

ECONOMIC GROWTH: THE IMPORTANCE OF EDUCATION AND TECHNOLOGICAL DEVELOPMENT

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EXECUTIVE SUMMARY

This paper reviews the lessons economists have learned from investigating growth experiences and income gaps across countries. After a review of the pertinent literature, the paper asks whether these lessons can be extended to growth and income differentials between regions or states of the United States.

The Importance of Growth

The growth rate of an economy is defined as the rate of change of real gross domestic product (GDP) per capita. It is important to distinguish overall growth that is fueled predominantly by the influx of people from growth on a per capita basis. The latter is more closely aligned with the trajectories of living standards and individual prosperity.

A comparison of growth rates across countries over a long historical span reveals that small differences in growth rates can have a big impact on achieving particular standards of living. But, what are the determinants of growth? Why do some countries remain trapped in poverty? How do countries “catch up” to the growth leader? How can growth leaders maintain leadership? These questions are considered in turn.

A different, but not less common, way to summarize the growth of nations is to examine GDP per worker or, if available, GDP per hour worked. In either form, this is a measure of the average labor productivity in an economy. Changes in average labor productivity and changes in average real wages are correlated over time. In the absence of productivity growth, wages and income will not normally improve in an economy.

While productivity gains typically are the source of wage growth and higher living standards for workers, when labor productivity increases, each worker is producing more output and so firms need fewer workers to produce the same amount of output. One might be tempted to conclude that this must imply fewer jobs, but there is little evidence that countries in which productivity grows faster suffer net employment losses.

While productivity growth need not result in net job losses, it is important to recognize that a dynamic economy produces short-run winners and short-run losers. The famous economist Joseph Schumpeter called this process of job turnover “creative destruction.” Creative destruction is the process by which economies innovate. The more rapid the innovation, the more rapid the rate of creative destruction. While good for the aggregate economy, the benefits from creative destruction might be little consolation to someone who has just lost a job. But, rapid turnover is actually necessary for economic growth measured by real wage increases and improved standards of living.

As with countries, regional growth (real output per capita of the region or the state) leads to increases in regional real wages and income. As growth occurs, the existence of losers at the regional level is inevitable and should by no means be a rationale for poorly conceived state policies (e.g. subsidization of declining manufacturing industries) that hinder creative destruction, and hence innovation.

The Phases of the Growth Process

According to Nobel Laureate Robert Solow, firms produce by combining labor and capital in a production process with known techniques. The foundation of the Solow model is the production function, used to study economic growth and productivity growth at the level of the firm, industry or country for various stages of aggregation.

During the growth process, a process of structural transformation occurs. This refers to the reallocation of labor and capital across major sectors. Anyone currently following the growth miracle in China sees all phases of this development process at work almost at the same time. China had an income per capita of \$401 in 1900. Since then, urbanization and industrialization have been occurring at a remarkable pace.

A famous prediction of the Solow model is that countries that *adopt similar production techniques*, broadly defined, will “converge” to a similar GDP per capita, called the steady state. No matter where a country starts, they all should eventually achieve the same income level per capita. Evidence of convergence is plentiful for developed economies which employ similar production techniques.

Without technological progress, capital is subject to the law of diminishing marginal returns — the additional output per unit of capital declines from very high levels initially to much lower levels later, reaching zero in the limit. Thus, the earliest stages of capital accumulation for a country are periods of time when growth rates can be spectacular. Inevitably, however, as the process proceeds, the productivity gains diminish to the point where all countries converge to the same stock of capital producing the same steady-state level of GDP per person, after which growth ends.

According to the Solow growth model, in the absence of new technology and production techniques, economies converge to a common level of GDP per person, the steady state. It then follows that leader economies *must* develop new efficiencies and new technologies to maintain leadership and to continue to grow while countries in the catch-up phase merely have to borrow technology from the leaders.

It is important to recall that the simple model of economic growth predicts that economies with *similar* production functions converge to the same GDP per capita. It does not predict that economies with different production functions show convergence. It is important to understand which policies and institutions are crucial to the adoption of efficient production processes of countries.

States that start richer (at more advanced technological development) grow more slowly just as advanced countries cannot grow at the same pace as “catch-up” countries (e.g. China). As states catch up in per capita terms, their growth advantage inevitably declines. The growth model also suggests that innovation is critical for the states comprising the United States. At some point in the economic development of every state, not much can be gained from a “follow the leader” strategy.

Growth Empirics: Measuring TFP

The Solow model offered little explanation of how efficiencies and technological progress occur. The process of technological progress is the key to understanding growth. Klenow and Rodriquez-Clare find that technological innovation accounts for more than 60 percent of the variation in income per worker across countries. Even more impressively, it accounts for 90 percent or so of cross-country differences in the *growth rate* of income per worker.

Technological progress, or total factor productivity (TFP), is the efficiency by which capital and labor are employed to produce output. TFP growth captures the part of output growth that cannot be accounted for by the accumulation of capital and labor. It often is called the “Solow Residual.” There is a growing consensus that TFP is a vital ingredient to economic growth. And understanding TFP growth is key to understanding growth itself.

