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ABSTRACT

At least since 1950, the United States has been stimulated by increases in educational attainment, increases in research intensity, and the increased openness and development of the world economy. Such changes suggest, contrary to the conventional view, that the U.S. economy is far from its steady state balanced growth path. The theoretical framework analyzed here provides a coherent interpretation of this evidence and indicates that when these increases cease and the U.S. economy reaches its steady state, U.S. per capita growth can be expected to fall to a rate of approximately 1/4 its post-war average.

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1 Introduction

Over the last 125 years, the average growth rate of per capita GDP in the U.S. economy has been a steady 1.8 percent per year. Indeed, the stability of U.S. growth rates underlies the conventional view that the U.S. economy is close to its long-run steady-state balanced growth path. This view is supported by a number of stylized facts such as the absence of trends in the U.S. capital-output ratio and U.S. real interest rates.

On the other hand, this conventional view is challenged by a number of remarkable changes that have occurred for at least the last 50 years, and probably for longer. Of particular interest in the study of economic growth are the following:

- Time spent accumulating skills through formal education, which we can associate with human capital investment, has increased substantially. As of 1940, less than one out of four adults had completed high school, and only one in twenty had completed four or more years of college. By 1993, more than 80 percent had completed high school, and more than 20 percent had completed at least four years of college.

- The search for new ideas has intensified. An increasing fraction of the labor force consists of scientists and engineers engaged in research and development (R&D). In 1950, this fraction was 1/4 of one percent. By 1993, the fraction had risen three-fold to 3/4 of a percent.

- The U.S. economy and the world economy have become increasingly "open." World trade and economic integration collapsed at the beginning of World War I, but have increased substantially since the end of World War II. Transportation costs and communication costs have fallen dramatically during this period.

In addition, these changes are not limited to the United States. Similar facts could be documented for many OECD countries, and probably for other countries as well.

In virtually any model that we use to understand economic growth, these changes should lead to long-run increases in income. In neoclassical models, such changes generate transition dynamics in the short run and "level effects" in the long run. The growth rate of the economy rises temporarily and then returns to its original value, but the level of income is permanently higher as a result. In many endogenous growth models, such changes should lead to permanent increases in the growth rate itself.

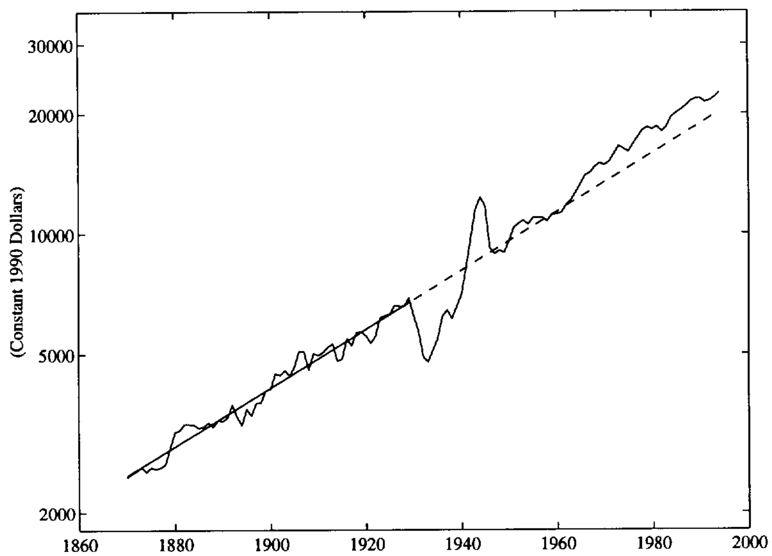
A puzzle arises when one examines the actual behavior of income in the U.S. economy. To illustrate this puzzle, consider the following exercise. Suppose we try to predict U.S. per capita GDP in 1994 by extrapolating a constant growth path using data from 1870 to 1929. Figure 1 shows the result: a constant growth path forecast from 1929 comes very close to predicting per capita GDP today.[1] The predicted value does understate U.S. income, but only by 10.6 percent of actual GDP per capita.

In Jones (1995b), I used such an exercise to argue against many endogenous growth models. Such models suggest that the long-run growth rate of per capita income should be rising with the increases in R&D intensity or with the increases in openness or time spent accumulating skills, but the data do not exhibit this phenomenon. Therefore, the data might be more consistent with a model in which such changes do not generate long-run growth effects.

However, the data raise another puzzle. Even neoclassical models suggest that these changes should generate level effects: the level of income should be much higher than is predicted by our simple exercise, but in fact it is

[1]The data are from Maddison (1995). Similar results are obtained with GDP per worker, but there is some difficulty obtaining employment data prior to 1900. The figure looks slightly different from that in Jones (1995b) because of revisions that Maddison has made to his data.

Figure 1: U.S. GDP Per Capita, Log Scale



only slightly higher. Consider the returns to education. Median years of schooling has increased by something like four years since 1940. If one year of education raises wages by approximately seven percent, then the skill accumulation by itself should raise incomes above the forecast path by at least 25 percent. And this doesn't include the changes in research intensity or openness. This puzzle, inherent in the exercise displayed in Figure 1, can be stated simply: What happened to the level effects?[2]

The answer proposed here is that large level effects are in fact present in Figure 1. But to see them, one must look below the forecast path instead of

[2]One possibility is that other changes have offset these movements. However, it is difficult to identify any particular variable to play the offsetting role. A tempting explanation is the increase in tax rates documented by Stokey and Rebelo (1995). There are two key problems with this explanation, however. First, the timing is wrong: by far the largest increase in taxes occurred in the early 1940s. Second and more importantly, in most theories taxes do not matter directly, but rather they work through an endogenous variable like the investment rate or research intensity. By focusing on the endogenous variables themselves, this paper already incorporates the effect of taxes.

above. More precisely, consider the counterfactual case in which educational attainment, research intensity, and openness did not increase over the post-war era. In this case, I'll argue, per capita GDP would have fallen far *below* the forecast path.

In the long-run, the fraction of time that individuals spend accumulating skills, the share of the labor force devoted to research, and the openness of the world economy must level off. Over the post-war period, and most likely even before, these variables have been rising — indeed, the rise prior to World War II presumably explains why the trend line computed up until 1929 fits the post-war data. Each increase generates a transition path growth effect and a level effect on income, and the series of increases during the last 50 or 100 years have generated a balanced growth path with a growth rate higher than the long-run, sustainable growth rate of the U.S. economy.

The easiest way to see how this might work is to consider a simple example. Imagine an economy described by a Solow model in which the investment rate, rather than being constant, is growing exponentially. Per capita growth in this economy could settle down to a constant rate that is higher than its long-run rate. Of course, the investment rate cannot grow forever (it is bounded at one), and when the investment rate stops growing, the growth rate of the economy will fall to its long-run rate. A similar phenomenon is occuring in the U.S. economy, except that the higher growth is driven by rising research intensity and educational attainment rather than a rising investment rate.

This argument is developed more fully in the remainder of the paper. Section 2 presents a formal model within which these issues can be analyzed. Motivated by this model, Section 3 decomposes the growth rate of output per worker during the post-war period into transitory effects related to the increases in research intensity and educational attainment and a permanent, long-run component. The decomposition suggests that "level effects" have played a very important role in raising growth above its long-run level. While the growth rate of labor productivity in the private business sector was 2.3 percent per year from 1950 to 1993, the decomposition suggests that the long-run growth rate for the U.S. economy is approximately 1/4 this rate, or about 0.6 percent per year.[3]

Section 4 examines more closely the one episode in recent history in which the fraction of the labor force devoted to R&D stopped rising, and even declined. This episode began in 1967, anticipating the productivity slowdown, and continued through 1975. Calibration of the model suggests that the model is well-equipped to explain at least part of the slowdown during the 1970s of productivity growth. This episode lends empirical support to the prediction of the model that growth rates must eventually fall.

