigma}-1]+\theta[AK^{\beta}N^{1-\beta}-Nc],$$

which is just the sum of current-period utility and [from (2)] the rate of increase of capital, the latter valued at the 'price' $\theta(t)$. An optimal allocation must maximize the expression H at each date t, provided the price $\theta(t)$ is correctly chosen.

The first-order condition for maximizing H with respect to c is

$$c^{-\sigma}=\theta, \tag{3}$$

which is to say that goods must be so allocated at each date as to be equally valuable, on the margin, used either as consumption or as investment. It is

[7]The inverse σ^{-1} of the coefficient of risk aversion is sometimes called the intertemporal elasticity of substitution. Since all the models considered in this paper are deterministic, this latter terminology may be more suitable.

known that the price $\theta(t)$ must satisfy

$$\dot{\theta}(t) = \rho\theta(t) - \frac{\partial}{\partial K} H(K(t), \theta(t), c(t), t)$$

$$= \left[\rho - \beta A(t) N(t)^{1-\beta} K(t)^{\beta-1}\right] \theta(t), \tag{4}$$

at each date t if the solution $c(t)$ to (3) is to yield an optimal *path* $(c(t))_{t=0}^{\infty}$.

Now if (3) is used to express $c(t)$ as a function $\theta(t)$, and this function $\theta^{-1/\sigma}$ is substituted in place of $c(t)$ in (2) and (4), these two equations are a pair of first-order differential equations in $K(t)$ and its 'price' $\theta(t)$. Solving this system, there will be a one-parameter family of paths $(K(t), \theta(t))$, satisfying the given initial condition on $K(0)$. The *unique* member of this family that satisfies the transversality condition:

$$\lim_{t \to \infty} e^{-\rho t} \theta(t) K(t) = 0 \tag{5}$$

is the optimal path. I am hoping that this application of Pontryagin's Maximum Principle, essentially taken from David Cass (1961), is familiar to most of you. I will be applying these same ideas repeatedly in what follows.

For this particular model, with convex preferences and technology and with no external effects of any kind, it is also known and not at all surprising that the *optimal* program characterized by (2), (3), (4) and (5) is also the unique *competitive equilibrium* program, provided either that all trading is consummated in advance, Arrow–Debreu style, *or* (and this is the interpretation I favor) that consumers and firms have rational expectations about future prices. In this deterministic context, rational expectations just means perfect foresight. For my purposes, it is this equilibrium interpretation that is most interesting: I intend to use the model as a positive theory of U.S. economic growth.

In order to do this, we will need to work out the predictions of the model in more detail, which involves solving the differential equation system so we can see what the equilibrium time paths look like and compare them to observations like Denison's. Rather than carry this analysis through to completion, I will work out the properties of a *particular* solution to the system and then just indicate briefly how the rest of the answer can be found in Cass's paper.

Let us construct from (2), (3) and (4) the system's *balanced growth path*: the particular solution $(K(t), \theta(t), c(t))$ such that the rates of growth of each of these variables is constant. (I have never been sure exactly what it is that is 'balanced' along such a path, but we need a term for solutions with this constant growth rate property and this is as good as any.) Let κ denote the rate of growth of per-capita consumption, $\dot{c}(t)/c(t)$, on a balanced growth path. Then from (3), we have $\dot{\theta}(t)/\theta(t) = -\sigma\kappa$. Then from (4), we must have

$$\beta A(t)N(t)^{1-\beta}K(t)^{\beta-1} = \rho + \sigma\kappa. \tag{6}$$

That is, along the balanced path, the marginal product of capital must equal the constant value $\rho + \sigma\kappa$. With this Cobb–Douglas technology, the marginal product of capital is proportional to the average product, so that dividing (2) through by $K(t)$ and applying (6) we obtain

$$\frac{N(t)c(t)}{K(t)} + \frac{\dot{K}(t)}{K(t)} = A(t)K(t)^{\beta-1}N(t)^{1-\beta} = \frac{\rho + \sigma\kappa}{\beta}. \tag{7}$$

By definition of a balanced path, $\dot{K}(t)/K(t)$ is constant so (7) implies that $N(t)c(t)/K(t)$ is constant or, differentiating, that

$$\frac{\dot{K}(t)}{K(t)} = \frac{\dot{N}(t)}{N(t)} + \frac{\dot{c}(t)}{c(t)} = \kappa + \lambda. \tag{8}$$

Thus per-capita consumption and per-capita capital grow at the common rate κ. To *solve* for this common rate, differentiate either (6) or (7) to obtain

$$\kappa = \frac{\mu}{1-\beta}. \tag{9}$$

Then (7) may be solved to obtain the constant, balanced consumption–capital ratio $N(t)c(t)/K(t)$ or, which is equivalent and slightly easier to interpret, the constant, balanced net savings rate s defined by

$$s = \frac{\dot{K}(t)}{N(t)c(t) + \dot{K}(t)} = \frac{\beta(\kappa + \lambda)}{\rho + \sigma\kappa}. \tag{10}$$

Hence along a balanced path, the rate of growth of per-capita magnitudes is simply proportional to the given rate of technical change, μ, where the constant of proportionality is the inverse of labor's share, $1-\beta$. The rate of time preference ρ and the degree of risk aversion σ have no bearing on this long-run growth rate. Low time preference ρ and low risk aversion σ induce a high savings rate s, and high savings is, in turn, associated with relatively high output *levels* on a balanced path. A thrifty society will, in the long run, be wealthier than an impatient one, but it will not grow faster.

In order that the balanced path characterized by (9) and (10) satisfy the transversality condition (5), it is necessary that $\rho + \sigma\kappa > \kappa + \lambda$. [From (10), one sees that this is the same as requiring the savings rate to be less than capital's share.] Under this condition, an economy that begins on the balanced path will find it optimal to stay there. What of economies that begin *off* the balanced path – surely the normal case? Cass showed – and this is exactly why the balanced path is interesting to us – that for *any* initial capital $K(0) > 0$, the optimal capital–consumption path $(K(t), c(t))$ will converge to the balanced path asymptotically. That is, the balanced path will be a good approximation to any actual path 'most' of the time.

Now given the taste and technology parameters (ρ, σ, λ, β and μ) (9) and (10) can be solved for the asymptotic growth rate κ of capital, consumption and real output, and the savings rate s that they imply. Moreover, it would be straightforward to calculate numerically the approach to the balanced path from any initial capital level $K(0)$. This is the exercise that an idealized planner would go through.

Our interest in the model is positive, not normative, so we want to go in the opposite direction and try to infer the underlying preferences and technology from what we can observe. I will outline this, taking the balanced path as the model's prediction for the behavior of the U.S. economy during the entire (1909–57) period covered by Denison's study.[8] From this point of view, Denison's estimates provide a value of 0.013 for λ, and two values, 0.029 and 0.024 for $\kappa + \lambda$, depending on whether we use output or capital growth rates (which the model predicts to be equal). In the tradition of statistical inference, let us average to get $\kappa + \lambda = 0.027$. The theory predicts that $1 - \beta$ should equal labor's share in national income, about 0.75 in the U.S., averaging over the entire 1909–57 period. The savings rate (net investment over NNP) is fairly constant at 0.10. Then (9) implies an estimate of 0.0105 for μ. Eq. (10) implies that the preference parameters ρ and σ satisfy

$$\rho + (0.014)\sigma = 0.0675.$$

(The parameters ρ and σ are not separately identified along a smooth consumption path, so this is as far as we can go with the sample averages I have provided.)

These are the parameter values that give the theoretical model its best fit to the U.S. data. How good a fit *is* it? Either output growth is underpredicted or capital growth overpredicted, as remarked earlier (and in the theory of growth, a half a percentage point is a *large* discrepancy). There are interesting secular changes in manhours per household that the model assumes away, and labor's share is secularly rising (in all growing economies), not constant as assumed. There is, in short, much room for improvement, even in accounting for the secular changes the model was designed to fit, and indeed, a fuller review of

[8]With the parameter values described in this paragraph, the half-life of the approximate linear system associated with this model is about eleven years.

the literature would reveal interesting progress on these and many other fronts.[9] A model as explicit as this one, by the very nakedness of its simplifying assumptions, invites criticism and suggests refinements to itself. This is exactly why we prefer explicitness, or why I think we ought to.

Even granted its limitations, the simple neoclassical model has made basic contributions to our thinking about economic growth. Qualitatively, it emphasizes a distinction between 'growth effects' – changes in parameters that alter growth rates along balanced paths – and 'level effects' – changes that raise or lower balanced growth paths without affecting their slope – that is fundamental in thinking about policy changes. Solow's 1956 conclusion that changes in savings rates are level effects (which transposes in the present context to the conclusion that changes in the discount rate, ρ, are level effects) was startling at the time, and remains widely and very unfortunately neglected today. The influential idea that changes in the tax structure that make savings more attractive can have large, sustained effects on an economy's growth rate sounds so reasonable, and it may even be true, but it is a clear implication of the theory we have that it is not.

Even sophisticated discussions of economic growth can often be confusing as to what are thought to be level effects and what growth effects. Thus Krueger (1983) and Harberger (1984), in their recent, very useful surveys of the growth experiences of poor countries, both identify inefficient barriers to trade as a limitation on growth, and their removal as a key explanation of several rapid growth episodes. The facts Krueger and Harberger summarize are not in dispute, but under the neoclassical model just reviewed one would not expect the removal of inefficient trade barriers to induce sustained increases in growth rates. Removal of trade barriers is, on this theory, a level effect, analogous to the one-time shifting upward in production possibilities, and not a growth effect. Of course, level effects can be drawn out through time through adjustment costs of various kinds, but not so as to produce increases in growth rates that are both large and sustained. Thus the removal of an inefficiency that reduced output by five percent (an enormous effect) spread out over ten years in simply a one-half of one percent annual growth rate stimulus. Inefficiencies are important and their removal certainly desirable, but the familiar ones are level effects, not growth effects. (This is exactly why it is not paradoxical that centrally planned economies, with allocative inefficiencies of legendary proportions, grow about as fast as market economies.) The empirical connections between trade policies and economic growth that

[9] In particular, there is much evidence that capital stock growth, as measured by Denison, understates true capital growth due to the failure to correct price deflators for quality improvements. See, for example, Griliches and Jorgenson (1967) or Gordon (1971). These errors may well account for all of the 0.005 discrepancy noted in the text (or more!).