Determinants of Total Factor Productivity

Economists agree that to sustain TFP growth, leading economies must develop new technologies and new products. The process of creative destruction plays a key role. The key ideas in this “Schumpeterian Paradigm” is that output growth requires the processes of invention and innovation; and that creative destruction must occur to allow for the implementation of these new processes. It follows from the notion of creative destruction that there are characteristics of an economy that should aid the process.

- According to some theories of technological progress, research and development (R&D) has the obvious direct effect on innovation, and hence productivity, and an indirect effect of causing accumulation of new technologically efficient capital. The secondary effect can be very large. Furthermore, advances in R&D create new knowledge that becomes available to others at no cost, inducing still more innovations at lower cost than the original discovery. R&D is especially crucial for the invention process of leading economies. In contrast, emerging economies can simply adopt the leading technologies from the developer of the technology.
- To the extent that the productivity changes are caused by technological change, skilled labor becomes relatively more important, and the need for human capital development becomes a crucial factor of continued growth. An educated work force is more adaptable to innovations on the job.
- The Schumpeterian Paradigm implies that policies and institutions that promote competition and facilitate entry and exit are instrumental. Moreover, markets that work well allocate resources freely across competing uses to the ones that are most likely to result in growth. An extension of this principle is the Schumpeterian notion of creative destruction. Conversely, subsidization (protection) of industries, firms, products, and jobs reduces efficient turnover and the process of creative destruction.

Many factors influence the rate of innovation in a country or geographic area. A maintained hypothesis is that *complete* markets are the superior mechanism to achieve a competitive environment and to allocate resources across entering-exiting firms. However, markets are not always complete (perfect). If markets are incomplete then inefficiencies can arise and reduce the rate of technological progress when not addressed. The private market, left to its own, will then

underproduce the good from a social (and efficiency) perspective because the social benefit (the sum of the private and public benefit) exceeds the private return.

- Economies characterized with high diversion rates and high tax rates tend to have slow rates of growth of TFP. The corollary is that economies that rely more on competitive private markets are more productive.
- There is a role for government involvement with respect to efficient transportation and communication networks, including cost-effective access to private or public “rights of way” in corridors, trenches, conduits, tower sites, etc.
- The market for education can be incomplete because individuals do not have full access to it.
- Without aid, (e.g. student loan subsidies) the market will underproduce educational services, human capital accumulation will be inefficiently low, and growth in living standards will suffer. The government has a role in providing economically efficient access to the market for education.
- R&D is not like normal products because it involves ideas. Knowledge cannot easily be restricted. Its ownership is difficult to determine and even more difficult to confine. As such, the development of R&D benefits more than just the inventor and provides spillover benefits to other users of the ideas, and hence, the economy. It follows that the developers of R&D cannot obtain the full rate of return for the invention because of the spillover. Hence, the market will underproduce R&D from the perspective of society and the government can be justified in intervening.

Lessons for Regional Growth

The growth rates of states do converge. States with the highest per capita incomes tend to grow slower than those starting further behind. The stage of advanced growth requires the proper institutions, policies, infrastructure, etc. to incent technological progress. There must be enough tax revenue collected to pay for the institutions and infrastructure that promote growth — without imposing stifling tax rates. State and local governments also must take care to promote competition and facilitate entry and exit. Finally, states that wish to continue to grow must rely on the same things that advanced countries do — cutting edge technology, including the R&D sector and educational sector, particularly higher education. Research universities are very valuable for the R&D that they produce and the production of education that provides infrastructure support for all forms of technologically advanced industries.

But why is it not better and cheaper for a state government to allow other states to remain growth leaders, incurring the necessary costly education and R&D, while maintaining their own economy perpetually in the catch-up phase by simply adopting the growth leader’s technology from 20 or 30 years ago? Maintaining a stable position in the catch-up stage might imply (if it can be done at all) that an economy is perpetually 20 years behind the standard of living of the growth leader. Imagine setting the goal of attaining a standard of living in 2008 that California had in 1988, for instance.

Even if this strategy is appealing, one has to realize that it implicitly assumes that a state’s comparative advantage can be maintained in the less-productive sectors. There is reason to be concerned about such a strategy because to succeed in these sectors the state at question will

have to compete with low-cost leaders such as China, India and the next set of countries that will emerge. The state would have to be a low cost-low wage state, which does not seem attractive.

Conclusion

Economic growth is critically important for individual well being. Even small differences in growth rates over long horizons lead to large differences in living standard.

There are two ways in which a country or a region can grow: either catch up with the leading economies or it can be a leading economy itself. The first paradigm applies to many developing countries, whereas the second paradigm applies to U.S. states or regions. Suggestions for crafting a regional policy that nurtures a pro-growth environment are examined. Clearly, the literature stresses the particular importance of education and R&D, and research universities are a natural way of supporting this growth-conducive climate.

INTRODUCTION

How do economies grow over time? Robert E. Lucas, the University of Chicago economist who won the 1995 Nobel Prize in economics for his work in business cycles, not growth, famously said before the Cambridge faculty in 1986:

“Is there some action a government like India’s could take that would lead the Indian economy to grow...If so, what action 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.”

Not long after the question was asked, India did begin to grow after a century of stagnation. And economists focused much attention on issues of growth. Another famous business cycle theorist, Edward C. Prescott, the 2004 Nobel Laureate and W. P. Carey Professor of Economics at Arizona State University, introduced his book, *Barriers to Riches*, with a similar question:

“One of the most important questions facing economists today is: Why do international incomes differ by so much? Or why isn’t the whole world as rich as the United States or Switzerland?”