Section 5 of the paper examines one remaining issue, which is an explanation for why research intensity and rates of skill accumulation have been increasing in the post-war period. The increase in research intensity is potentially explained by appealing to the increase in the openness and level of development of the world economy and the decline in transport costs. Section 6 provides some concluding remarks.

2 Modeling U.S. Growth

We will model U.S. economic growth using an idea-based growth model that is motivated by the Romer (1990) model. Relative to Romer (1990), the model here differs in that standard policy changes generate level effects

[3]It is worth mentioning that there are other reasons not explored here why one might predict a decline in growth rates. For example, Evenson (1984) interprets the observed declining patent-scientist ratio as evidence of the depletion of research opportunities. Similarly, Gordon (1993) documents the end of "one big wave" of TFP growth that kept growth rates high before the recent slowdown. Alternatively, the model in this paper predicts that long-run growth is possible only in the presence of population growth. If one expects world population growth to fall because of a demographic transition, one might expect per capita growth rates to fall as well.

instead of growth effects in the long run. Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) have idea-based growth models in which the rate of per capita growth depends on the *size* of the economy: more populous economies grow faster. Jones (1995a) argued that this prediction is sharply contradicted by the lack of the upward trend in growth rates that is implied by the presence of population growth. When those models are reformulated to eliminate this prediction, they produce a scale effect in levels, instead of growth rates, as we will see shortly. In addition, the reformulated model predicts long-run level effects instead of growth effects from standard policy changes, such as a permanent subsidy to research. While policy changes have Solow-like effects, the research process itself drives technological change and is endogenized, so that one might think of the reformulated model as a "semi-endogenous" growth model. The details of this point are discussed in Jones (1995a).

Like the Romer model, the model here should be thought of as describing the evolution of the world technological frontier. One would certainly not want to use such a model to analyze individual developing countries. In applying the model to the U.S. economy, we are assuming that to a first approximation it is not misleading to ignore the diffusion to the United States of ideas created in the rest of the world. We will discuss later why relaxing this assumption only reinforces the results.

As in the Romer formulation, the economy consists of three sectors. A competitive final goods sector produces a homogeneous output good that is used for consumption and investment. A research sector, which is also perfectly competitive, invents new designs for the capital goods that serve as inputs to the final goods sector. Finally, a monopolistically competitive intermediate goods sector uses the designs created by the research sector to produce the capital goods.

Production of final output, Y, uses labor L_Y and a collection of intermediate capital inputs x_i according to

$$Y = (hL_Y)^{1-\alpha} \left(\int_0^\infty x_i^\rho \, di \right)^{\alpha/\rho}, \tag{1}$$

where α and ρ are parameters between zero and one, and h represents human capital per worker. While production of final output can employ capital goods indexed on $[0, \infty)$, not all goods are available. At any point in time t, the research sector will only have invented the designs for capital goods in the range $[0, A(t)]$.

In this representative agent model, each member of the labor force has the same level of human capital. This level is determined by the fraction of time individuals spend accumulating skills, s_h:

$$h = e^{\psi s_h}. \tag{2}$$

The exponential formulation is motivated by the empirical observation of Mincer (1974) and others that one additional year of schooling raises wages proportionally.[4] As we will see, it is appropriate to think of the parameter ψ as the return to schooling.

The intermediate goods sector consists of a continuum of monopolistically competitive firms that have purchased infinitely-lived patents from the research sector. These patents grant the owner the exclusive right to produce a particular capital good and provide the instructions for transforming units of raw capital into the intermediate goods. To simplify the model, we assume that this transformation occurs costlessly, that it is fully reversible, and that one unit of raw capital is required to produce one unit of the intermediate capital good. During the production of final goods, however, a constant fraction d of the intermediate good depreciates.

Let r denote the (gross of depreciation) rental price of a unit of raw capital. The symmetry and constant elasticity structure of equation (1) im-

[4] Bils and Klenow (1996) suggest that a model of human capital accumulation should have this feature.

plies that monopoly producers of intermediate goods will charge an identical price given by a constant markup over marginal cost, r/ρ. Each monopoly producer then earns profits equal to

$$\pi = (1-\rho)\alpha\frac{Y}{A}. \tag{3}$$

That is, the profits earned by a monopoly producer of a capital good are proportional to economy-wide output per idea.

The supply of raw capital to the economy is given by K, and the total amount of capital used to produce intermediate goods is constrained by this supply:

$$\int_0^A x_i \, di = K. \tag{4}$$

Symmetry implies that $x_i = x = K/A$, that is, all capital goods are employed in the same quantity. This relationship can be substituted into the production function in equation (1) to yield

$$Y = A^{\sigma}K^{\alpha}(hL_Y)^{1-\alpha} = A^{\sigma}K^{\alpha}H_Y^{1-\alpha} \tag{5}$$

where $\sigma \equiv \alpha(1/\rho - 1)$ and $H_Y \equiv hL_Y$.

Two remarks about this aggregate production function are worth noting. First, the production function exhibits constant returns to the private inputs capital K and effective labor H_Y. The fact that skills are embodied in people allows us to maintain a perfectly competitive setup in the final goods sector, taking A as given. Second, the production function is characterized by increasing returns once the stock of ideas A is recognized as an input. Increasing returns directly reflects the nonrivalry of ideas, as emphasized by Romer (1990). A given idea can be exploited by many units of capital and skilled labor. The usual replication argument applies to private inputs given the stock of ideas. If ideas are also increased, then output will rise more than one-for-one.[5]

[5]With increasing returns, not all factors can be paid their marginal products. It is easy

2.1 Dynamics

There are three sources of dynamics in the model. Most simply, the labor force of the economy grows at a constant exogenous rate $n > 0$. Second, raw capital accumulates in the usual way, through foregone consumption:

$$\dot{K} = s_K Y - dK, \tag{6}$$

where s_K is the investment rate in the economy.

The third and most important source of dynamics in this model is the production function for new ideas. New ideas are produced by skilled labor $H_A \equiv hL_A$:

$$\dot{A} = \bar{\delta} H_A, \tag{7}$$

Individual researchers take $\bar{\delta}$ as given and see constant returns to research effort: each unit of research yields $\bar{\delta}$ new ideas.

In fact, however, the productivity of researchers may depend on the number of researchers and on the stock of ideas in the economy. The true technology for producing ideas is

$$\dot{A} = \delta H_A^{\lambda} A^{\phi}, \tag{8}$$

where δ, λ, and ϕ are constant parameters. The presence of the A^{ϕ} term captures the fact that the productivity of current researchers may depend on the stock of ideas discovered in the past. Previous ideas like the steam engine or the computer may raise current research productivity through an intertemporal knowledge spillover ($\phi > 0$). Or, perhaps a "fishing out" interpretation is more appropriate, in which case it becomes more and more difficult to find new ideas over time ($\phi < 0$).

The presence of $\lambda < 1$ is intended to capture congestion effects or the depletion of talent in the research process. Other things equal, if we double

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to show that the return to capital is given by $r = \rho\alpha Y/K$, which is strictly less than the marginal product of capital $\alpha Y/K$. As usual in these models, capital is underpaid so that some resources remain to pay for the invention of new designs.

the number of researchers, we may less than double the number of new ideas created. Some researchers may simply duplicate the ideas of others, and the talent of the marginal researcher may not be as great as the talent of the average researcher.