Boxall (1986) develops a modification of the Solow–Cass model in which labor supply is variable, and which has the potential (at least) to account for long-run changes in manhours.

Krueger and Harberger document are of evident importance, but they seem to me to pose a real paradox to the neoclassical theory we have, not a confirmation of it.

The main contributions of the neoclassical framework, far more important than its contributions to the clarity of purely qualitative discussions, stem from its ability to *quantify* the effects of various influences on growth Denison's monograph lists dozens of policy changes, some fanciful and many others seriously proposed at the time he wrote, associating with each of them rough upper bounds on their likely effects on U.S. growth.[10] In the main, the theory adds little to what common sense would tell us about the *direction* of each effect – it is easy enough to guess which changes stimulate production, hence savings, and hence (at least for a time) economic growth. Yet most such changes, quantified, have *trivial* effects: The growth rate of an entire economy is not an easy thing to move around.

Economic growth, being a summary measure of all of the activities of an entire society, necessarily depends, in some way, on everything that goes on in a society. Societies differ in many easily observed ways, and it is easy to identify various economic and cultural peculiarities and imagine that they are keys to growth performance. For this, as Jacobs (1984) rightly observes, we do not need economic theory: 'Perceptive tourists will do as well.' The role of theory is not to catalogue the obvious, but to help us to sort out effects that are crucial, quantitatively, from those that can be set aside. Solow and Denison's work shows how this can be done in studying the growth of the U.S. economy, and of other advanced economies as well. I take success at this level to be a worthy objective for the theory of economic development.

3. Neoclassical growth theory: Assessment

It seems to be universally agreed that the model I have just reviewed is not a theory of economic development. Indeed, I suppose this is why we think of 'growth' and 'development' as distinct fields, with growth theory defined as those aspects of economic growth we have some understanding of, and development defined as those we don't. I do not disagree with this judgment, but a more specific idea of exactly where the model falls short will be useful in thinking about alternatives.

If we were to attempt to use the Solow–Denison framework to account for the diversity in income levels and rates of growth we observe in the world today, we would begin, theoretically, by imagining a world consisting of many

[10] Denison (1961, ch. 24). My favorite example is number 4 in this 'menu of choices available to increase the growth rate': '0.03 points [i.e., 0.03 of one percentage point] maximum potential ... Eliminate all crime and rehabilitate all criminals.' This example and many others in this chapter are pointed rebukes to those in the 1960s who tried to advance their favorite (and often worthy) causes by claiming ties to economic growth.

economies of the sort we have just described, assuming something about the way they interact, working out the dynamics of this new model, and comparing them to observations. This is actually much easier than it sounds (there isn't much to the theory of international trade when everyone produces the same, single good!), so let us think it through.

The key assumptions involve factor mobility: Are people and capital free to move? It is easiest to start with the assumption of *no* mobility, since then we can treat each country as an isolated system, just like the one we have just worked out. In this case, the model predicts that countries with the same preferences and technology will converge to identical levels of income and asymptotic rates of growth. Since this prediction does not accord at all well with what we observe, if we want to fit the theory to observed cross-country variations, we will need to postulate appropriate variations in the parameters (ρ, σ, λ, β and μ) and/or assume that countries differ according to their initial technology levels, $A(0)$. Or we can obtain additional theoretical flexibility by treating countries as differently situated relative to their steady-state paths. Let me review these possibilities briefly.

Population growth, λ, and income shares going to labor, $1-\beta$, do of course differ across countries, but neither varies in such a way as to provide an account of income differentials. Countries with rapid population growth are not systematically poorer than countries with slow-growing populations, as the theory predicts, either cross-sectionally today or historically. There are, certainly, interesting empirical connections between economic variables (narrowly defined) and birth and death rates, but I am fully persuaded by the work of Becker (1981) and others that these connections are best understood as arising from the way decisions to maintain life and to initiate it *respond* to economic conditions. Similarly, poor countries have lower labor shares than wealthy countries, indicating to me that elasticities of substitution in production are below unity (contrary to the Cobb–Douglas assumption I am using in these examples), but the prediction (9) that poorer countries should therefore grow more rapidly is not confirmed by experience.

The parameters ρ and σ are, as observed earlier, not separately identified, but if their joint values differed over countries in such a way as to account for income differences, poor countries would have systematically much higher (risk-corrected) interest rates than rich countries. Even if this were true, I would be inclined to seek other explanations. Looking ahead, we would like also to be able to account for sudden large changes in growth rates of individual countries. Do we want a theory that focuses attention on spontaneous shifts in people's discount rates or degree of risk aversion? Such theories are hard to refute, but I will leave it to others to work this side of the street.

Consideration of off-steady-state behavior would open up some new possibilities, possibly bringing the theory into better conformity with observation, but I do not view this route as at all promising. Off steady states, (9) need not hold and capital and output growth rates need not be either equal or constant, but it still follows from the technology (2) that output growth (g_{yt}, say) and capital growth (g_{kt}, say), both per capita, obey

$$g_{yt} = \beta g_{kt} + \mu.$$

But g_{yt} and g_{kt} can both be measured, and it is well established that for no value of β that is close to observed capital shares is it the case that $g_{yt} - \beta g_{kt}$ is even approximately uniform across countries. Here 'Denison's Law' works against us: the insensitivity of growth rates to variations in the model's underlying parameters, as reviewed earlier, makes it hard to use the theory to account for large variations across countries or across time. To conclude that even large changes in 'thriftiness' would not induce large changes in U.S. growth rates is really the same as concluding that differences in Japanese and U.S. thriftiness cannot account for much of the difference in these two economies' growth rates. By assigning so great a role to 'technology' as a source of growth, the theory is obliged to assign correspondingly minor roles to everything else, and so has very little ability to account for the wide diversity in growth rates that we observe.

Consider, then, variations across countries in 'technology' – its level and rate of change. This seems to me to be the one factor isolated by the neoclassical model that has the potential to account for wide differences in income levels and growth rates. This point of departure certainly does accord with everyday usage. We say that Japan is technologically more advanced than China, or that Korea is undergoing unusually rapid technical change, and such statements seem to mean something (and I think they do). But they cannot mean that the 'stock of useful knowledge' [in Kuznets's (1959) terminology] is higher in Japan than in China, or that it is growing more rapidly in Korea than elsewhere. 'Human knowledge' is just human, not Japanese or Chinese or Korean. I think when we talk in this way about differences in 'technology' across countries we are not talking about 'knowledge' in general, but about the knowledge of particular people, or perhaps particular subcultures of people. If so, then while it is not exactly wrong to describe these differences by an exogenous, exponential term like $A(t)$ neither is it useful to do so. We want a formalism that leads us to think about individual decisions to acquire knowledge, and about the consequences of these decisions for productivity. The body of theory that does this is called the theory of 'human capital', and I am going to draw extensively on this theory in the remainder of these lectures. For the moment, however, I simply want to impose the terminological convention that 'technology' – its level and rate of change – will be used to refer to something common to all countries, something 'pure' or 'disembodied', something whose determinants are outside the bounds of our current inquiry.

In the absence of differences in pure technology then, and under the assumption of no factor mobility, the neoclassical model predicts a strong tendency to income equality and equality in growth rates, tendencies we can observe within countries and, perhaps, within the wealthiest countries taken as a group, but which simply cannot be seen in the world at large. When factor mobility is permitted, this prediction is very powerfully reinforced. Factors of production, capital or labor or both, will flow to the highest returns, which is to say where each is relatively scarce. Capital–labor ratios will move rapidly to equality, and with them factor prices. Indeed, these predictions survive differences in preference parameters and population growth rates. In the model as stated, it makes no difference whether labor moves to join capital or the other way around. (Indeed, we know that with a many-good technology, factor price equalization can be achieved without mobility in *either* factor of production.)

The eighteenth and nineteenth century histories of the Americas, Australia and South and East Africa provide illustrations of the strength of these forces for equality, and of the ability of even simple neo-classical models to account for important economic events. If we replace the labor–capital technology of the Solow model with a land–labor technology of the same form, and treat labor as the mobile factor and land as the immobile, we obtain a model that predicts exactly the immigration flows that occurred and for exactly the reason – factor price differentials – that motivated these historical flows. Though this simple deterministic model abstracts from considerations of risk and many other elements that surely played a role in actual migration decisions, this abstraction is evidently not a fatal one.

In the present century, of course, immigration has been largely shut off, so it is not surprising that this land–labor model, with labor mobile, no longer gives an adequate account of actual movements in factors and factor prices. What *is* surprising, it seems to me, is that capital movements do not perform the same functions. Within the United States, for example, we have seen southern labor move north to produce automobiles. We have also seen textile mills move from New England south (to 'move' a factory, one lets it run down and builds its replacement somewhere else: it takes some time, but then, so does moving families) to achieve this same end of combining capital with relatively low wage labor. Economically, it makes no difference which factor is mobile, so long as one is.

Why, then, should the closing down of international labor mobility have slowed down, or even have much affected, the tendencies toward factor price equalization predicted by neoclassical theory, tendencies that have proved to be so powerful historically? If it is profitable to move a textile mill from New England to South Carolina, why is it not more profitable still to move it to Mexico? The fact that we do see *some* capital movement toward low-income countries is not an adequate answer to this question, for the theory predicts that *all* new investment should be so located until such time as return and real wage differentials are erased. Indeed, why did these capital movements not take place during the colonial age, under political and military arrangements that eliminated (or long postponed) the 'political risk' that is so frequently cited as a factor working against capital mobility? I do not have a satisfactory answer to this question, but it seems to me a major – perhaps *the* major – discrepancy between the predictions of neoclassical theory and the patterns of trade we observe. Dealing with this issue is surely a minimal requirement for a theory of economic development.