Economists are still searching for the ultimate answers to these questions. Nevertheless, a great deal has been learned about growth and development since Lucas’ lecture. Through research, both theoretical and empirical, an understanding is developing about how rich economies remain rich, how some poor countries remain poor, and how others enter a “catch-up” phase that eventually turn them into rich economies.

This paper provides a capsule perspective on the lessons economists have learned from investigating growth and income gaps across countries. After providing the lessons for growth and development across countries, the paper concludes by asking whether these lessons can be extended to growth and income differentials between regions or states of the United States. It should be stressed that applying to regional growth what is known about country growth is partly untested at this time, and hence merely suggestive.

THE IMPORTANCE OF GROWTH

The fundamental measure of economic activity used by economists to measure growth is real gross domestic product (GDP). GDP captures the total output of an economy. Equivalently, it can be regarded as the total income earned in that economy.¹ *Real* GDP, as opposed to *nominal* GDP, cancels out the effects of inflation over time. Economists also prefer to cancel out the effect of different population sizes, and so real GDP is divided most often by population size, thus arriving at real GDP per capita. This is especially important when comparing economic activity across geographic regions that have different population sizes. The growth rate of an economy is then commonly defined as the rate of change of real GDP per capita.

Higher Living Standards: Small Differences Have Large Effects

Table 1 presents a long-run comparison — approximately a century — of growth rates and living standards across countries. There are several interesting lessons in the exhibit. First, some countries fail to grow at all. As the example of Bangladesh shows, such persistent lack of growth resulted in very low levels of GDP per capita at the end of this time period. The second lesson is that relatively small differences in growth rates over a long period of time accumulate to rather large differences in GDP per capita. The magic of compounding is important here. For example, compare the United States to the United Kingdom. In 1870, per capita GDP was similar in the two countries. Subsequently, growth in the United States was on average just 0.4 percentage

**TABLE 1
LONG-TERM ECONOMIC GROWTH IN REAL PER CAPITA
GROSS DOMESTIC PRODUCT IN SELECTED COUNTRIES**

Country	Period	Real GDP Per Person: Beginning of Period*	Real GDP Per Person: End of Period*	Annual Average Growth in Real GDP
Japan	1890-1990	\$842	\$16,144	3.00%
Brazil	1900-1987	436	3,417	2.39
Canada	1870-1990	1,330	17,070	2.15
West Germany	1870-1990	1,223	14,288	2.07
United States	1870-1990	2,244	18,258	1.76
China	1900-1987	401	1,748	1.71
Mexico	1900-1987	649	2,667	1.64
United Kingdom	1870-1990	2,693	13,589	1.36
Argentina	1900-1987	1,284	3,302	1.09
Indonesia	1900-1987	499	1,200	1.01
Pakistan	1900-1987	413	885	0.88
India	1900-1987	378	662	0.65
Bangladesh	1900-1987	349	375	0.08

*Real GDP is measured in 1985 dollars.

Source: Robert J. Barro and Xavier Sala-i-Martin, *Economic Growth* (New York: McGraw-Hill, 1995), tables 10.2 and 10.3.

¹ Official data on national income is derived from GDP in the national income accounts.

points per year more. As a result of this small difference in growth rates, an average person in the United States enjoyed a \$5,000 per year higher income at the end of this time period. The third lesson is that very rapid growth can transform a poor economy into a rich one. The example of Japan is illustrative here. At the beginning of the period, Japan's GDP per capita stood at less than 40 percent of that of the United States. Growing at a staggering 3.0 percent per year until 1990, Japan's GDP per capita rose to almost 90 percent of U.S. level.

This suggests several important questions: What are the determinants of growth? Why do some countries remain trapped in poverty? How do countries "catch up" to the growth leader? How can growth leaders maintain leadership? Economic models will be important to understand the growth process and to answer these questions. Before turning to such models, however, more data are presented that link productivity growth to other measures of prosperity.