Total employment in the economy, L, is used for research and final goods production: $L_A + L_Y = L$. The total endowment of labor in the economy, N, is equal to total employment L plus the total quantity of the endowment spent accumulating skills, $s_h N$. That is, the resource constraint with respect to labor for this economy is

$$L_A + L_Y = N(1 - s_h). \tag{9}$$

2.2 Balanced Growth Path Analysis

We now solve for the level of output per worker along the balanced growth path. It simplifies the presentation slightly if we focus on $y \equiv Y/L_Y$ instead of Y/L.[6] In addition, let us focus on the case in which s_K, s_R, and s_h are given exogenously. This is not at all necessary, and in Section 5, we will discuss the determination of these variables within an optimizing framework.

First, note that along a balanced growth path, the capital accumulation equation in (6) implies

$$\frac{K}{Y} = \xi_K \equiv \frac{s_K}{n + g_y + d}, \tag{10}$$

where g_y is the growth rate of y along a balanced growth path.

Substituting this relationship into the aggregate production function in (5) and rewriting, we have

$$y^*(t) = \xi_K^{\frac{\alpha}{1-\alpha}} h A^*(t)^{\frac{\sigma}{1-\alpha}}, \tag{11}$$

[6]Empirically, $L_Y/(L_Y + L_A)$ is greater than .99 for the U.S. economy, so that this distinction is of no practical consequence. Notice that the denominator of this fraction is the empirical counterpart of the total labor force since individuals accumulating schooling are not counted as part of the labor force in the data.

where the superscript asterisk is used to denote a variable along the balanced growth path, and we include explicitly the time index to highlight variables that are changing over time. Equation (11) consists of terms that are largely familiar from the Solow model. For example, ignoring h and assuming that $\sigma = 1-\alpha$ so that technology is labor augmenting, this is exactly the relationship one would derive from a standard Solow setup. The term $\xi_K \equiv s_K/(n+g_y+d)$ simply captures the neoclassical results that economies that invest more in capital will be richer along the balanced growth path and that higher rates of population growth reduce the effectiveness of investment as more capital must be devoted to capital widening.

The stock of ideas along a balanced growth path $A^*(t)$ is readily calculated from the production function for new ideas in equation (8) as

$$\begin{aligned} A^*(t) &= \left(\frac{\delta}{g_A} H_A(t)^{\lambda}\right)^{\frac{1}{1-\phi}} \\ &= \left(\frac{\delta}{g_A}\right)^{\frac{1}{1-\phi}} (h s_R L(t))^{\frac{\lambda}{1-\phi}}, \end{aligned} \tag{12}$$

where $s_R \equiv L_A/L$ is the fraction of the labor force engaged in research and g_A is the growth rate of A. We require, as discussed in Jones (1995a), that $\phi < 1$. Otherwise, there is no balanced growth path for the economy, and the growth rate accelerates over time. Substituting this relationship into equation (11) yields one of the key equations of the paper:

$$y^*(t) = \xi_K^{\frac{\alpha}{1-\alpha}} h^{1+\gamma} s_R^{\gamma} L(t)^{\gamma}, \tag{13}$$

where $\gamma \equiv \frac{\lambda}{1-\phi}\frac{\sigma}{1-\alpha}$, and we have omitted an unimportant multiplicative constant. Recall also that $h = e^{\psi s_h}$.

Several features of equation (13) merit discussion. First, there is a fundamental scale effect in the model. Output per worker $y(t)$ is an increasing function of the size of the labor force in the economy $L(t)$. The larger is the world (or U.S.) economy, the richer it is. This scale effect is a direct consequence of the increasing returns to scale of the aggregate production function that is implied by the nonrivalry of ideas.

Second, a further consequence of the increasing returns is that the growth rate of y in steady state depends on the rate of population growth. It is well-known that in models like this one, s_K, s_h, and s_R are constant in steady state, even when they are endogenized. Then, log-differentiating equation (13) reveals that

$$g_y^{SS} = \gamma n. \tag{14}$$

That is, the per capita growth rate of the economy in steady state is proportional to the rate of population growth. This is simply the growth rate analog to the scale effect on levels of income.

Third, the parameter γ is obviously crucial in the model. It is directly related to the magnitude of the scale effect, and it summarizes how a given rate of population growth translates into per capita income growth. In addition, however, γ is related to the level effect that results from a permanent one-time increase in the fraction of the labor force engaged in R&D.

Finally, the model illustrates that the accumulation of skills has both a direct and an indirect effect on the level of income. The direct effect, emphasized by the labor market evidence, is that an additional year of schooling raises wages by something like 7 percent. In the model, this is captured by the effect of s_h on h: an increase in s_h will have a proportional effect on labor productivity through h, directly increasing Y/L and wages. However, there is also an indirect effect that operates through γ. A better trained workforce is more effective at creating new ideas, and these new ideas also raise per capita income. Therefore, the total effect of an increase in s_h is to raise income proportionately by a factor $\psi(1+\gamma)$.

3 Where are the level effects?

The model set forth in the previous section constitutes a rigorous theoretical framework for addressing the puzzle implied by Figure 1. In this section, we provide one resolution and explore its implications. The resolution hinges on the distinction between a steady state balanced growth path and an out-of-steady state balanced growth path. In particular, it is possible for an economy with increasing human capital investment and increasing R&D investment to exhibit balanced growth, at least for a finite time. Clearly, of course, this is not steady state behavior.

To begin, we first document more carefully the rising rate of investment in skills and the increase in research intensity. Figure 2 plots median educational attainment in the U.S. for persons age 25 and over, from 1950 to 1993.[7] Median educational attainment rises sharply from 1950 to 1967, from 9.3 years to 12.0 years. After 1967, educational attainment continues to rise, but the changes are much smaller, and the level reaches 12.8 years by 1993. To map this data into s_h, one needs to divide by some measure like the lifetime of an individual. Instead, we will measure s_h as years of schooling, as in the figure, and move the length of lifetime into the parameter ψ. This has the advantage that ψ can then be interpreted directly as the Mincerian return to schooling. Ideally, one would like to also measure skills accumulated outside the formal education process, for example through on-the-job training, but this data doesn't seem to be available.

Figure 3 shows the fraction of the labor force that consists of scientists and engineers engaged in R&D. For the United States, this fraction rises considerably over the post-war period. In 1950, the fraction is 0.26 percent, while by 1993 the fraction is nearly three times higher at 0.75 percent. This three-fold increase masks an interesting change that occurs in the middle of the sample. The share of the labor force in research peaks temporarily

[7] Appendix B at the end of the paper lists the sources for this and other data.