4. Human capital and growth

To this point, I have reviewed an example of the neoclassical model of growth, compared it to certain facts of U.S. economic history, and indicated why I want to use this theory as a kind of model, or image, of what I think is possible and useful for a theory of economic development. I have also described what seem to me two central reasons why this theory is not, as it stands, a useful theory of economic development: its apparent inability to account for observed diversity across countries and its strong and evidently counterfactual prediction that international trade should induce rapid movement toward equality in capital–labor ratios and factor prices. These observations set the stage for what I would like to do in the rest of the lectures.

Rather than take on both problems at once, I will begin by considering an alternative, or at least a complementary, engine of growth to the 'technological change' that serves this purpose in the Solow model, retaining for the moment the other features of that model (in particular, its closed character). I will do this by adding what Schultz (1963) and Becker (1964) call 'human capital' to the model, doing so in a way that is very close technically to similarly motivated models of Arrow (1962), Uzawa (1965) and Romer (1986).

By an individual's 'human capital' I will mean, for the purposes of this section, simply his general skill level, so that a worker with human capital $h(t)$ is the productive equivalent of two workers with $\frac{1}{2}h(t)$ each, or a half-time worker with $2h(t)$. The theory of human capital focuses on the fact that the way an individual allocates his time over various activities in the current period affects his productivity, or his $h(t)$ level, in future periods. Introducing human capital into the model, then, involves spelling out both the way human capital levels affect current production and the way the current time allocation affects the accumulation of human capital. Depending on one's objectives, there are many ways to formulate both these aspects of the 'technology'. Let us begin with the following, simple assumptions.

Suppose there are N workers in total, with skill levels h ranging from 0 to infinity. Let there be $N(h)$ workers with skill level h, so that $N = \int_0^\infty N(h)\,\mathrm{d}h$. Suppose a worker with skill h devotes the fraction $u(h)$ of his non-leisure time to current production, and the remaining $1 - u(h)$ to human capital accumulation. Then the effective workforce in production – the analogue to $N(t)$ in (2) – is the sum $N^e = \int_0^\infty u(h)N(h)h\,\mathrm{d}h$ of the skill-weighted manhours devoted to current production. Thus if output as a function of total capital K

and effective labor N^e is $F(K, N^e)$, the hourly wage of a worker at skill h is $F_N(K, N^e)h$ and his total earnings are $F_N(K, N^e)hu(h)$.

In addition to the effects of an individual's human capital on his own productivity – what I will call the *internal effect* of human capital – I want to consider an *external effect*. Specifically, let the *average* level of skill or human capital, defined by

$$h_a = \frac{\int_0^\infty hN(h)\,\mathrm{d}h}{\int_0^\infty N(h)\,\mathrm{d}h},$$

also contribute to the productivity of all factors of production (in a way that I will spell out shortly). I call this h_a effect external, because though all benefit from it, no individual human capital accumulation decision can have an appreciable effect on h_a, so no one will take it into account in deciding how to allocate his time.

Now it will simplify the analysis considerably to follow the preceding analysis and treat all workers in the economy as being identical. In this case, if all workers have skill level h and all choose the time allocation u, the effective workforce is just $N^e = uhN$, and the average skill level h_a is just h. Even so, I will continue to use the notation h_a for the latter, to emphasize the distinction between internal and external effects. Then the description (2) of the technology of goods production is replaced by

$$N(t)c(t) + \dot{K}(t) = AK(t)^\beta[u(t)h(t)N(t)]^{1-\beta}h_a(t)^\gamma, \tag{11}$$

where the term $h_a(t)^\gamma$ is intended to capture the external effects of human capital, and where the technology level A is now assumed to be constant.

To complete the model, the effort $1 - u(t)$ devoted to the accumulation of human capital must be linked to the rate of change in its level, $h(t)$. Everything hinges on exactly how this is done. Let us begin by postulating a technology relating the growth of human capital, $\dot{h}(t)$, to the level already attained and the effort devoted to acquiring more, say:

$$\dot{h}(t) = h(t)^\zeta G(1 - u(t)), \tag{12}$$

where G is increasing, with $G(0) = 0$. Now if we take $\zeta < 1$ in this formulation, so that there is diminishing returns to the accumulation of human capital, it is easy to see that human capital cannot serve as an alternative engine of growth to the technology term $A(t)$. To see this, note that, since $u(t) \geq 0$, (12) implies that

$$\frac{\dot{h}(t)}{h(t)} \leq h(t)^{\zeta-1}G(1),$$

so that $\dot{h}(t)/h(t)$ must eventually tend to zero as $h(t)$ grows no matter how much effort is devoted to accumulating it. This formulation would simply complicate the original Solow model without offering any genuinely new possibilities.

Uzawa (1965) worked out a model very similar to this one [he assumed $\gamma = 0$ and $U(c) = c$] under the assumption that the right-hand side of (12) is *linear* in $u(t)$ ($\zeta = 1$). The striking feature of his solution, and the feature that recommends his formulation to us, is that it exhibits sustained per-capita income growth from endogenous human capital accumulation alone: no external 'engine of growth' is required.

Uzawa's linearity assumption might appear to be a dead-end (for our present purposes) because we seem to see diminishing returns in observed, individual patterns of human capital accumulation: people accumulate it rapidly early in life, then less rapidly, then not at all – as though each additional percentage increment were harder to gain than the preceding one. But an alternative explanation for *this* observation is simply that an individual's lifetime is finite, so that the return to increments falls with time. Rosen (1976) showed that a technology like (12), with $\zeta = 1$, is consistent with the evidence we have on individual earnings. I will adapt the Uzawa–Rosen formulation here, assuming for simplicity that the function G is linear:

$$\dot{h}(t) = h(t)\delta[1 - u(t)]. \tag{13}$$

According to (13), if no effort is devoted to human capital accumulation, $[u(t) = 1]$, then none accumulates. If all effort is devoted to this purpose $[u(t) = 0]$, $h(t)$ grows at its maximal rate δ. In between these extremes, there are *no* diminishing returns to the stock $h(t)$: A given *percentage* increase in $h(t)$ requires the same effort, no matter what level of $h(t)$ has already been attained.

It is a digression I will not pursue, but it would take some work to go from a human capital technology of the form (13), applied to each finite-lived individual (as in Rosen's theory), to this same technology applied to an entire infinitely-lived typical household or family. For example, if each individual acquired human capital as in Rosen's model but if *none* of this capital were passed on to younger generations, the 'household's' stock would (with a fixed demography) stay constant. To obtain (13) for a family, one needs to assume both that each individual's capital follows this equation *and* that the initial level each new member begins with is proportional to (not equal to!) the level already attained by older members of the family. This is simply one instance of a general fact that I will emphasize again and again: that human capital accumulation is a *social* activity, involving *groups* of people in a way that has no counterpart in the accumulation of physical capital.

Aside from these changes in the technology, expressed in (11) and (13) to incorporate human capital and its accumulation, the model to be discussed is identical to the Solow model. The system is closed, population grows at the fixed rate λ, and the typical household has the preferences (1). Let us proceed to the analysis of this new model.[11]

In the presence of the external effect $h_a(t)^\gamma$, it will not be the case that optimal growth paths and competitive equilibrium paths coincide. Hence we cannot construct the equilibrium by studying the same hypothetical planning problem used to study Solow's model. But by following Romer's analysis of a very similar model, we can obtain the optimal and equilibrium paths separately, and compare them. This is what I will now do.

By an *optimal* path, I will mean a choice of $K(t)$, $h(t)$, $H_a(t)$, $c(t)$ and $u(t)$ that maximizes utility (1) subject to (11) and (13), *and* subject to the constraint $h(t)=h_a(t)$ for all t. This is a problem similar in general structure to the one we reviewed in section 2, and I will turn to it in a moment.

By an *equilibrium* path, I mean something more complicated. First, take a path $h_a(t)$, $t \geq 0$, to be given, like the exogenous technology path $A(t)$ in the Solow model. Given $h_a(t)$, consider the problem the private sector, consisting of atomistic households and firms, would solve if each agent *expected* the average level of human capital to follow the path $h_a(t)$. That is, consider the problem of choosing $h(t)$, $k(t)$, $c(t)$ and $u(t)$ so as to maximize (1) subject to (11) and (13), taking $h_a(t)$ as exogenously determined. When the solution path $h(t)$ for this problem coincides with the given path $h_a(t)$ – so that actual and expected behavior are the same – we say that the system is in equilibrium.[12]

The current-value Hamiltonian for the optimal problem, with 'prices' $\theta_1(t)$ and $\theta_2(t)$ used to value increments to physical and human capital respectively, is

$$\begin{aligned}
&H(K,h,\theta_1,\theta_2,c,u,t)\\
&=\frac{N}{1-\sigma}(c^{1-\sigma}-1)+\theta_1\left[AK^\beta(uNh)^{1-\beta}h^\gamma-Nc\right]\\
&\quad+\theta_2\left[\delta h(1-u)\right].
\end{aligned}$$

In this model, there are two decision variables – consumption, $c(t)$, and the time devoted to production, $u(t)$ – and these are (in an optimal program)

[11] The model discussed in this section (in contrast to the model of section 2) has not been fully analyzed in the literature. The text gives a self-contained derivation of the main features of balanced paths. The treatment of behavior off balanced paths is largely conjecture, based on parallels with Uzawa (1965) and Romer (1986).

[12] This formulation of equilibrium behavior in the presence of external effects is taken from Arrow (1962) and Romer (1986). Romer actually carries out the study of the fixed-point problem in a space of $h(t)$, $t \geq 0$, paths. Here I follow Arrow and confine explicit analysis to balanced paths only.

selected so as to maximize H. The first-order conditions for this problem are thus:

$$c^{-\sigma} = \theta_1, \tag{14}$$

and

$$\theta_1(1-\beta)AK^{\beta}(uNh)^{-\beta}Nh^{1+\gamma} = \theta_2\delta h. \tag{15}$$

On the margin, goods must be equally valuable in their two uses – consumption and capital accumulation [eq. (14)] – and time must be equally valuable in its two uses – production and human capital accumulation [eq. (15)].