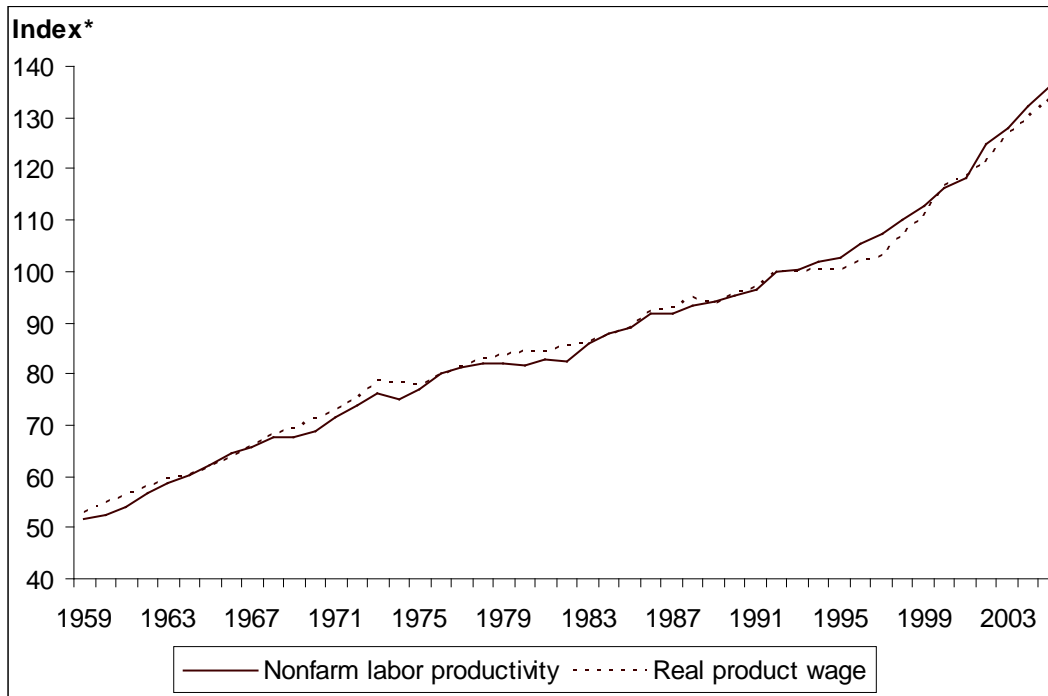
A Source of Real Wage Growth

Growth in GDP per capita is a proxy for the change in real living standards in an economy. The dramatic improvements in income per person from rather modest differences in growth rates when compounded over long periods of time were displayed in Table 1. A different, but not less common, way to summarize the growth of nations is to examine GDP per worker or, if available, GDP per hour worked. In either form, this is a measure of the average labor productivity in an economy. Standard theory predicts a strong positive correlation between changes in average labor productivity and changes in average real wages over a period of time. More concretely, if average labor productivity grows by 2 percent in the long run, then average wages should grow by 2 percent too. Chart 1 displays data for the United States, indeed showing that growth in labor productivity is associated with growth in real wages. For instance, in the 1960s, the United States enjoyed rapid growth in real wages and productivity. This was followed by a prolonged slowdown throughout the 1970s and 1980s. In the latter part of the 1990s, it became popular to talk about the "New Economy" as a new period of rapid growth in productivity began. As theory predicts, real wages increased commensurately at a rate not experienced since the 1960s. To restate the first proposition, economic growth is important because it is the source of improvements in real income and real wages. In the absence of productivity growth, wages and income will not normally improve in an economy.

Having stated the proposition that productivity growth is crucial to growth in real income, it is important to comment on a subtle difference between GDP per capita and labor productivity. Two economies can have identical labor productivities and real wages, and yet one of them can have a higher GDP per capita because a larger proportion of its population works or because its workforce works more hours. Edward Prescott has an interesting example in his Federal Reserve Bank of Minneapolis Quarterly Review article from 2004: Between 1993 and 1996, French and German GDP per capita were approximately equal. At the same time, French GDP per hour worked (productivity) exceeded German output per hour worked by more than 10 percent. How is this possible? The number of hours Germans worked per person exceeded their French counterparts by more than 10 percent.

Strictly speaking, the models pursued in this paper are about labor productivity. But because of data limitations, particularly for less developed countries, economists are often forced to revert to GDP per capita as a proxy.

**CHART 1
PRODUCTIVITY AND WAGE GROWTH IN THE UNITED STATES**



* Index, 1992=100

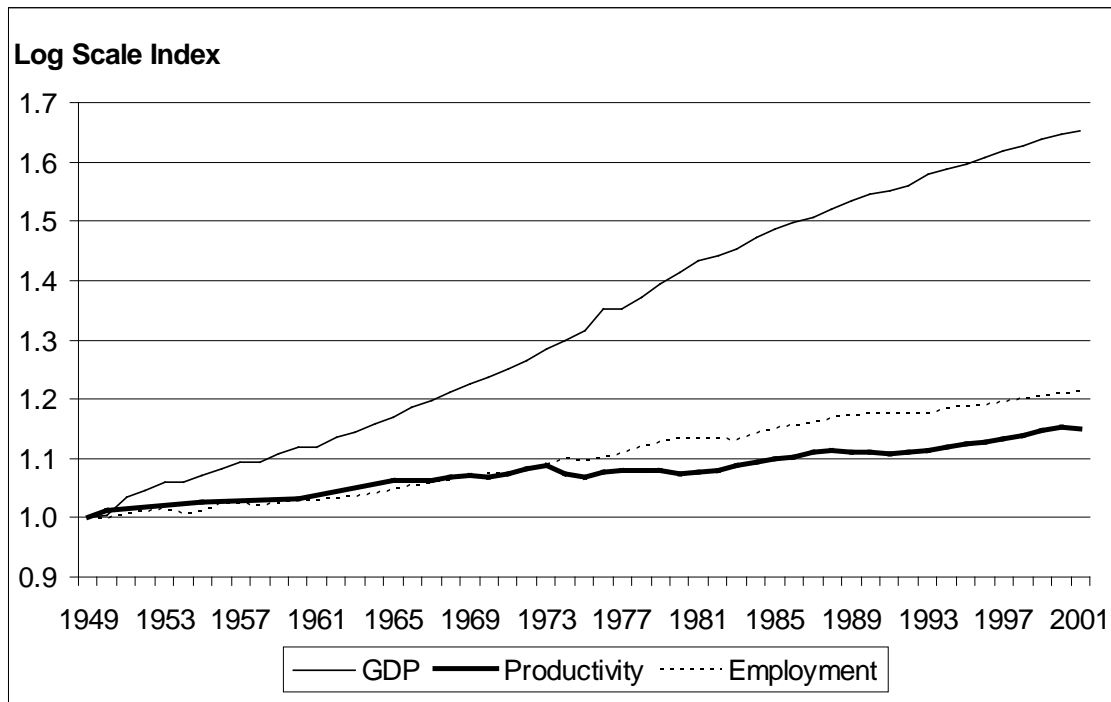
Source: Economic Report of the President and U.S. Department of Labor, Bureau of Labor Statistics.