Figure 2: Median U.S. Educational Attainment, Persons Age 25 and Over

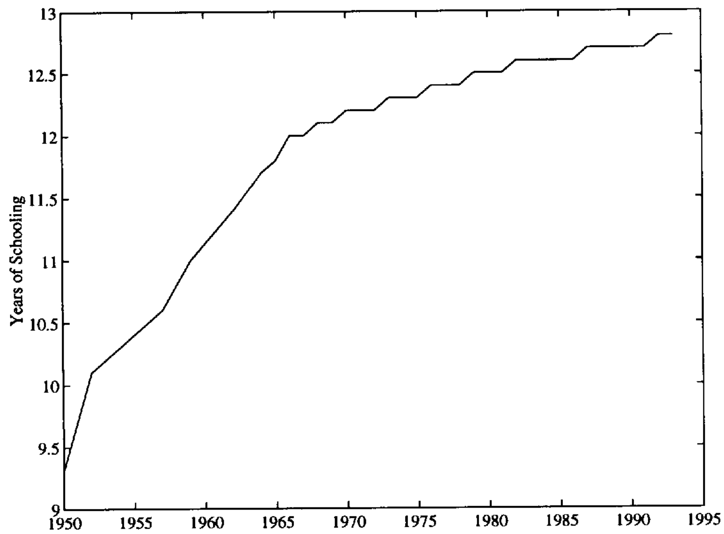


Figure 3: Scientists and Engineers Engaged in R&D, Fraction of Labor Force

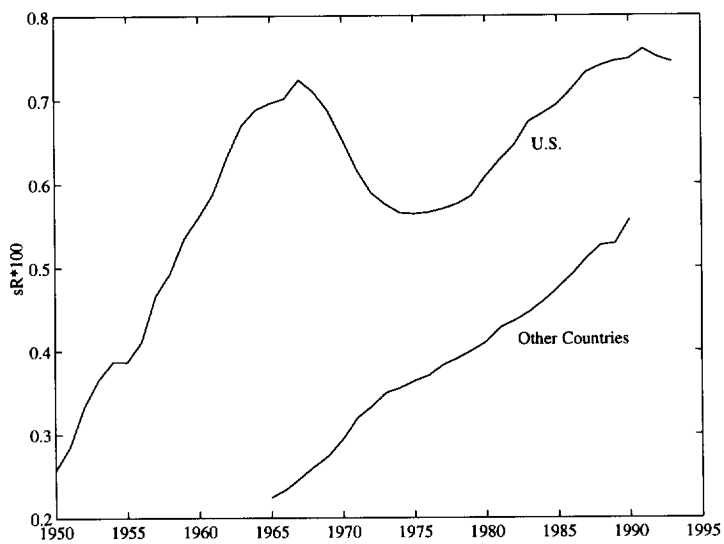
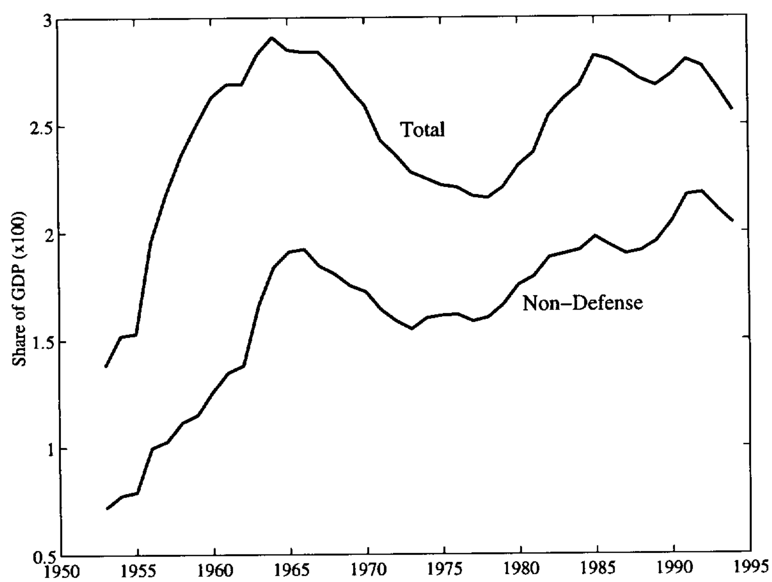


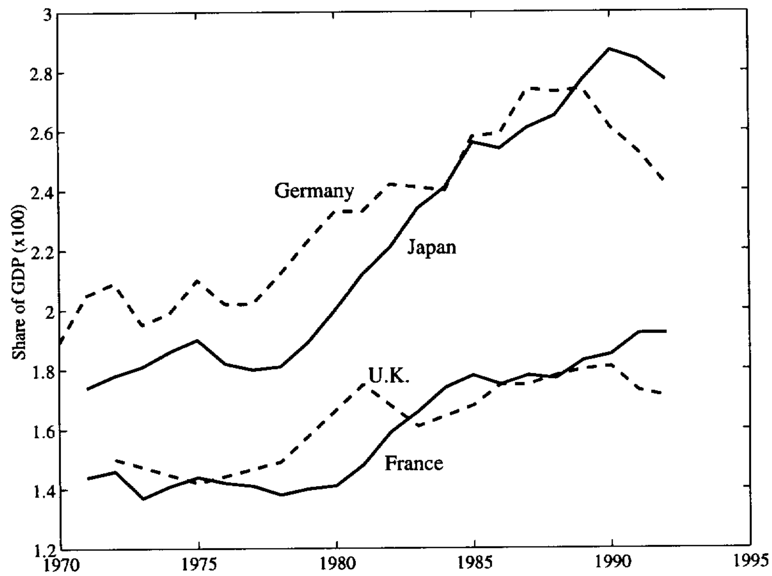
Figure 4: R&D Expenditure as a Share of GDP



in 1967 and then declines until the mid-1970s before starting to rise again. We will explore this feature of the data in much more detail in Section 4. The figure also shows the behavior of the share of labor devoted to R&D for France, Germany, Japan, and the U.K., by plotting the average share for these countries. This share rises sharply from just over .2 percent in 1965 to about .55 percent in 1992. For this reason, we assert that expanding the model to incorporate the flow of ideas across countries would not change the spirit of the results presented here: the increase in research intensity seems to be a phenomenon that occurs througout the OECD.

Finally, we present two figures to illustrate that the increase in R&D intensity is not simply an artifact of the labor force data. Figure 4 shows the change in R&D expenditure as a share of GDP. The total R&D expenditure share shows a large increase between 1950 and 1965, then falls through 1977 before rising until 1990. This is the one series for which a "trend" in R&D

Figure 5: Non-Defense R&D/GDP for Other Countries



intensity is most difficult to justify. The second line in the figure, however, examines non-defense R&D, for which the trend is much more apparent. Much of the enormous rise in R&D during the 1960s is associated with defense and the space program (the latter is included in the second line in the figure). Because many of the studies in the productivity literature find little effect on private productivity from defense-related research, a case can be made that non-defense or even non-defense/non-space research is the appropriate measure of R&D for this study.

Figure 5 plots R&D expenditures not associated with defense as a share of GDP for a number of other countries. Research intensity rises considerably for these countries, even after 1970.

These figures illustrate that a rising R&D intensity characterizes the richest countries in the world. Ideally, one would like to model the idea flows among these countries to characterize the impact of foreign R&D on U.S. and

OECD productivity. This is a difficult and complicated problem, although some interesting progress has recently been made by Eaton and Kortum (1995). A coarse approach would be to construct a distributed lag of U.S. and foreign R&D intensities to feed into the production function for ideas used in the United States. For our purposes, the problem is complicated by the fact that data on R&D intensity prior to 1965 for these economies appears to be unavailable. Still, the key feature suggested by the data that we do have is that research intensity has been rising. By focusing primarily on the fraction of the U.S. labor force engaged in R&D, we match this key property.

We now use the model developed in the previous section to interpret this evidence in light of the apparent absence of level effects in Figure 1. The argument is seen by taking logs and differencing equation (13). Assuming ξ_K is constant over time (which is roughly true for the U.S. economy in the post-war period),

$$g_y = (1+\gamma)\psi\Delta s_h + \gamma g_{s_R} + \gamma n, \tag{15}$$

where g_x denotes the growth rate of x along a balanced growth path.

In steady state, Δs_h and g_{s_R} must be zero, so that this equation reduces back to equation (14). Out of steady state, however, we see that the growth rate of output per capita can be constant and greater than its long-run growth rate provided Δs_h and g_{s_R} are constant and positive. This is, to a first approximation, the situation that characterizes the U.S. economy in the post-war period. In other words, the continued increases in skill investment and research intensity have led to a series of level effects that have temporarily raised the growth rate of the economy above its long-run growth rate.