The rates of change of the prices θ_1 and θ_2 of the two kinds of capital are given by

$$\dot{\theta}_1 = \rho\theta_1 - \theta_1\beta AK^{\beta-1}(uNh)^{1-\beta}h^{\gamma}, \tag{16}$$

$$\dot{\theta}_2 = \rho\theta_2 - \theta_1(1-\beta+\gamma)AK^{\beta}(uN)^{1-\beta}h^{-\beta+\gamma} - \theta_2\delta(1-u). \tag{17}$$

Then eqs. (11) and (13) and (14)–(17), together with two transversality conditions that I will not state here, implicitly describe the optimal evolution of $K(t)$ and $h(t)$ from any initial mix of these two kinds of capital.

In the *equilibrium*, the private sector 'solves' a control problem of essentially this same form, but with the term $h_a(t)^{\gamma}$ in (11) taken as given. Market clearing then requires that $h_a(t) = h(t)$ for all t, so that (11), (13), (14), (15) and (16) are necessary conditions for equilibrium as well as for optimal paths. But eq. (17) no longer holds: It is precisely in the valuation of human capital that optimal and equilibrium allocations differ. For the private sector, in equilibrium, (17) is replaced by

$$\dot{\theta}_2 = \rho\theta_2 - \theta_1(1-\beta)AK^{\beta}(uN)^{1-\beta}h^{-\beta}h_a^{\gamma} - \theta_2\delta(1-u).$$

Since market clearing implies $(h(t) = h_a(t))$ for all t, this can be written as

$$\dot{\theta}_2 = \rho\theta_2 - \theta_1(a-\beta)AK^{\beta}(uN)^{1-\beta}h^{-\beta+\gamma} - \theta_2\delta(1-u). \tag{18}$$

Note that, if $\gamma = 0$, (17) and (18) are the same. It is the presence of the external effect $\gamma > 0$ that creates a divergence between the 'social' valuation formula (17) and the private valuation (18).

As with the simpler Solow model, the easiest way to characterize both optimal and equilibrium paths is to begin by seeking balanced growth solutions of both systems: solutions on which consumption and both kinds of capital are growing at constant percentage rates, the prices of the two kinds of capital are declining at constant rates, and the time allocation variable $u(t)$ is constant. Let us start by considering features that optimal and equilibrium paths have in common [by setting aside (17) and (18)].

Let κ denote $\dot{c}(t)/c(t)$, as before, so that (14) and (16) again imply the marginal productivity of capital condition:

$$\beta A K(t)^{\beta-1}\big(u(t)h(t)N(t)\big)^{1-\beta}h(t)^{\gamma}=\rho+\sigma\kappa, \tag{19}$$

which is the analogue to condition (6). As in the earlier model, it is easy to verify that $K(t)$ must grow at the rate $\kappa+\lambda$ and that the savings rate s is constant, on a balanced path, at the value given by (10). For the derivation of these facts concerning physical capital accumulation, it is immaterial whether $h(t)$ is a matter of choice or an exogenous force as was technological change in the earlier model.

Now if we let $\nu=\dot{h}(t)/h(t)$ on a balanced path, it is clear from (13) that

$$\nu=\delta(1-u), \tag{20}$$

and from differentiating (19) that κ, the common growth rate of consumption and per-capita capital is

$$\kappa=\left(\frac{1-\beta+\gamma}{1-\beta}\right)\nu. \tag{21}$$

Thus with $h(t)$ growing at the fixed rate ν, $(1-\beta+\gamma)\nu$ plays the role of the exogenous rate of technological change μ in the earlier model.

Turning to the determinants of the rate of growth ν of human capital, one sees from differentiating both first-order conditions (14) and (15) and substituting for $\dot{\theta}_1/\theta_1$ that

$$\frac{\dot{\theta}_2}{\theta_2}=(\beta-\sigma)\kappa-(\beta-\gamma)\nu+\lambda. \tag{22}$$

At this point, the analyses of the efficient and equilibrium paths diverge. Focusing first on the efficient path, use (17) and (15) to obtain

$$\frac{\dot{\theta}_2}{\theta_2}=\rho-\delta-\frac{\gamma}{1-\beta}\delta u. \tag{23}$$

Now substitute for u from (20), eliminate $\dot{\theta}_2/\theta_2$ between (22) and (23), and solve for ν in terms of κ. Then eliminating κ between this equation and (21) gives the solution for the *efficient* rate of human capital growth, which I will call ν^*:

$$\nu^* = \sigma^{-1}\left[\delta - \frac{1-\beta}{1-\beta+\gamma}(\rho-\lambda)\right]. \tag{24}$$

Along an equilibrium balanced path (18) holds in place of (17) so that in place of (23) we have

$$\frac{\dot{\theta}_2}{\theta_2} = \rho - \delta. \tag{25}$$

Then by the same procedure used to derive the efficient growth rate ν^* from (23), we can obtain from (25) the equilibrium growth rate ν:

$$\nu = [\sigma(1-\beta+\gamma)-\gamma]^{-1}[(1-\beta)(\delta-(\rho-\lambda))]. \tag{26}$$

[For the formulas (24) and (26) to apply, the rates ν and ν^* must not exceed the maximum feasible rate δ. This restriction can be seen to require

$$\sigma \geq 1 - \frac{1-\beta}{1-\beta+\gamma}\frac{\rho-\lambda}{\delta}, \tag{27}$$

so the model cannot apply at levels of risk aversion that are too low (that is, if the intertemporal substitutability of consumption is too high).[13] When (27) holds with equality, $\nu = \nu^* = \delta$; when the inequality is strict, $\nu^* > \nu$, as one would expect.]

Eqs. (24) and (26) give, respectively, the efficient and the competitive equilibrium growth rates of human capital along a balanced path. In either case, this growth increases with the effectiveness δ of investment in human capital and declines with increases in the discount rate ρ. (Here at last is a connection between 'thriftiness' and growth!) In either case, (21) gives the corresponding rate of growth of physical capital, per capita. Notice that the theory predicts sustained growth whether or not the external effect γ is positive. If $\gamma = 0$, $\kappa = \nu$, while if $\gamma > 0$, $\kappa > \nu$, so that the external effect induces more rapid physical than human capital growth.

For the case $\sigma = 1$, the difference between efficient and equilibrium human capital growth rates is, subtracting (26) from (24),

$$\nu^* - \nu = \frac{\gamma}{1-\beta+\gamma}(\rho-\lambda).$$

[13] If utility is too nearly linear (σ is too near zero) and if δ is high enough, consumers will keep postponing consumption forever. [This does not occur in Uzawa's model, even though he assumes $\sigma = 0$, because he introduces diminishing returns to $1-u(t)$ in his version of (13).]

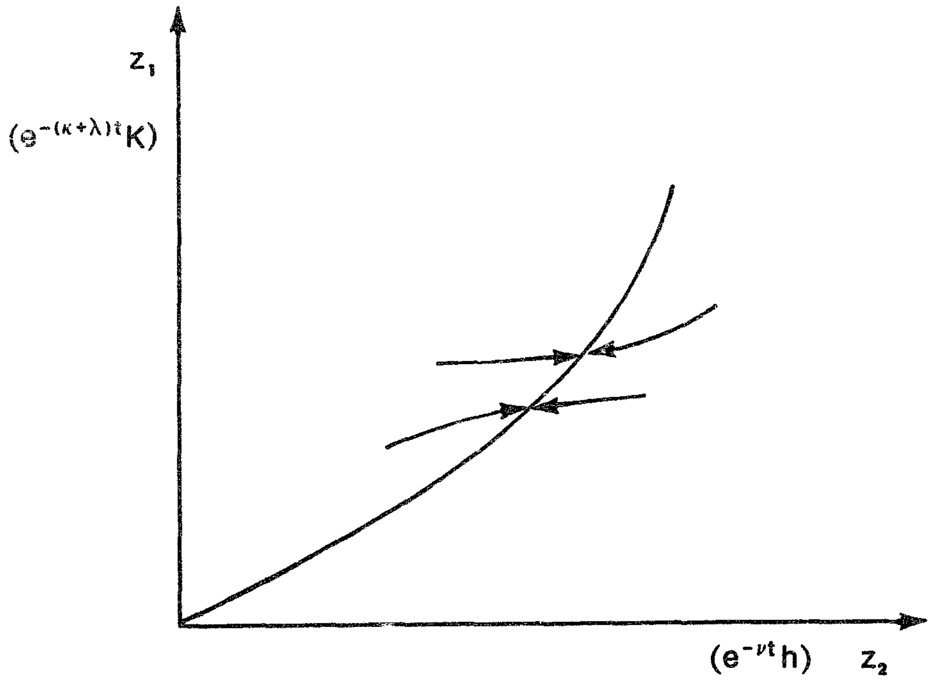

Fig. 1

Thus the inefficiency is small when either the external effect is small ($\gamma \simeq 0$) or the discount rate is low ($\rho - \lambda \simeq 0$).

Eqs. (21), (24) and (26) describe the asymptotic rates of change of both kinds of capital, under both efficient and equilibrium regimes. What can be said about the *levels* of these variables? As in the original model, this information is implicit in the marginal productivity condition for capital, eq. (19). In the original model, this condition – or rather its analogue, eq. (6) – determined a unique long-run value of the normalized variable $z(t) = e^{-(\kappa+\lambda)t}K(t)$. In the present, two-capital model, this condition defines a curve linking the *two* normalized variables $z_1(t) = e^{-(\kappa+\lambda)t}K(t)$ and $z_2(t) = e^{-\nu t}h(t)$. Inserting these variables into (19) in place of $K(t)$ and $h(t)$ and applying the formula (21) for κ, we obtain

$$\left(\beta A N_0^{1-\beta} u^{1-\beta}\right) z_1^{\beta-1} z_2^{1-\beta+\gamma} = \rho + \sigma\kappa. \tag{28}$$

It is a fact that *all* pairs (z_1, z_2) satisfying (28) correspond to balanced paths. Let us ask first what this locus of (normalized) capital combinations looks like, and second what this means for the dynamics of the system.