Labor Productivity and Employment Growth

The popular press frequently raises the question whether improvements in labor productivity are a double-edged sword. On the one hand, the gains typically are the source of wage growth and higher living standards for workers. On the other hand, when labor productivity increases, then each worker is producing more output and so firms need fewer workers to produce the same amount of output. One might be tempted to conclude that this must imply fewer jobs.

There is little evidence that countries which grow faster suffer net employment losses. Chart 2 shows the long run association of GDP, productivity, and employment in a set of seven large developed economies from Organisation for Economic Co-Operation and Development (OECD) data. The average trend is clear. As labor productivity improved, employment grew as well. There are a number of theoretical reasons why this should be expected. To give one of several explanations, recall that productivity growth is associated with improvements in real wages. When real wages increase, consumers can purchase additional goods. To produce these additional goods, employment needs to increase.

CHART 2
GROSS DOMESTIC PRODUCT, PRODUCTIVITY AND
EMPLOYMENT GROWTH IN THE UNITED STATES



Source: Economic Report of the President and U.S. Department of Labor, Bureau of Labor Statistics.

Winners and Losers

This long-run “macro” perspective of how sustained increases in labor productivity occur without losses in employment is subject to an important caveat. The gross employment data shown above are the result of flows into and out of employment, sometimes referred to as job creation and job destruction. As technology changes and productivity improves, there will be new types of jobs producing new products — job creation. Old jobs dependent on old technology or on old products no longer in demand will disappear — job destruction.

It is important to recognize that the transition from old to new jobs can be painful for the people whose skills are no longer in demand, or for the people who must relocate to find the new job. As always, a dynamic economy produces short-run winners and short-run losers. At one time, blacksmiths became production workers in automobile factories, but not without disruption. Today, blue-collar manufacturing jobs increasingly give way to service-sector jobs, again not without disruption.

The famous economist Joseph Schumpeter called this process of job turnover “creative destruction” many decades ago when describing the dynamics of a market economy. Creative destruction is the process by which economies innovate. The more rapid the innovation, the more rapid is the rate of creative destruction. To give an example, in the United States, more than 1 in 10 jobs are created every year and more than 1 in 10 jobs are destroyed every year. This reallocation is a primary source of productivity improvement for the nation. While good for the

aggregate economy, the benefits from creative destruction might be little consolation to someone who has just lost a job. However, the wait between jobs need not be long. If an economy is sufficiently flexible (constrained less by regulation), reallocation can occur relatively quickly from a destroyed job to a created one. Whether one likes it or not, there is considerable evidence that rapid turnover is actually necessary for economic growth. More remains to be said about these institutional features later in this paper.

Lessons for Regional Growth

Most of the national relationships apply one-to-one to regions or U.S. states. To begin, the standard measure of regional economic activity is real output per capita of the region or the state. As with countries, regional growth leads to increases in regional real wages and income. Finally, while growth is beneficial to the region as a whole, there may well be groups of individuals who lose during job destruction inherent in any growth process. In other words, the existence of losers at the regional level is inevitable and should by no means be a rationale for poorly conceived state policies that hinder creative destruction, and hence innovation. Subsidization of declining manufacturing industries would be such a policy.

THE PHASES OF THE GROWTH PROCESS

In the simplest model of economic growth, that of Nobel Laureate Robert Solow, firms produce by combining labor and capital in a production process with known techniques. The foundation of the Solow model is the production function, a well known and well used model by economists of all political persuasions to study economic growth and productivity growth at the level of the firm, industry or country for various stages of aggregation. It is referred to as the “aggregate” production function when summed across all firms and all production process to represent an economy’s capacity to produce GDP. The Solow model actually is quite useful to understand the experience of economies at lesser stages of development, *once the growth process has begun*. Furthermore, the basic features of the model can be made more sophisticated so that richer sets of experiences can be explained, from persistent poverty to growth leadership. To start, it is useful to understand some basic stylized facts about the growth process. It seems there are two distinct phases of growth: the “catch-up phase” and the “advanced stage.”

Stage 1: Convergence in the “Catch-up Phase”

Sectoral Redistribution of Work

At the beginning of economic growth, countries enter their “catch-up” phase. During this stage, they experience a process of structural transformation. This refers to the reallocation of labor and capital across major sectors. The main features of the catch-up phase follow:

- In the pregrowth period, economies remain locked in persistent subsistence living conditions.
- In the early stage, labor flows *from* agriculture *into* industry and services.
- In a later stage, labor flows *from* agriculture and industry *into* services.
- As countries further progress, they purchase modern capital from the advanced economies and adopt the advanced production techniques appropriate for their level of development. Countries in this stage of development become competitive in their labor productivity compared to the leading countries.
- In the catch-up phase, countries experience very rapid, unsustainable growth rates. While the period of catch up can last many decades, it eventually ends as countries “converge” to patterns common to the growth leaders.