The empirical counterparts of the variables in equation (15) are readily observed. We have already shown data on s_h and s_R. The growth rate of the labor force can be used to measure n. To measure g_y, one simply needs to

Table 1: Data on U.S. Growth, 1950-1993

Growth Rate of	Variable	Sample Value
Output per worker	g_y	.0226
R&D labor	g_{L_A}	.0418
Total labor force	n	.0170
Share of R&D in labor	g_{s_R}	.0248
Effective R&D labor	g_{H_A}	.0475
Labor-augmenting TFP	g_B	.0169
Annual change in s_h	Δs_h	.0814

Note: For data sources, see the appendix.

adjust a standard measure of labor productivity growth for the empirically small difference between Y/L and Y/L_Y. We use data from the Bureau of Labor Statistics (1996) on labor productivity growth in the private business sector for this purpose. These data are displayed in Table 1.

The parameter ψ is readily inferred from a wealth of microeconomic evidence. Interpreting s_h as years of schooling, the parameter ψ corresponds to the return to schooling estimated by Mincer (1974) and others using log-wage regressions. The labor market literature suggests that a reasonable value for ψ is .07, which we adopt here. This value implies that an additional year of schooling has a direct effect of raising labor productivity by seven percent.

The parameter γ can be obtained in two superficially different ways that turn out to be identical. First, one could use equation (13) to calculate γ since all of the other terms are observed empirically.

An alternative calculation proves more intuitive. Define $B(t)$ to be labor-augmenting total factor productivity. Specifically, let $B^{1-\alpha} = A^{\sigma}$. Thus, the production function for final output can be written $Y = K^{\alpha}(BH_Y)^{1-\alpha}$. With this definition of B, one can rewrite the production function for ideas in equation (8) as

$$\frac{\dot{B}}{B} = Const \left(\frac{H_A}{B^{1/\gamma}}\right)^{\lambda}, \tag{16}$$

where $Const$ is an unimportant constant.

In order for total factor productivity (TFP) growth to be constant on average, the ratio $H_A/B^{1/\gamma}$ must be constant. That is, γ must be chosen to detrend this ratio, and this leaves very little flexibility in choosing its value: both H_A and B are rising exponentially over time. With this motivation, we calculate γ as the ratio of TFP growth to growth in "effective" R&D labor H_A. Using the data from Table 1 yields a value of $\gamma = .356$.[8]

The fact that this calculation yields numerically the same estimate of γ as would calculating γ directly from equation (15) is a function of how we have computed labor-augmenting TFP growth. Specifically, the time series for B is measured directly from the production function $Y = K^{\alpha}(BH_Y)^{1-\alpha}$ under the assumption that the capital-output ratio is constant. Empirically, according to the BLS data, there is a slight increase in the capital-output ratio in the U.S. economy from 1950 to 1993. However, we also know that the nominal U.S. investment rate is relatively constant over this period. I suspect, then, that much of the increase is due to changes in the relative price of capital (for example, the nominal rate of investment in equipment is relatively constant, while the real rate has been rising rapidly; the increase is due to the decline in the relative price of equipment). From the standpoint of the model used in this paper, it makes sense to ascribe these relative price

[8] Alternative ways of calculating γ yield similar values. For example, one can regress $\log B$ on $\log H_A$ (and a constant) to obtain a slightly higher value of .420. As one might expect, the standard error of this coefficient is extremely small, at .021. Running the reverse regression yields an implied estimate of .462 for γ. All methods of obtaining γ are "superconsistent" and robust to endogeneity problems because the parameter is identified from the time trends in the data.

Table 2: Understanding U.S. Growth, 1950-1993

Description	Variable	Sample Value	Percent of g_y
Growth Rate of Y/L_Y	g_y	.0226	100
Equals:			
Direct Effect of Education	$\psi \Delta s_h$	.0057	25
+ Indirect Effect of Education	$\gamma \psi \Delta s_h$	.0020	9
+ R&D Intensity Effect	γg_{s_R}	.0088	39
+ Scale Effect of Labor Force	γn	.0060	27

effects to the creation of new ideas. Imposing a constant capital-output ratio in the data will force these relative price effects to show up in total factor productivity, which in the model is directly related to R&D.

With the empirical counterparts of the terms in equation (15) identified, we can perform the growth decomposition specified in that equation. This accounting exercise is shown in Table 2. The direct effect of increased skill accumulation accounts for .57 percentage points of growth, or twenty-five percent. This effect explains the difference between growth in output per worker and labor-augmenting TFP (2.26 minus 1.69).

The remaining three lines make up total factor productivity growth. In the long-run, both TFP growth and output per worker growth must be equal to γn. This term, labeled the "Scale Effect of Labor Force" in the table, is equal to 0.60 percentage points and accounts for only twenty-seven percent of growth in output per worker. TFP growth is greater than this amount for two reasons. First, the skill-level of the labor going into research has been increasing, contributing 0.20 percentage points of growth. Second, research intensity has increased. The rise in the share of labor devoted to R&D

has increased growth by 0.88 percentage points and accounts for thirty-nine percent of growth in output per worker.

One of the most interesting features of these calculations is the large gap between actual U.S. economic growth and the long-run rate of growth given by $g_y^{SS} = \gamma n$. Evaluated at the actual rate of growth of the labor force (1.7 percent), g_y^{SS} is only 0.60 percent, far less than the 2.26 percent rate observed from 1950 to 1993. It is hard to escape the prediction that U.S. growth must slow down in the long run. The increases in the rate of skill accumulation and R&D intensity cannot continue forever. The calculations presented here suggest that the magnitude of the slowdown could be considerable.[9]

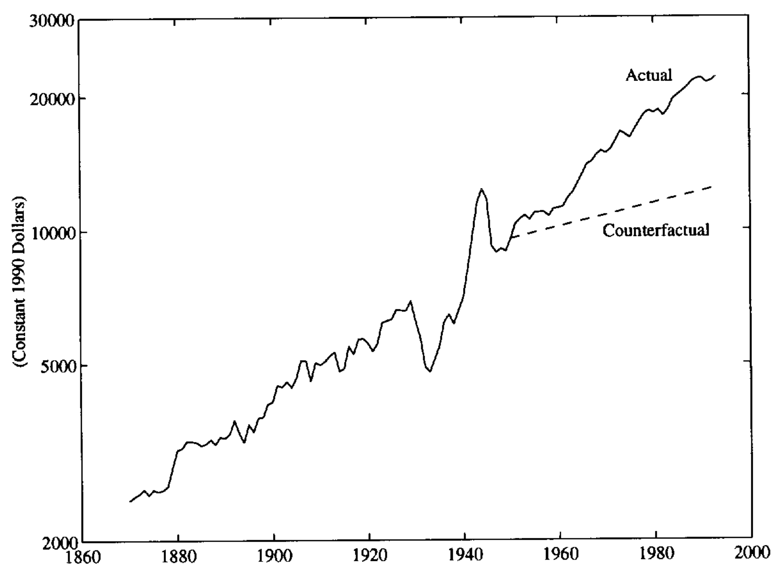
The parameter γ is the key parameter in this calculation, and it can be given an alternative interpretation. Recall from equation (13) that γ is the elasticity of balanced growth path output per worker with respect to the R&D share of labor. That is, the parameter is directly related to the magnitude of the long-run level effect that results from increasing research. Research intensity has risen from 0.26 percent in 1950 to 0.75 percent in 1993. This change implies a level effect equal to 46 percent of initial income. This is a very large effect: by moving 1/2 of one percent of the labor force into research, the economy achieved an increase in income of nearly 50 percent.[10]

A similar calculation can be done for the increase in educational attainment. Median years of schooling rose by 3.5 years from 1950 to 1993. With a rate of return to schooling of 7 percent, this implies an increase in output

[9] This analysis holds the rate of population growth constant. To the extent that population growth rates will decline in the future, e.g. because of a demographic transition, the model would predict an even larger slowdown in per capita growth.