Fig. 1 shows the curve defined by (28). With no external effect ($\gamma = 0$) it is a straight line through the origin; otherwise ($\gamma > 0$) it is convex. The position of the curve depends on u and κ, which from (20) and (21) can be expressed as functions of ν. Using this fact one can see that increases in ν shift the curve to the right. Thus an efficient economy, on a balanced path, will have a higher level of human capital (z_2) for any given level of physical capital (z_1), since $\nu^* > \nu$.

The dynamics of this system are not as well understood as those of the one-good model, but I would conjecture that for any initial configuration $(K(0), h(0))$ of the two kinds of capital, the solution paths (of either the efficient or the equilibrium system) $(z_1(t), z_2(t))$ will converge to *some* point on the curve in fig. 1, but that this asymptotic position will depend on the initial position. The arrows in fig. 1 illustrate some possible trajectories. Under these dynamics, then, an economy beginning with low levels of human and physical capital will remain *permanently* below an initially better endowed economy.

The curve in fig. 1 is *defined* as the locus of long-run capital pairs (K, h) such that the marginal product of capital has the common value $\rho + \sigma\kappa$ given by the right side of (19). Along this curve, then, returns to capital are constant and also constant over time even though capital stocks of both kinds are growing. In the absence of the external effect γ, it will also be true that the real wage rate for labor of a given skill level (the marginal product of labor) is constant along the curve in fig. 1. This may be verified simply by calculating the marginal product of labor from (11) and making the appropriate substitutions.

In the general case, where $\gamma \geq 0$, the real wage increases as one moves up the curve in fig. 1. Along this curve, we have the elasticity formula

$$\frac{K}{w}\frac{\partial w}{\partial K} = \frac{(1+\beta)\gamma}{1-\beta+\gamma},$$

so that wealthier countries have higher wages than poorer ones for labor of any given skill. (Of course, workers in wealthy countries are typically also more skilled than workers in poor countries.) In all countries, wages at each skill level grow at the rate

$$\omega = \frac{\gamma}{1-\beta}\nu.$$

Then taking skill growth into account as well, wages grow at

$$\omega + \nu = \frac{1-\beta+\gamma}{1-\beta}\nu = \kappa,$$

or at a rate equal to the growth rate in the per-capita stock of physical capital.

The version of the model I propose to fit to, or estimate from, U.S. time series is the equilibrium solution (21), (26) and (10). As in the discussion of Solow's version λ, κ, β and s are estimated, from Denison (1961), at 0.013, 0.014, 0.25 and 0.1, respectively. Denison also provides an estimate of 0.009 for the annual growth rate of human capital over his period, an estimate based mainly on the changing composition of the workforce by levels of education and on observations on the relative earnings of differently schooled workers. I will use this 0.009 figure as an estimate of ν, which amounts to assuming that human capital is accumulated to the point where its private return equals its social (and private) cost. (Since schooling is heavily subsidized in the U.S., this assumption may seem way off, but surely most of the subsidy is directed at early schooling that would be acquired by virtually everyone anyway, and so does not affect the margins relevant for my calculations.) Then the idea is to use (10), (21) and (26) to estimate ρ, σ, γ and δ.

As was the case in the Solow model, ρ and σ cannot separately be identified along steady-state paths, but eq. (10) (which can be derived for this model in exactly the same way as I derived it for the model of section 2) implies $\rho+\sigma\kappa=0.0675$. Eq. (21) implies $\gamma=0.417$. Combining eqs. (21) and (26) yields a relationship involving γ, ν, β, δ, λ and $\rho+\sigma\kappa$, but not ρ or σ separately. This relationship yields an estimate for δ of 0.05. The implied fraction of time devoted to goods production is then, from (20), $u=0.82$.

Given these parameter estimates, the *efficient* rate of human capital growth can be calculated, as a function of σ, from (24). It is: $\nu^*=0.009+0.0146/\sigma$. Table 1 gives some values of this function and the associated values of u^* and $\kappa^*=(1.556)\nu^*$. Under log utility ($\sigma=1$), then, the U.S. economy 'ought' to devote nearly three times as much effort to human capital accumulations as it does, and 'ought' to enjoy growth in per-capita consumption about two full percentage points higher than it has had in the past.

One could as easily fit this model to U.S. data under the assumption that *all* returns to human capital are internal, or that $\gamma=0$. In this case ν, ν^* and κ have the common value, from (21), (24) and (26), $\sigma^{-1}[\delta-(\rho-\lambda)]$, and the *ratio* of physical to human capital will converge to a value that is independent of initial conditions (the curve in fig. 1 will be a straight line). Identifying this common growth rate with Denison's 0.014 estimate for κ implies a u value of 0.72, or that 28% of effective workers' time is spent in human capital

Table 1

σ	ν^*	u^*	κ^*
1	0.024	0.52	0.037
2	0.016	0.68	0.025
3	0.014	0.72	0.022

accumulation. Accepting Denison's estimate of a 0.009 growth rate of human capital due to schooling, this would leave 0.005 to be attributed to other forms, say on-the-job training that is distinct from productive activities.

What can be concluded from these exercises? Normatively, it seems to me, very little: The model I have just described has *exactly* the same ability to fit U.S. data as does the Solow model, in which equilibrium and efficient growth rates coincide. Moreover, it is clear that the two models can be merged [by re-introducing exogenous technical change into (11)] to yield a whole class of intermediate models that also fit data in this same rough sense. I am simply generating new possibilities, in the hope of obtaining a theoretical account of cross-country *differences* in income levels and growth rates. Since the model just examined is consistent with the *permanent* maintenance of per-capita income differentials of any size (though not with differences in growth rates) some progress toward this objective has been made. But before returning to empirical issues in more detail, I would like to generate another, quite different, example of a system in which human capital plays a central role.

5. Learning-by-doing and comparative advantage

The model I have just worked through treats the decision to accumulate human capital as equivalent to a decision to withdraw effort from production – to go to school, say. As many economists have observed, on-the-job-training or learning-by-doing appear to be at least as important as schooling in the formation of human capital. It would not be difficult to incorporate such effects into the previous model, but it is easier to think about one thing at a time so I will just set out an example of a system (again, for the moment, closed) in which *all* human capital accumulation is learning-by-doing. Doing this will involve thinking about economies with many consumption goods, which will open up interesting new possibilities for interactions between international trade and economic growth.[14]

Let there be two consumption goods, c_1 and c_2, and no physical capital. For simplicity, let population be constant. The ith good is produced with the Ricardian technology:

$$c_i(t) = h_i(t)u_i(t)N(t), \qquad i = 1,2, \tag{29}$$

where $h_i(t)$ is human capital specialized to the production of good i and $u_i(t)$ is the fraction of the workforce devoted to producing good i (so $u_i \geq 0$ and $u_1 + u_2 = 1$). Of course, it would not be at all difficult to incorporate physical capital into this model, with (29) replaced by something like (11) for each good i. Later on, I will conjecture the behavior of such a hybrid model, but it will be simpler for now to abstract from capital.

[14] The formulation of learning used in this section is taken from Krugman (1985).

In order to let $h_i(t)$ be interpreted as a result of learning-by-doing, assume that the growth of $h_i(t)$ increases with the effort $u_i(t)$ devoted to producing good i (as opposed to increasing with the effort *withdrawn* from production). A simple way to do this is

$$\dot{h}_i(t) = h_i(t)\delta_i u_i(t). \tag{30}$$

To be specific, assume that $\delta_1 > \delta_2$, so that good 1 is taken to be the 'high-technology' good. For the sake of discussion, assume at one extreme that the effects of $h_i(t)$ in (29) and (30) are entirely external: production and skill accumulation for each good depend on the average skill level in that industry only.

As was the case with (13), the equation for human capital accumulation in the model discussed earlier, (30) seems to violate the diminishing returns we observe in studies of productivity growth for particular products. Learning-by-doing in any particular activity occurs rapidly at first, then more slowly, then not at all. Yet as in the preceding discussion, if we simply incorporate diminishing returns into (30), human capital will lose its status as an engine of growth (and hence its interest for the present discussion). What I want (30) to 'stand for', then, is an environment in which new goods are continually being introduced, with diminishing returns to learning on each of them separately, and with human capital specialized to old goods being 'inherited' in some way by new goods. In other words, one would like to consider the inheritance of human capital within 'families' of goods as well as within families of people.[15]

Under these assumptions of no physical capital accumulation and purely external human capital accumulation, the individual consumer has no inter-temporal tradeoffs to decide on, so all we need to know about his preferences is his current-period utility function. I will assume a constant elasticity of substitution form:

$$U(c_1, c_2) = \left[\alpha_1 c_1^{-\rho} + \alpha_2 c_2^{-\rho}\right]^{-1/\rho}, \tag{31}$$

where $\alpha_i \geq 0$, $\alpha_1 + \alpha_2 = 1$, $\rho > -1$, and $\sigma = 1/(1+\rho)$ is the elasticity of substitution between c_1 and c_2. (Please note that the parameters ρ and σ represent completely different aspects of preferences in this section from those they represented in sections 2–4.) With technology and preferences given by (29)–(31), I will first work out the equilibrium under autarchy and then turn to international trade considerations.