Anyone currently following the growth miracle in China sees all phases of this development process at work almost at the same time. China had an income per capita of \$401 in 1900. Per capita income increased to only \$614 in the next 50 years. Since then, urbanization and industrialization have been occurring at a remarkable pace. In the next 50 years or so, per capita income rose by a factor of nine, with most of this gain occurring in only the last 25 years. Now, markets seem to develop overnight and the most technologically advanced capital goods and production processes are imported into the country. Still lacking a well-functioning service sector, China has started to introduce modern banking, insurance, and real estate. Given the large part of the population that is still working in agriculture, there is ample room for further sectoral allocation.

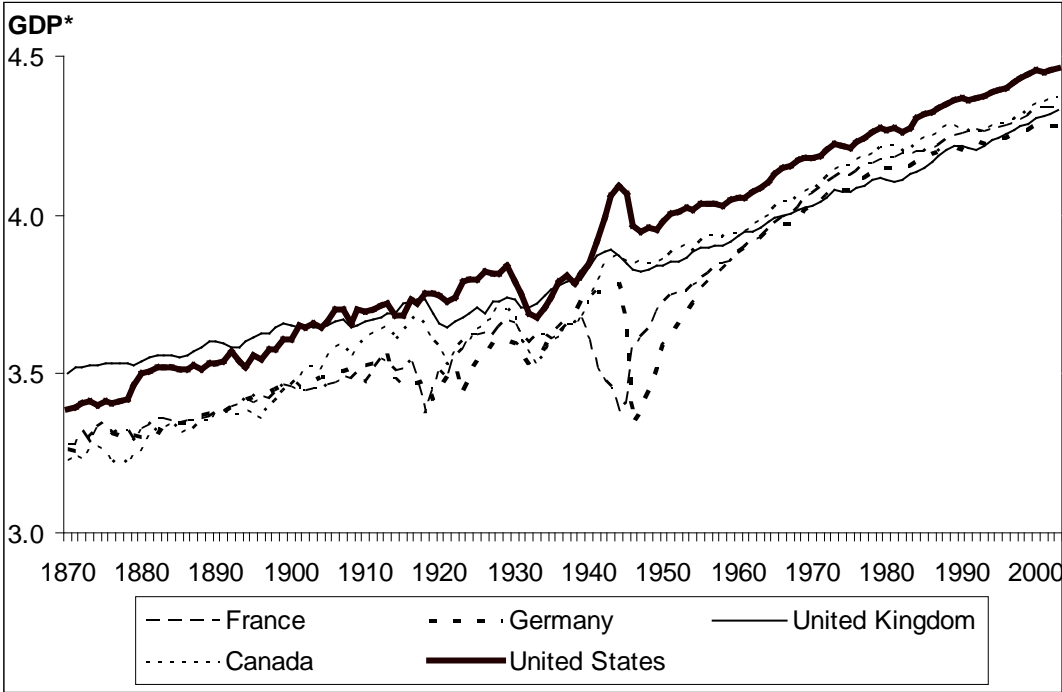
The Convergence Proposition

As mentioned above, a famous prediction of the Solow model is that countries that *adopt similar production techniques*, broadly defined, will “converge” to similar GDP per capita, called the

steady state. No matter where a country starts, they all should eventually achieve the same income level per capita. Evidence of convergence is well known for developed economies which employ similar production techniques. Chart 3 contains a small sample but there is no shortage of country examples that fit this pattern. Even in China, the catch-up phase will reach the point at which China will converge to a rate of economic growth similar to that in other the leading industrial powers.

What determines the rate of convergence or “catch up”? Recall from the opening paragraph of this section that, according to the production function, firms produce by combining labor and capital in a production process with known techniques. Pursuing this concept further, there seems to be three elements, in general terms, which help determine the rate at which economies catch up in terms of GDP per worker. One is the rate at which capital accumulates. Another is the rate at which labor improves in qualitative terms. Labor can increase in terms of efficiency units with increased training and education. Finally, there is the technique. The level of technological sophistication can vary greatly across countries in the techniques used to produce a road, car, house, electricity or perform brain surgery. But this oversimplified form of the production function cannot be the whole explanation. According to this, for instance, the country that accumulates capital the fastest, all else the same, would always achieve the fastest growth rates — convergence would not occur.

**CHART 3
GROWTH CONVERGENCE IN SELECTED COUNTRIES**



* Real gross domestic product per capita in 1990 international dollars, using a log scale.

Source: Organisation for Economic Co-Operation and Development.

To account for convergence, account must be taken of the limits to the gains from accumulation in the absence of technological progress. The first tractor put on a farm increases the productivity of the farm greatly; the tenth tractor improves output less; and the hundredth tractor improves farm output by far less. As capital is employed in the manufacturing sector and then the service sector, the same pattern occurs. Without technological progress, capital is subject to the law of diminishing marginal returns — the additional output per unit of capital declines from very high levels initially to much lower levels later, reaching zero in the limit. Thus, the earliest stages of capital accumulation for a country are periods of time when growth rates can be spectacular. Inevitably, however, as the process proceeds, the productivity gains diminish to the point where all countries converge to the same stock of capital producing the same steady-state level of GDP per person, after which growth ends. The Solow growth model, when fully specified, comes equipped with the law of diminishing returns, and hence, delivers the convergence proposition.