[10] This statement is potentially a little misleading. The 50 percent number is based solely on the growth rate of research intensity, not on its level. For example, it is easily imaginable that research intensity is mismeasured by a constant factor of ten — people that we do not call scientists and engineers may also produce ideas. In this case, the 50 percent increase would be the result of shifting 5 percent of the labor force, not 1/2 of one percent.

Figure 6: The Level Effect



per worker of 24.5 percent. The fact that researchers are more highly skilled adds an additional 9 percent to the level of income. In sum, then, the U.S. economy in 1993 has benefitted from a level effect on the order of 80 percent of income in 1950.

This level effect is shown graphically in Figure 6. In addition to plotting GDP per capita from 1870 to 1993, the figure shows the counterfactual level of income the U.S. would have achieved had income grown at its long-run rate of 0.6 percent per year, starting in 1950. Income in 1950 was approximately $9,500 per person suggesting a level effect by 1993 of approximately $7500. In fact, per capita income in 1993 was $22,000, while counterfactual income per capita is $12,500. The level effects outlined in this paper explain most of the difference.

4 Transition Dynamics and the Productivity Slowdown

A key prediction from the preceding analysis is that once research intensity and the rate of investment in skills stop increasing, the growth rate of the economy will slow considerably. Important supporting evidence for this prediction comes from stepping away from the constant growth path analysis of the previous section and analyzing transition dynamics. As shown in Figure 2 and 3, the last thirty years provides a relevant experiment for testing this prediction. Beginning in 1967, research intensity stopped increasing and declined for nearly a decade, and the rate of change of educational attainment has slowed considerably in the last twenty years.

Griliches (1988) and others have recognized that the timing of the slowdown in research inputs is remarkably well-suited to explain the slowdown in productivity growth beginning in the 1970s. We explore this hypothesis — augmented to include the slowdown in educational attainment — in the context of our fully-specified model.

To analyze transition dynamics, let's focus on total factor productivity growth. The log-linearized, discrete time version of equation (16) is

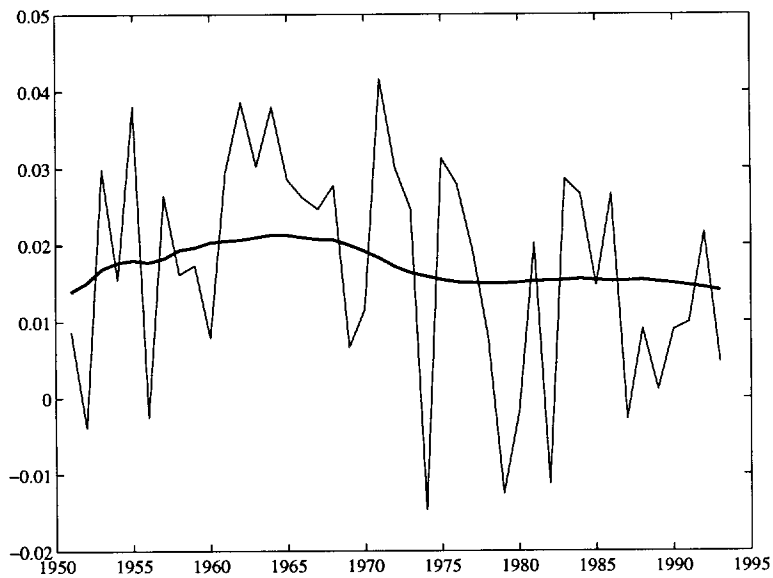
$$\Delta \log B(t) = Const + \lambda g_B \left(\log H_A(t-1) - \frac{1}{\gamma} \log B(t-1) \right). \qquad (17)$$

With knowledge of the parameters of this equation, one can compute a dynamic forecast of total factor productivity growth using only the observed time path of $\log H_A(t)$.[11]

We parameterize equation (17) as follows. First, we use the estimate of

[11] In practice, one might question the exact timing of the relationship in equation (17). For example, perhaps research takes three years instead of one year to have an effect on productivity growth. Or perhaps a more general lag structure is preferred. Two points are relevant. First, for the exercise conducted here, the point turns out not to be very important. Second, the empirical literature that has tried to estimate the relationship between R&D and TFP growth using firm and industry-level data has found it impossible to distinguish among competing lag structures. See, e.g., Hall (1995).

Figure 7: Actual and Predicted TFP Growth, 1952-1993



γ obtained in the previous section. Second, we choose the value of *Const* so that the mean of the simulated TFP growth series is equal to the actual mean (which we also use for g_B). Finally, we require an estimate of λ, the elasticity of new ideas with respect to skilled labor input. This parameter has proved difficult to estimate in practice, as noted by Stokey (1995). Jones and Williams (1996) provide evidence that .5 is a lower bound on λ. Since a value of one seems like a reasonable upper bound, we will report results for λ midway between these bounds, i.e. for $\lambda = 3/4$.[12]

Figure 7 plots actual and predicted total factor productivity growth for the U.S. economy from 1952 to 1993. The decline in research intensity and the reduction in the rate of increase of educational attainment show through clearly in the figure by predicting a productivity growth slowdown starting

[12]Attempting to estimate λ by running OLS on equation (17) yields a point estimate greater than 2, far beyond the plausible range. The problem, of course, is one of endogeneity: more researchers may be hired when times are good.

Table 3: The Productivity Slowdown

Years	Actual TFP Growth	Predicted TFP Growth
1952-1993	0.0172	0.0172
1952-1973	0.0221	0.0190
1974-1993	0.0118	0.0152

in the 1970s.

Table 3 reports a predicted slowdown of 0.4 percentage points of total factor productivity growth. Interestingly, for the Bureau of Labor Statistics data used here (after adjusting for educational attainment), the productivity slowdown is much larger, at a full percentage point. This finding accords well with the regression evidence presented by Griliches and others that the decline in R&D can only explain part of the productivity slowdown in the 1970s. The gap, however, may be artificially high for at least two reasons. First, it includes the effects of the oil price shocks in the 1970s, which are probably better thought of as business cycle effects. Second, productivity data from the manufacturing sector, where measurement problems are less severe, show a smaller slowdown.

The evidence from the last thirty years thus supports the contention that economic growth will slow considerably when research intensity and the rate of skill acquisition settle down. We know from the estimate of γ what the long-run growth rate will be, at least as a function of population growth. What we don't know is how long it will take the economy to transit to this lower long-run rate.

Some information about this transition can be obtained analytically by considering an extreme experiment: suppose research intensity and educational attainment stabilize immediately. Define x as labor-augmenting TFP growth from equation (16):

$$\frac{\dot{B}}{B} = x \equiv Const \left(\frac{H_A}{B^{1/\gamma}}\right)^{\lambda}. \tag{18}$$

Log-differentiating equation (18) starting from the time at which research intensity and educational attainment stabilize, one sees that the dynamics for TFP growth x are given by

$$\frac{\dot{x}}{x} = -\frac{\lambda}{\gamma}(x - x^*), \tag{19}$$

where $x^* = g^{SS} = \gamma n$. Solving this differential equation, one finds[13]

$$\frac{\dot{B(t)}}{B(t)} = g^{SS}\left(1 - \frac{g_0 - g^{SS}}{g_0} e^{-\lambda g^{SS} t/\gamma}\right)^{-1}, \tag{20}$$

where g_0 is total factor productivity growth at the time when research intensity initially stabilizes.