Take the first good as numeraire, and let $(1, q)$ be the equilibrium prices in a closed economy. Then q must equal the marginal rate of substitution in

[15] Stokey (1987) formulates a model of learning on an infinite family of produced and potentially producible goods that captures exactly these features.

consumption, or

$$q = \frac{U_2(c_1,c_2)}{U_1(c_1,c_2)} = \frac{\alpha_2}{\alpha_1}\left(\frac{c_2}{c_1}\right)^{-(1+\rho)}.$$

Solving for the consumption ratio,

$$\frac{c_2}{c_1} = \left(\frac{\alpha_2}{\alpha_1}\right)^{\sigma} q^{-\sigma}. \tag{32}$$

Hence both goods will be produced, so that (29) plus profit maximization implies that relative prices are dictated by the human capital endowments: $q = h_1/h_2$. Then (29) and (32) together give the equilibrium workforce allocation as a function of these endowments,

$$\frac{c_2}{c_1} = \frac{u_2 h_2}{u_1 h_1} = \left(\frac{\alpha_2}{\alpha_1}\right)^{\sigma}\left(\frac{h_2}{h_1}\right)^{\sigma},$$

or

$$\frac{1-u_1}{u_1} = \left(\frac{\alpha_2}{\alpha_1}\right)^{\sigma}\left(\frac{h_2}{h_1}\right)^{\sigma-1}. \tag{33}$$

The dynamics of this closed economy are then determined by inserting this information into eq. (30). Solving first for the autarchy price path, $q(t) = h_1(t)/h_2(t)$, we have

$$\frac{1}{q}\frac{\mathrm{d}q}{\mathrm{d}t} = \frac{1}{h_1}\frac{\mathrm{d}h_1}{\mathrm{d}t} - \frac{1}{h_2}\frac{\mathrm{d}h_2}{\mathrm{d}t} = \delta_1 u_1 - \delta_2(1-u_1),$$

or

$$\frac{1}{q}\frac{\mathrm{d}q}{\mathrm{d}t} = (\delta_1+\delta_2)\left[1+\left(\frac{\alpha_2}{\alpha_1}\right)^{\sigma} q^{1-\sigma}\right]^{-1} - \delta_2. \tag{34}$$

Solving this first-order equation for $q(t) = h_1(t)/h_2(t)$, given the initial endowments $h_1(0)$ and $h_2(0)$, determines the workforce allocation at each date [from (33)] and hence, from (30), the paths of $h_1(t)$ and $h_2(t)$ separately.

It will come as no surprise to trade theorists that the analysis of (34) breaks down into three cases, depending on the elasticity of substitution σ between the two goods. I will argue below, on the basis of trade considerations, that the interesting case for us is when $\sigma > 1$, so that c_1 and c_2 are assumed to be good

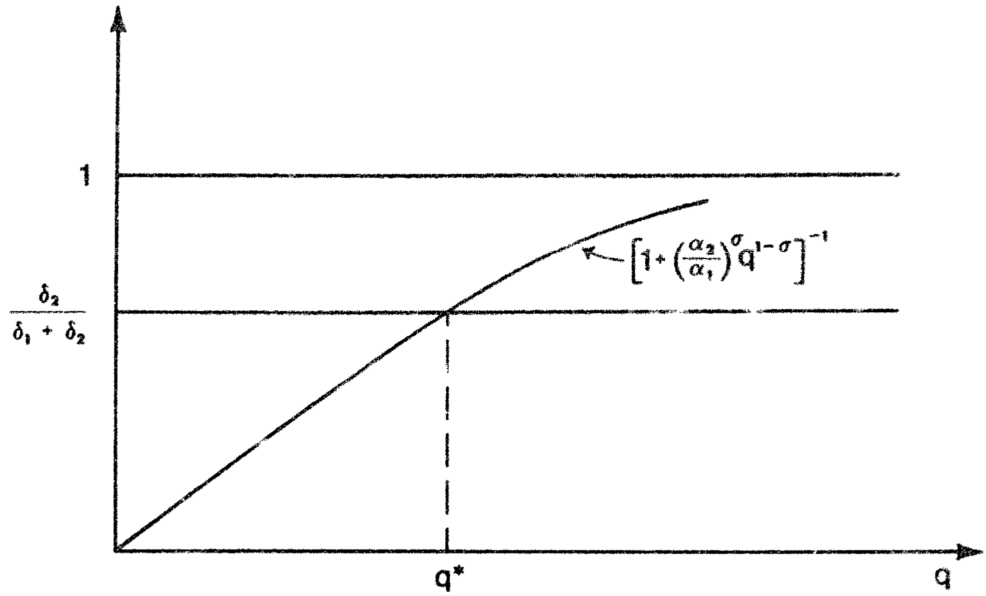

Fig. 2

substitutes. But in order to make this case, we need all three possibilities in front of us. Refer to fig. 2.

The figure is drawn for the case $\sigma > 1$, in which case the function $[1 + (\alpha_2/\alpha_1)^\sigma q^{1-\sigma}]^{-1}$ has the depicted upward slope. To the left of q^*, $\mathrm{d}q/\mathrm{d}t < 0$, so $q(t)$ tends to 0. To the right, $\mathrm{d}q/\mathrm{d}t > 0$, so $q(t)$ grows without bound. Thus the system in autarchy converges to specialization in one of the two goods [unless $q(0) = q^*$]. The choice of *which* good to specialize in is dictated by initial conditions. If we are initially good at producing c_1 [if $q(0) > q^*$], we produce a lot of it, get relatively better and better at producing more of it, eventually, since c_1 and c_2 are good substitutes, producing vanishingly small amounts of c_2.

If the goods are poor substitutes, $\sigma < 1$, the curve in fig. 2 slopes down and q^* becomes a *stable* stationary point. At this point, the workforce is so allocated as to equate $\delta_1 u_1$ and $\delta_2 u_2$.

In the borderline case of $\sigma = 1$, the curve is flat. The workforce is initially allocated as dictated by the demand weights, $ui = \alpha_i$, $i = 1, 2$, and this allocation is maintained forever. The autarchy price grows (or shrinks) at the constant rate $(1/q)(\mathrm{d}q/\mathrm{d}t) = \alpha_1\delta_1 - \alpha_2\delta_2$ forever.

As we learn how to produce computers more and more cheaply, then, we can substitute in their favor and consume more calculations and fewer potatoes, or we can use this benefit to release resources from computer production so as to consume more potatoes as well. The choice we take, not surprisingly, depends on whether these two goods are good substitutes or poor ones.

As was the case with the human capital model of the preceding section, it is obvious that the equilibrium paths we have just calculated will *not* be efficient. Since learning effects are assumed to be external, agents do not take them into account. If they did, they would allocate labor toward the 'high δ_i' good, relative to an equilibrium allocation, so as to take advantage of its higher growth potential.

Thus, except for the absence of physical capital, this closed economy model captures very much the same economics as does the preceding one. In both cases, the accumulation of human capital involves a sacrifice of current utility. In the first model, this sacrifice takes the form of a decrease in current consumption. In the second, it takes the form of a less desirable *mix* of current consumption goods than could be obtained with slower human capital growth. In both models the equilibrium growth rate falls short of the efficient rate and yields lower welfare. A subsidy to schooling would improve matters in the first. In the second, in language that is current in the United States, an 'industrial policy' focused on 'picking winners' (that is, subsidizing the production of high δ_i goods) would be called for. In the model, 'picking winners' is easy. If only it were so in reality!

The introduction of international trade into this second model leads to possibilities that I think are of real interest, though I have only begun to think them through analytically. The simplest kind of world to think about is one with perfectly free trade in the two final goods and with a continuum of small countries, since in that case prices in all countries will equal world prices $(1, p)$, say, and each country will take p as given. Fig. 3 gives a snapshot of this world at a single point in time. The contour lines in this figure are intended to depict a joint distribution of countries by their initial human capital endowments. A country is a point (h_1, h_2), and the distribution indicates the concentration of countries at various endowment levels.

At a given world price p, countries above the indicated line are producers of good 2, since for them $h_1/h_2 < p$ and they maximize the value of their production by specializing in this good. Countries below the line specialize in producing good 1, for the same reason. Then for each p one can calculate world supply of good 1 by summing (or integrating) the h_1 values below this price line, and the world supply of good 2 by summing the h_2 values above the line. Clearly, the supply of good 2 is an increasing function of p and of good 1 a decreasing function, so that the ratio c_2/c_1 of total quantities supplied increases as p increases.

Now world relative demand, with identical homothetic preferences, is just the same decreasing function of p that described each country's demand in the autarchic case: $c_2/c_1 = (\alpha_2/\alpha_1)^{\sigma} p^{-\sigma}$. Hence this static model determines the equilibrium world relative price p uniquely. Let us turn to the dynamics.

Those countries above the price line in fig. 3 are producing only good 2, so their h_1 endowments remain fixed while their h_2 endowments grow at the rate δ_2. Each country below the price line will produce only good 1, so that its h_2 is

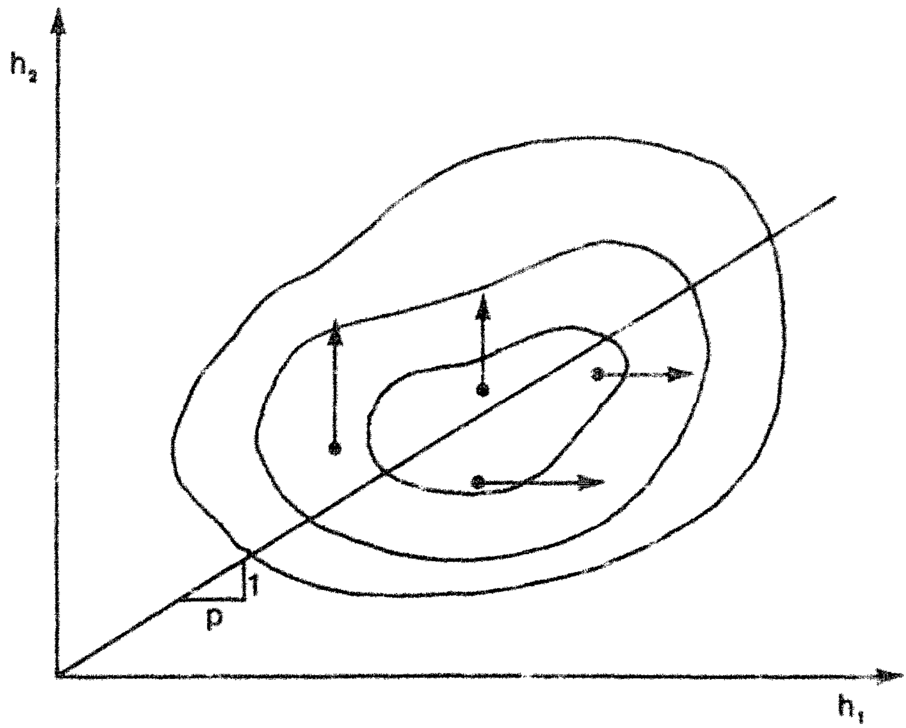

Fig. 3

constant while h_1 grows at the rate δ_1. Thus each country's (h_1, h_2) coordinates are changing as indicated by the arrows in fig. 3, altering the distribution of endowments that determines goods supplies over time. These movements obviously intensify the comparative advantages that led each country to specialize in the first place. On the other hand, as the endowment distribution changes, so does the equilibrium price p. Is it possible that these price movements will induce any country to switch its specialization from one good to the other?