Now consider the other feature of the production function, technological progress or knowledge accumulation. As discussed above, when a tractor is added to the farm, each tractor produces less *additional* output as the previous tractor. Suppose instead, each tractor could be retrofitted with new technology so that a tractor of 1970 vintage could be made equivalent to a tractor of 2000 vintage, a hypothetical efficiency improvement of ten fold. The first tractor is now ten times more productive, as is the hundredth tractor. Improvements in technology are not restricted by diminishing returns. In this way, technological progress can be increased forever without reaching a limit. It follows from this concept that improvements in the efficiency of the economy through technological progress are the key to sustained growth rates.

Even though technological progress is not subject to diminishing returns, there is a type of “catch-up” feature associated with it. As just shown, an economy can grow continuously in the long run as technological progress (denoted as A in equation 1) grows. To make this notion generally applicable, the basic Solow growth model can be enhanced greatly by adding a process for technological progress as in Aghion and Howitt (2005). Consider that technology, broadly defined, consists of different vintages of technological knowledge. Assume that the newest technology is invented, developed and implemented at a rate τ_n . Assume further this newest technology enhances productivity by multiples, ρ , relative to the productivity of the vintage technology, A . The pre-existing state of art technology also can be purchased and implemented at rate τ_o , and it enhances productivity according to the distance between the productivity of the pre-existing technology frontier, A^* , and the vintage (productivity) of the technology currently in use. In such a case, it is easy to show that technological progress changes according to²:

$$(1) \Delta A = \tau_n (\rho - 1)A + \tau_o (A^* - A)$$

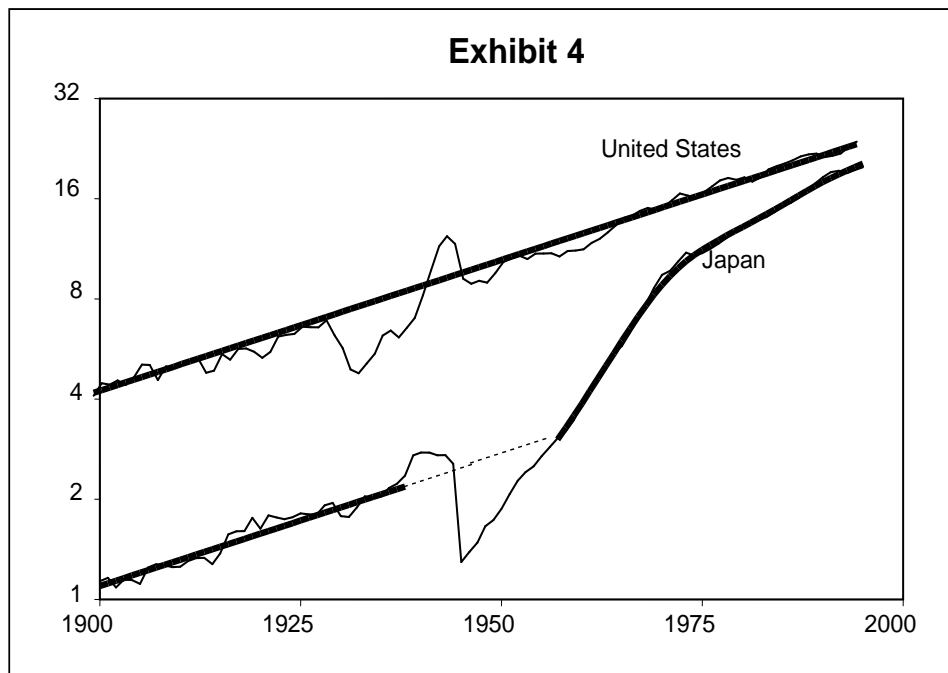
This formulation has potential to add to the explanation of how countries can catch up at such fast rates. The greater is the “technology gap” ($A^* - A$), the greater is the potential rate of catch up. Countries with a large technology gap need not develop or implement any leading-edge technology to grow at spectacular rates in this phase of development. Even if τ_n is zero, a country with a large gap merely needs to adopt technology of more recent vintage compared to what is

² The symbol Δ is used to denote “changes”, in this case changes in A (technology).

currently being used. The faster they adopt the newer vintages (τ_0) and the greater the gap that they close ($A^* - A$), the greater will be ΔA (growth in technological progress).

An example is Japan, as seen in Chart 4. A few decades before the turn of the 20th century, Japan started as an essentially agricultural economy with low GDP relative to the U.S. As it added capital and adopted more advanced production techniques from the West, it grew rapidly, as agricultural resources poured into industrial uses. During World War II, Japan lost its capital, and growth plunged. When the economy was reformed, it began accumulating capital again with the inevitable increase in real GDP per person. But the technology gap had become immense following the destruction, much larger than the pre-war condition. As Japan added capital it also modernized its industrial structure and developed well-functioning markets, thus closing the technology gap. As a consequence, Japan enjoyed spectacular growth rates — the trajectory of their growth path is much steeper after WWII than before. But the more it developed, the more it began to look like the growth leaders, transforming from a productive low-cost producer of industrial goods in the 1950s to a leader of technologically advanced goods and services in the last part of the century. As the technology gap closed, Japan's growth rate declined from the stellar (and unsustainable) rate of the catch-up period following the war and converged to similar (or even lower) growth rates as those of the leading industrial powers.