Finally, the time it takes for TFP growth to move half-way from g_0 to g^{SS} is given by

$$\begin{aligned} T^* &= -\frac{\gamma}{\lambda g^{SS}} \log \frac{g_0}{g_0 + g^{SS}} \\ &\approx \frac{\gamma}{\lambda} \cdot \frac{1}{g_0 + g^{SS}}. \end{aligned} \tag{21}$$

With $\gamma = .356$, $\lambda = 3/4$, $g_0 = .015$, and $g^{SS} = .006$, the half-life is equal to 27 years. This number suggests that the slowdown is likely to occur very gradually.

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[13]The key formula is

$$\int \frac{dx}{x(a + bx)} = -\frac{1}{a} \log \frac{a + bx}{x}.$$

5 Why has research intensity risen?

The main purpose of this paper is to explore the implications of the rise in research intensity and the increase in educational attainment for U.S. economic growth. In this section, we step back to ask, somewhat more speculatively, why these changes have occurred in the post-war period.

Recall that we began this paper with three observations: investment in skills through education has increased, research intensity has increased, and the openness of the world economy has increased. The hypothesis pursued here is that the third observation is responsible for the first. The enormous decline in international transactions costs, the successful and continued economic development of many countries outside the United States, and the reduction in world trade barriers have considerably increased the effective market for U.S. ideas. In response, U.S. research intensity has risen.

The economic distance between the countries of the world has fallen sharply during the last century. For example, average ocean freight charges per short ton declined from \$95 in 1920 to \$29 in 1990. An even sharper reduction is present in airline transportation: revenue per passenger-mile fell from 68 cents in 1930 to 11 cents in 1990. Finally, between 1930 and 1990, the cost of a three minute phone call from New York to London went from \$244.65 to \$3.32.[14]

The continued development of countries throughout the world has presumably also increased the global return to U.S. ideas. In 1960, for example, only 20 percent of the countries in the world had GDP per worker higher than forty percent of U.S. GDP per worker, and only 3 percent had incomes higher than eighty percent of the U.S. By 1988, the fraction of countries in these two categories had risen to 31 percent and 9 percent, respectively.[15]

[14] These examples are taken from the *Economic Report of the President* (1997), page 243.

[15] See Jones (1997).

The reduction in trade barriers in the OECD and the world following World War II has been documented by a number of authors. Ben-David (1993) pays particular attention to trade liberalizations in the European Community and the OECD. Sachs and Warner (1995) discuss to the return of the world to a system of "global capitalism" like that which prevailed at the turn of the 19th century. Krugman (1995) emphasizes the political forces responsible for the decline in trade barriers achieved through GATT and regional trade agreements.[16]

Understanding how these changes are likely to affect research intensity is difficult in the model presented in Section 2. A more complete analysis needs to be conducted in a model that explicitly includes multiple countries. However, some progress can be made. Imagine extending the model to a multicountry setting as follows. Ideas can be invented anywhere in the world, and there is an international patent system that (more or less) enforces property rights. The incentive to invent new ideas then depends not only on the profits that can be earned domestically, but also on the profits that can be earned abroad.

As shown in the appendix, the fraction of employment devoted to R&D in the U.S. is then given by (for s_R small)

$$\begin{aligned} s_R &\approx Const\ (\pi_{dom} + (1-\tau)\pi_{for}) \\ &= Const\ (1-\rho)\alpha \left(1 + (1-\tau)\frac{A_{dom}}{A_{for}}\frac{Y_{for}}{Y_{dom}}\right), \end{aligned} \tag{22}$$

where π is profits per idea, and the subscripts *dom* and *for* indicate domestic and foreign variables. The second line of the equation comes from noting, as in equation (3), that $A\pi/Y$ is given by $(1-\rho)\alpha$. τ represents the effective tax rate that applies to profits earned abroad. It is meant to capture transactions costs, tariffs, bribes, etc.

[16]Dinopoulos and Segerstrom (1996) explore this part of the explanation for a rising research intensity more formally in a two-country model.

One might try to explain the rise in s_R using equation (22) as follows: τ has fallen over time so that inventors are allowed to keep more of the international gains that their ideas potentially create. In addition, Y^{for}/Y^{dom} is large and has been growing as the rest of the world continues to develop. For example, U.S. GDP is roughly 40 percent of OECD GDP, suggesting a current ratio of Y^{for}/Y^{dom} of 1.5. Alternatively, U.S. GDP is roughly 20 percent of world GDP, which gives a ratio of Y^{for}/Y^{dom} of about 4. This simple back of the envelope calculation suggests that it is not out of the question that the increased openness, reduced transportation and communication costs, and increased development of the world economy is responsible for much of the rise in the U.S. (and OECD) R&D intensity.[17]

Finally, the model is well-suited to explain one other feature of the data. How do we understand the presence of trends in research intensity and skill accumulation and the absence of a trend in saving or investment rates? Shouldn't the changes that generate the trends in the former also generate a trend in the latter? Another way of asking this question is to note that in neoclassical models with transition dynamics it is common to see large declines in the marginal product of capital, but we don't see these in the U.S. data.

This pattern is in fact easy to understand. Consider a standard Ramsey-Cass-Koopmans model with exogenous technological progress at rate g. Suppose that, exogenously, g takes the constant value g_{high} for some period of time and then permanently declines to some lower value g_{low}. The Ramsey consumers know exactly when this change will occur and they know how large it will be. (Notice that this is a very rough characterization of how I think the U.S. economy is behaving.) First, suppose that g_{high} is expected

[17]Interestingly, this general explanation will not generate an increase in educational attainment in the model. Matching this fact may require a different explanation — such as an increase in the public funding of education — or perhaps a richer model that incorporates skill-biased technological change.

to prevail for a very long period of time, like a thousand years. In this case, a turnpike theorem applies, and the Ramsey consumers will evolve toward the steady state corresponding to g_{high}, stay very close to this steady state maintaining a near-constant ratio of C/Y, and then depart toward the "new" stable arm when the regime-change nears.

This thought experiment reveals two interesting things. First, the lack of a trend in saving and investment rates is certainly consistent with the story. Second, the relatively stable value of real interest rates suggests that Ramsey consumers do not think the transition to lower growth rates is going to occur in the near future. When the transition nears, interest rates will begin to fall.

6 Conclusion

It is traditional in the macroeconomics literature to view the U.S. economy as a good example of an economy that is very close to steady state. After all, growth rates in the U.S. have been relatively stable for the last century, and the stability of the U.S. capital-output ratio is one of the basic stylized facts of economic growth. This paper argues that this traditional view is mistaken. In fact, the U.S. economy is not at all close to its steady state. Research intensity, the rate of skill accumulation, and the openness of the world economy have all increased substantially in the post-war era. Each of these changes is inconsistent with steady state behavior.

In the model used here to analyze U.S. economic growth, standard policies like a subsidy to research have "level effects" instead of growth effects. However, a sequence of level effects can raise the growth rate of the economy above its long-run rate. This is exactly what has happened in the U.S. economy for at least the last fifty years, and perhaps for the last century. Rising research intensity and rising educational attainment have led growth in U.S. GDP per worker to be about one and a half percentage points above its long-run rate.

Eventually, research intensity and educational attainment must stabilize. Indeed, on the education side, the rate of change of educational attainment has already fallen considerably. When complete stabilization occurs, U.S. growth can be expected to fall to its long-run level, with a half-life of approximately 27 years.

When can this stabilization be expected to occur? The answer depends strongly on what one thinks is the underlying cause of the increase in research intensity and educational attainment in the first place. A plausible explanation is related to the increased openness and economic development of the world economy. These changes have substantially increased the relevant market for U.S. ideas, stimulating the rise in research intensity. There seems to be no sign of a slowdown in this phenomenon. For example, India and China, which together account for forty percent of the world's population, have been growing rapidly in the last decade. Such changes may continue to increase the returns to the creation of ideas in the coming decades, drawing more and more of the U.S. labor force into this activity.