A little reflection suggest that if anyone switches, it will have to be a producer of the high-δ good: good 1. The terms of trade are moving against good 1 (in the absence of switching) since its supply is growing faster. The issue again turns on the degree of substitutability between the two goods. If σ is low, the terms of trade may deteriorate so fast that a marginal good 1 producer may switch to producing good 2: he is getting relatively better at producing good 1, but not fast enough. The inequality that rules this possibility out is

$$\sigma \geq 1 - \frac{\delta_2}{\delta_1}. \tag{35}$$

I have already said that I think $\sigma > 1$ is the interesting case, so I want to accept (35) for the rest of the discussion.

Under (35) – that is, with no producer switching – we can read the dynamics of prices right off the relative demand schedule:

$$\frac{1}{p}\frac{\mathrm{d}p}{\mathrm{d}t} = \frac{\delta_1 - \delta_2}{\sigma}. \tag{36}$$

With relative price movements determined, the growth rates of real output in all countries is also determined. Measured in units of good 1, output of the good 1 producers grows at the rate δ_1. Output of the good 2 producers, also measured in units of good 1, grows at the rate $\delta_2 + (1/p)(\mathrm{d}p/\mathrm{d}t) = \delta_2 + (\delta_1 - \delta_2)/\sigma$. In general, then countries in equilibrium will undergo constant but not equal growth rates of real output.

Which countries will grow fastest? The condition that producers of the high-δ good, good 1, will have faster real growth is just

$$\delta_1 > \delta_2 + \frac{\delta_1 - \delta_2}{\sigma},$$

which is equivalent to the condition: $\sigma > 1$. That is, producing (having a comparative advantage in) high-learning goods will lead to higher-than-average real growth *only* if the two goods are good substitutes. Since it is exactly this possibility that the model is designed to capture, the case $\sigma > 1$ seems to me the only one of potential interest. If the terms-of-trade effects of technological change dominated the direct effects on productivity (which would be the case if $\sigma < 1$), those countries with rapid technological change would enjoy the slowest real income growth. There may be instances of such 'immiserizing growth', but if so they are surely the exceptions, not the rule. (These are the 'trade considerations' I mentioned earlier.)

This simple model shares with the model of section 4 the prediction of constant, endogenously determined real growth rates. In addition, it offers the possibility of different growth rates across countries, though differences that are not systematically related to income levels. In the equilibrium of the model, production patterns are dictated by comparative advantage: Each country produces goods for which its human capital endowment suits it. Given a learning technology like (30), countries accumulate skills by doing what they are already good at doing, intensifying whatever comparative advantage they begin with. This aspect of the theory will tend to lock in place an initial pattern of production, with rates of output growth variable across countries but stable within each country. There is no doubt that we observe forces for stability of this type, but there seem to be offsetting forces in reality that this model does not capture.

One of these has to do with the composition of demand. With homothetic utility the composition of world demand will remain fixed as income grows. In fact, we know that income elasticities for important classes of goods differ significantly from unity (contrary to the assumption of homotheticity). (We know, for example, that demand shifts systematically away from food consumption as income grows.) This force will 'create' comparative advantages in the production of other goods as time passes, altering world production patterns and growth rates as it does.

Another, I would guess more important, force has to do with the continual introduction of new goods and the fall-off of learning rates on old goods. By modeling learning as occuring at fixed rates on a fixed set of goods, I have here abstracted from important sources of change in world trade patterns. Modifying the model to incorporate possibilities of these two types is an entirely practical idea, given current theoretical technology, but the general equilibrium possibilities for such a modified system have not as yet been worked out.[16]

The present model provides a simple context for discussing two popular 'strategies' for economic development: 'import substitution' and 'export promotion'. Consider first a country with $q = h_1/h_2$ currently to the right of q^* in fig. 2, but with (h_1, h_2) lying above the equilibrium world price price line in fig. 3. Under free trade, this country will specialize in the production of good 2 forever. Under autarchy (which is just the extreme version of an import substitution policy) this country will specialize in producing good 1. Eventually its expertise in this protected industry will grow to the point where it will have a comparative advantage in good 1 under free trade, and the maintenance of autarchy will no longer serve any purpose, but this need not be so from the beginning.

I hasten to add that this is only one theoretical possibility among many. Another possibility is an initial q value below q^* in fig. 2. In this case, autarchy will not provide nurture for the infant industry, but will rather permanently cut off the country from consuming the high-learning good. Within the context of this model, then, there is no substance-free way to deduce useful guides for trade and development policies. One needs to know something about the actual technological possibilities for producing different goods in different places in order to arrive at definite conclusions.

I take an 'export promotion' strategy to mean something slightly different: the manipulation through taxes and subsidies of the terms of trade p faced by a country's producers. With this kind of flexibility, one need not simply choose between world price p and autarchy price q, but can rather set any production incentives and hence choose any growth rate between the two extremes in the free trade equilibrium. Obviously, even with this flexibility it does not follow

[16]Again, see Stokey (1987).

that 'growth-increasing' and 'welfare-improving' policies will necessarily coincide, but they certainly might.

My objective in this section has been to offer one example of a theoretical model in which rates of growth differ across countries, and not to offer policy advice. The case for infant industry protection based on external effects that this model formalizes is the classic one, and it does not become either more or less valid, empirically, by being embedded in a slightly new framework. But is it possible, I wonder, to account for the large cross-country differences in growth rates that we observe in a theoretical model that does *not* involve external effects of the sort I have postulated here? I have not seen it done.

6. Cities and growth

My concern to this point has been almost exclusively with the aggregate mechanics of economic development, and I am afraid the discussion in these lectures will not get much beyond these mechanics. But I believe a successful theory of development (or of anything else) has to involve more than aggregative modeling, and I would like both to explain what I mean by this and to indicate where one might look to extend the analysis to a deeper and more productive level.

The engine of growth in the models of sections 4 and 5 is *human capital*. Within the context of these two models, human capital is simply an unobservable magnitude or force, with certain assumed properties, that I have postulated in order to account for some observed features of aggregative behavior. If these features of behavior were *all* of the observable consequences of the idea of human capital, then I think it would make little difference if we simply re-named this force, say, the Protestant ethic or the Spirit of History or just 'factor X'. After all, we can no more directly measure the amount of human capital a society has, or the rate at which it is growing, than we can measure the degree to which a society is imbued with the Protestant ethic.

But this is *not* all we know about human capital. This same force, admittedly unobservable, has also been used to account for a vast number of phenomena involving the way people allocate their time, the way individuals' earnings evolve over their lifetimes, aspects of the formation, maintenance and dissolution of relationships within families, firms and other organizations, and so on. The idea of human capital may have seemed ethereal when it was first introduced – at least, it did to me – but after two decades of research applications of human capital theory we have learned to 'see' it in a wide variety of phenomena, just as meteorology has taught us to 'see' the advent of a warm front in a bank of clouds or 'feel' it in the mugginess of the air.

Indeed, for me the development of the theory of human capital has very much altered the way I think about physical capital. We can, after all, no more directly measure a society's holdings of physical capital than we can its human capital. The fiction of 'counting machines' is helpful in certain abstract contexts but not at all operational or useful in actual economies – even primitive ones. If this was the issue in the famous 'two Cambridges' controversy, then it has long since been resolved in favor of this side of the Atlantic.[17] Physical capital, too, is best viewed as a force, not directly observable, that we postulate in order to account in a unified way for certain things we *can* observe: that goods are produced that yield no immediate benefit to consumers, that the production of these goods enhances labor productivity in future periods, and so on.

The fact that the postulates of both human and physical capital have many observable implications outside the contexts of aggregate models is important in specific, quantitative ways, in addition to simply giving aggregative theorists a sense of having 'microeconomic foundations'. For example, in my application of a human capital model to U.S. aggregative figures, I matched the U.S. observations to the predictions of a competitive model (as opposed to an efficient one) in spite of the fact that education, in the U.S., involves vast government intervention and is obviously not a competitive industry in any descriptive sense. Why not instead identify the observed paths with the model's efficient trajectories? The aggregative data have *no* ability to discriminate between these two hypotheses, so this choice would have yielded as good a 'fit' as the one I made. At this point, I appealed to the observation that most education subsidies are infra-marginal from the individual's point of view. This observation could stand considerable refinement before it could really settle this particular issue, but the point is that aggregate models based on constructs that have implications for data *other* than aggregates – models with 'microeconomic foundations' if you like – permit us to bring evidence to bear on questions of aggregative importance that cannot be resolved with aggregate theory and observations alone. Without the ability to do this, we can do little more than extrapolate past trends into the future, and then be caught by surprise every time one of these trends changes.

The particular aggregate models I have set out utilize the idea of human capital quite centrally, but assign a central role as well to what I have been calling the *external effects* of human capital. This latter force is, it seems to me, on a quite different footing from the idea of human capital generally: The twenty years of research I have referred to earlier is almost exclusively concerned with the *internal* effects of human capital, or with investments in human capital the returns to which accrue to the individual (or his immediate family). If it is this research that permits us to 'see' human capital, then the external effects of this capital must be viewed as remaining largely invisible, or visible at the aggregative level only. For example, in section 4 I arrived at an estimate of $\gamma = 0.4$ for the elasticity of U.S. output with respect to the external effects of human capital on production. Does this seem a plausible number?

[17] That is, the English side.