Still, it is important to recognize that this is not steady state behavior. In the long run, these changes must come to an end, and when this happens, U.S. growth rates can be expected to fall considerably.

A Deriving s_R

Individuals must be indifferent between working in the final goods sector and working in the research sector. The wage paid per efficiency unit of labor in the final goods sector is

$$w_y = (1-\alpha)\frac{Y}{hL_Y}.$$

In the research sector, workers are identical and earn the same wage, which satisfies the (free entry) zero profit condition

$$w_A h L_A = P_A \dot{A},$$

where P_A is the market value of a new idea and $\dot{A}$ is the total number of new ideas created.

The market value of a new idea is equal to the present discounted value of profits that can be earned in the intermediate goods sector. Along a constant growth path, this value is given by

$$P_A = \frac{\pi}{r-(g_Y - g_A)},$$

where $g_Y - g_A$ is the growth rate of π — see equation (3).

Setting $w_A = w_y$ and solving yields

$$\frac{L_A}{L_Y} = \frac{1}{1-\alpha}\cdot\frac{g_A}{r-(g_Y-g_A)}\cdot\frac{A\pi}{Y} \equiv m.$$

Then, noting that $s_R \equiv L_A/(L_A+L_Y)$ one finds

$$s_R = \frac{m}{1-m}.$$

Finally, if s_R is small (as it is empirically), then

$$s_R \approx m \equiv Const\frac{A\pi}{Y}.$$

To get the formula reported in equation (22) in the text, we need to discuss dividing the world into two regions. Call the regions "dom" and "for", and let $\pi = \pi_{dom} + (1-\tau)\pi_{for}$. That is, the profits a (domestic) innovator earns on a new idea is the sum of the profits earned at home and those earned abroad, after taking into account the effective tax rate τ. Furthermore, from equation (3),

$$\pi_i = (1-\rho)\alpha \frac{Y_i}{A_i}, \quad i = dom, for.$$

Therefore,

$$s_R \approx Const_1 \frac{A}{Y_{dom}} \left(\frac{Y_{dom}}{A_{dom}} + (1-\tau)\frac{Y_{for}}{A_{for}} \right)$$

which can be rewritten as

$$s_R \approx Const_2 \left(1 + (1-\tau)\frac{A_{dom}}{A_{for}}\frac{Y_{for}}{Y_{dom}} \right).$$

This last equation is the one reported in equation (22).

B Data Appendix

The data used in this paper are taken from several different sources. Many of the sources are now available on-line, and the actual data series that I have used are available from http://www.stanford.edu/˜chadj/index.html.

- g_y. The Bureau of Labor Statistics (1996) provides an index for output per hour worked in the private business sector in their Table 1. This data is available on-line at http://stats.bls.gov/mprhome.html. As discussed in the paper, I adjust this data for the (empirically small) difference between L and L_Y.

- *Educational Attainment.* Median educational attainment in the population among persons 25 years old and over is taken from Bureau of the Census (1996), Table 17 (Historical). Medians were no longer computed after 1991, so I extrapolated the values of 12.8 for 1992 and 1993.

Missing data are linearly interpolated. This data is available on-line at http://www.census.gov/population/www/socdemo/education.htm.

- *Scientists and Engineers Engaged in R&D.* This data is taken primarily from National Science Board (1996) and National Science Board (1993). For years prior to 1965 for the U.S., data from various issues of the *Statistical Abstract of the U.S. Economy* are used. Missing data are log-linearly interpolated. National Science Board (1996) is now available on-line at http://www.nsf.gov/sbe/srs/seind96/start.htm.

- *R&D Expenditure as a Share of GDP.* This data is taken from National Science Foundation (1994), Tables B-15, B-14, and B-20. It is available on-line at http://www.nsf.gov/sbe/srs/s2194/dst1.htm.

- *Labor Force.* Taken from the *Economic Report of the President* (1997), Table B-33, Employed Civilian Labor Force.

References

Aghion, Philippe and Peter Howitt, "A Model of Growth through Creative Destruction," *Econometrica*, March 1992, *60*, 323–351.

Ben-David, Dan, "Equalizing Exchange: Trade Liberalization and Income Convergence," *Quarterly Journal of Economics*, August 1993, *108* (3), 653–680.

Bils, Mark and Peter Klenow, "Does Schooling Cause Growth or the Other Way Around?," 1996. University of Chicago GSB mimeo.

Bureau of Labor Statistics, U.S. Department of Labor, "Multifactor Productivity Trends, 1994," January 1996. USDL 95-518.

Bureau of the Census, "Current Population Reports: Educational Attainment in the United States: March 1995," August 1996. P20-489.

Council of Economic Advisers, *Economic Report of the President*, Washington, D.C.: U.S. Government Printing Office, 1997.

Dinopoulos, Elias and Paul Segerstrom, "A Schumpterian Model of Protection and Relative Wages," 1996. University of Florida mimeo.

Eaton, Jonathan and Samuel S. Kortum, "Trade in Ideas: Patenting and Productivity in the OECD," 1995. NBER Working Paper No. 5049.

Evenson, Robert E., "International Invention: Implications for Technology Market Analysis," in Zvi Griliches, ed., *R&D, Patents and Productivity*, Chicago: University of Chicago Press, 1984, pp. 89–126.

Gordon, Robert J., "American Economic Growth: One Big Wave?," March 1993. Northwestern University mimeo.

Griliches, Zvi, "Productivity Puzzles and R&D: Another Nonexplanation," *Journal of Economic Perspectives*, 1988, *2*, 9–21.

Grossman, Gene M. and Elhanan Helpman, *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press, 1991.

Hall, Bronwyn H., "The Private and Social Returns to Research and Development: What have we Learned?," June 1995. mimeo.

Jones, Charles I., "R&D-Based Models of Economic Growth," *Journal of Political Economy*, August 1995, *103*, 759–784.

—— , "Time Series Tests of Endogenous Growth Models," *Quarterly Journal of Economics*, May 1995, *110*, 495–525.

—— , "On the Evolution of the World Income Distribution," *Journal of Economic Perspectives*, Forthcoming 1997.

—— **and John C. Williams**, "Too Much of a Good Thing? The Economics of Investment in R&D," 1996. Stanford Economics Working Paper.

Krugman, Paul, "Growing World Trade: Causes and Consequences," *Brookings Papers on Economic Activity*, 1995, *1*, 327–377.

Maddison, Angus, *Monitoring the World Economy 1820-1992*, Paris: Organization for Economic Cooperation and Development, 1995.

Mincer, Jacob, *Schooling, Experience, and Earnings*, New York: Columbia University Press, 1974.

National Science Board, *Science & Engineering Indicators – 1993*, Washington D.C.: U.S. Government Printing Office, 1993.

—— , *Science & Engineering Indicators – 1996*, Washington D.C.: U.S. Government Printing Office, 1996.

National Science Foundation, "National Patterns of R&D Resources: 1994," *NSF 95-304*, 1994.

Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, October 1990, *98* (5), S71–S102.

Sachs, Jeffrey D. and Andrew Warner, "Economic Reform and the Process of Global Integration," *Brookings Papers on Economic Activity*, 1995, *1*, 1–95.

Stokey, Nancy L., "R&D and Economic Growth," *Review of Economic Studies*, 1995, *62*, 469–489.

___ **and Sergio Rebelo**, "Growth Effects of Flat-Rate Taxes," *Journal of Political Economy*, June 1995, *103*, 519–550.