Or, putting the question in a better way: Is $\gamma = 0.4$ consistent with other evidence? But *what* other evidence? I do not know the answer to this question, but it is so central that I want to spend some time thinking about where the answer may be found. In doing so, I will be following very closely the lead of Jane Jacobs, whose remarkable book *The Economy of Cities* (1969) seems to me mainly and convincingly concerned (though she does not use this terminology) with the external effects of human capital.

I have been concerned with modeling the economic growth of *nations*, considered either singly or as linked through trade. In part, this was a response to the form of the observations I cited at the beginning: Most of our data come in the form of national time series, so 'fitting the facts' is taken to mean fitting national summary facts. For considering effects of changes in policies the nation is again the natural unit, for the most important fiscal and commercial policies are national and affect national economies in a uniform way. But from the viewpoint of a *technology* – like (11) – through which the average skill level of a group of people is assumed to affect the productivity of each individual within the group, a *national* economy is a completely arbitrary unit to consider. Surely if Puerto Rico were to become the fifty-first state this would not, by itself, alter the productivity of the people now located in Puerto Rico, even though it would sharply increase the average level of human capital of those politically defined as their fellow citizens. The external effects that the term h_a^γ in (11) is intended to capture have to do with the influences people have on the productivity of others, so the *scope* of such effects must have to do with the ways various groups of people interact, which may be affected by political boundaries but are certainly an entirely different matter conceptually.

Once this question of the scope of external effects is raised, it is clear that it cannot have a single correct answer. Many such effects can be internalized within small groups of people – firms or families. By dealing with an infinitely-lived family as a typical agent, I have assumed that such effects are dealt with at the non-market level and so create no gap between private and social returns. At the other extreme, basic discoveries that immediately become common property – the development of a new mathematical result say – are human capital in the sense that they arise from resources allocated to such discoveries that could instead have been used to produce current consumption, but to most countries as well as to most individual agents they appear 'exogenous' and would be better modelled as $A(t)$ in section 2 than as $h_a(t)$ in section 4.

If it were easy to classify most external productivity effects as either global in scope or as so localized as to be internalizable at the level of the family or the firm, then I think a model that incorporated internal human capital effects only plus other effects treated as exogenous technical change would be adequate. Such a model would fit time series from advanced countries about as well as any I have advanced, being an intermediate model to those I discussed in sections 2 and 4, which were in turn not distinguishable on such data alone.

Such a model would, I think, have difficulty reconciling observed pressures for immigration with the absence of equivalent capital flows, but perhaps this anomaly could be accounted for in some other way.

But we *know* from ordinary experience that there are group interactions that are central to individual productivity and that involve groups larger than the immediate family and smaller than the human race as a whole. Most of what we know we learn from other people. We pay tuition to a few of these teachers, either directly or indirectly by accepting lower pay so we can hand around them, but most of it we get for free, and often in ways that are mutual – without a distinction between student and teacher. Certainly in our own profession, the benefits of colleagues from whom we hope to learn are tangible enough to lead us to spend a considerable fraction of our time fighting over who they shall be, and another fraction travelling to talk with those we wish we could have as colleagues but cannot. We know this kind of external effect is common to all the arts and sciences – the 'creative professions'. All of intellectual history is the history of such effects.

But, as Jacobs has rightly emphasized and illustrated with hundreds of concrete examples, much of economic life is 'creative' in much the same way as is 'art' and 'science'. New York City's garment district, financial district, diamond district, advertising district and many more are as much intellectual centers as is Columbia or New York University. The specific ideas exchanged in these centers differ, of course, from those exchanged in academic circles, but the process is much the same. To an outsider, it even *looks* the same: A collection of people doing pretty much the same thing, each emphasizing his own originality and uniqueness.

Considerations such as these may convince one of the existence of external human capital, and even that it is an important element in the growth of knowledge. But they do not easily lend themselves to quantification. Here again I find Jacobs's work highly suggestive. Her emphasis on the role of cities in economic growth stems from the observation that a city, economically, is like the nucleus of an atom: If we postulate only the usual list of economic forces, cities should fly apart. The theory of production contains nothing to hold a city together. A city is simply a collection of factors of production – capital, people and land – and land is always far cheaper outside cities than inside. Why don't capital and people move outside, combining themselves with cheaper land and thereby increasing profits? Of course, people like to live near shopping and shops need to be located near their customers, but circular considerations of this kind explain only shopping centers, not cities. Cities are centered on wholesale trade and primary producers, and a theory that accounts for their existence has to explain why these producers are apparently choosing high rather than low cost modes of operation.

It seems to me that the 'force' we need to postulate account for the central role of cities in economic life is of exactly the same character as the 'external human capital' I have postulated as a force to account for certain features of aggregative development. If so, then land rents should provide an indirect measure of this force, in much the same way that schooling-induced earnings differentials provide a measure of the productive effects of internal human capital. It would require a much more detailed theory of the external effects of human capital than anything I have provided to make use of the information in urban land rents (just as one needs a more detailed theory of human capital than that in section 4 to utilize the information in earnings data), but the general logic is the same in the two cases. What can people be paying Manhattan or downtown Chicago rents *for*, if not for being near other people?

7. Conclusions

My aim, as I said at the beginning of these lectures, has been to try to find what I called 'mechanics' suitable for the study of economic development: that is, a system of differential equations the solution to which imitates some of the main features of the economic behavior we observe in the world economy. This enterprise has been taken about as far as I am able to take it, at present, so I will stop and try to sum up what the main features of these mechanics are and the sense in which they conform to what we observe.

The model that I think is central was developed in section 4. It is a system with a given rate of population growth but which is acted on by no other outside or exogenous forces. There are two kinds of capital, or state variables, in the system: physical capital that is accumulated and utilized in production under a familiar neoclassical technology, and human capital that enhances the productivity or both labor and physical capital, and that is accumulated according to a 'law' having the crucial property that a constant level of effort produces a constant growth rate of the stock, independent of the level already attained.

The dynamics of this system, viewed as a single, closed economy, are as follows. Asymptotically, the marginal product of physical capital tends to a constant, given essentially by the rate of time preference. This fact, which with one kind of capital defines the long-run stock of that capital, in the two-capital model of section 4 defines a curve in the 'physical capital–human capital plane'. The system will converge to this curve from any initial configuration of capital stocks, but the particular point to which it converges will depend on initial conditions. Economies that are initially poor will remain poor, relatively, though their long-run rate of income growth will be the same as that of initially (and permanently) wealthier economies. A world consisting of such economies, then, each operating autarchically, would exhibit uniform rates of growth across countries and would maintain a perfectly stable distribution of income and wealth over time.

If trade in capital goods is introduced into this model world economy, with labor assumed immobile, there will be no tendency to trade, which is to say no systematic tendency for borrowing and lending relationships to emerge between rich and poor countries. Put another way, the long-run relationship between the two kinds of capital that holds in each country implies the same marginal productivity of physical capital, no matter what the level of capital that has been accumulated. The picture I have given for a world of closed economies thus carries over without change to a world with free trade in capital goods.

If labor mobility is introduced, everything hinges on whether the effects of human capital are internal – affecting the productivity of its 'owner' only – or whether they have external benefits that spill over from one person to another. In the latter case, and only in the latter case, the wage rate of labor at any given skill level will increase with the wealth of the country in which he is employed. Then if labor can move, it will move, flowing in general from poor countries to wealthy ones.

The model I have described fits the evidence of the last century for the U.S. economy as well as the now standard neoclassical model of Solow and Denison, which is to say, remarkably well. This is of course no accident, for the mechanics I have been developing have been modeled as closely as possible on theirs. It also fits, about as well, what seem to me the main features of the world economy: very wide diversity in income levels across countries, sustained growth in per-capita incomes at all income levels (though not, of course, in each country at each income level), and the absence of any marked tendency for growth rates to differ systematically at different levels of income. The model is also consistent with the enormous pressures for immigration that we observe in the world, even with its extreme assumptions that assign no importance to differences in endowments of natural resources and that permit perfectly free trade in capital and consumption goods. As long as people at each skill level are more productive in high human capital environments, such pressures are predicted to exist and nothing but the movement of people can relieve them.

Though the model of section 4 seems capable of accounting for *average* rates of growth, it contains no forces to account for diversity over countries or over time within a country (except for arbitrary shifts in tastes or technology). Section 5 develops a two-commodity elaboration of this model that offers more possibilities. In this set-up, human capital accumulation is taken to be specific to the production of particular goods, and is acquired on-the-job or through learning-by-doing. If different goods are taken to have different potentials for human capital growth, then the same considerations of comparative advantage that determine which goods get produced where will also dictate each country's rate of human capital growth. The model thus admits the possibility of wide and sustained differences in growth rates across countries, differences that one would not expect to be systematically linked to each country's initial capital *levels*.

With a fixed set of goods, which was the only case I considered, this account of cross-country differences does not leave room for within-country changes in growth rates. The comparative advantages that dictate a country's initial production mix will simply be intensified over time by human capital accumulation. But I conjecture that a more satisfactory treatment of product-specific learning would involve modeling the continuous introduction of new goods, with learning potentials on any particular good declining with the amount produced. There is no doubt that we observe this kind of effect occuring in reality on particular product lines. If it could be captured in a tractable aggregative model, this would introduce a factor continuously shaking up an existing pattern of comparative advantages, and offer some interesting possibilities for shifts over time in a country's growth rate, within the same general equilibrium framework used in section 5.

If such an analysis of trade-related shifts in growth rates should turn out to possible, this would be interesting, because the dramatic recent development success stories, the 'growth miracles' of Korea, Taiwan, Hong Kong and Singapore (not to mention the ongoing miracle of Japan) have all been associated with increases in exports, and more suggestively still, with exports of goods not formerly produced in these countries. There is surely no strain in thinking that a model stressing the effects of learning-by-doing is likely to shed light on these events.

A successful theory of economic development clearly needs, in the first place, mechanics that are consistent with sustained growth and with sustained diversity in income levels. This was the objective of section 4. But there is no one pattern of growth to which all economies conform, so a useful theory needs also to capture some forces for change in these patterns, and a mechanics that permits these forces to operate. This is a harder task, certainly not carried out in the analysis I have worked through, but I think the analysis of section 5 is a promising beginning.

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