CHART 4
ECONOMIC GROWTH IN THE UNITED STATES AND JAPAN
(Income Per Capita in Thousands of 1990 U.S. Dollars)



Source: Handbook of Economic Growth, Volume 1, Chapter 21.

The Advanced Phase — Maintaining Growth

According to the Solow growth model, in the absence of new technology and production techniques, economies converge to a common level of GDP per person, the so-called steady state.³ It then follows from theory that leader economies *must* develop new efficiencies and new technologies to maintain leadership and to continue to grow while countries in the catch-up phase merely have to borrow technology from the leaders. A return to equation (1) makes this specific. When an economy is already at the frontier, A^* equals A and the technology gap is zero — nothing can be gained from “follow the leader.” These countries must rely on new technological advances or cease growing, a basic conclusion of the fundamental model. New technology requires invention and implementation. As a consequence, new technology arrives at a slower pace than does old technology in emerging economies, $\tau_n < \tau_o$; and it has incremental impact on a well-developed economy that is relatively small, ρ . It follows that leading economies grow at slower rate than emerging economies. The trend growth in the United States has been 2 to 3 percent over a very long period of time (including population growth). If τ_n declined, so too would the improvement in real GDP per person. As explained later, differences in τ_n are important for explaining the differential growth rates of the United States and other developed economies in the European Union.

Explaining Persistent Poverty

Taken at face value, the basic Solow growth model has another obvious limitation. In its most basic form, this model seems unable to confront the utter lack of growth among some countries, the core of the questions posed by Lucas and Prescott in the Introduction. Consider for example the data in Chart 5. Following decades of stagnation, countries in East Asia and the Pacific entered the catch-up phase in the 1950s, referred to as modern economic growth by Prescott. At the time that Asia began converging to the standards of Western Europe and the United States, the countries in Latin America and Sub-Saharan Africa declined still further relative to the rest of the world. There was no catch up for these countries.

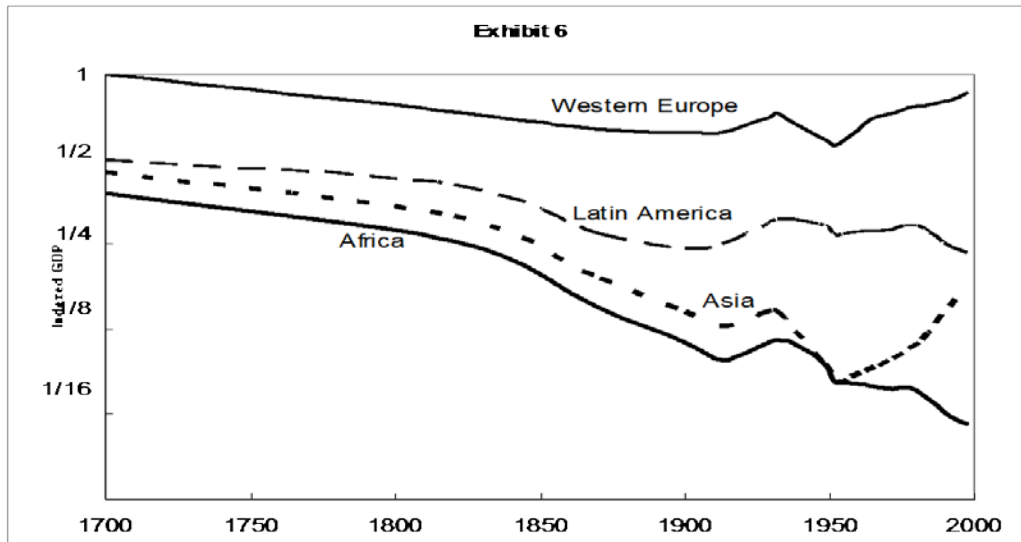
To rationalize this, it is important to recall that the simple model of economic growth predicts that economies with *similar* production functions converge to the same GDP per capita. It does not predict that economies with different production functions show convergence. Equation (1) provides an explanation, albeit unintuitive. Specifically, τ_o seems to be zero in these economies — there is no adoption of modern production processes. However, equation (1) cannot explain *why* τ_o is zero. Thus, another open question of growth theory to be confronted later in this paper is the determination of which policies and institutions are crucial to the adoption of efficient production processes of countries.

Lessons for Regional Growth

In the case of regional growth in the United States, the starting environment is the 50 states with relatively high incomes competing in highly competitive national and international markets. Furthermore, these states operate within the federal system that provides institutional structure in terms of fiscal policy, trade (national and international), communications, and the legal system. Given these similarities across states, it is fair to assume these states have access to similar

³ Note that if no country is developing new technology (τ_n is zero everywhere), the first term in equation (1) disappears and all countries converge to the steady state with A^* technology.

**CHART 5
INCOME AS A FRACTION OF THE LEADER**



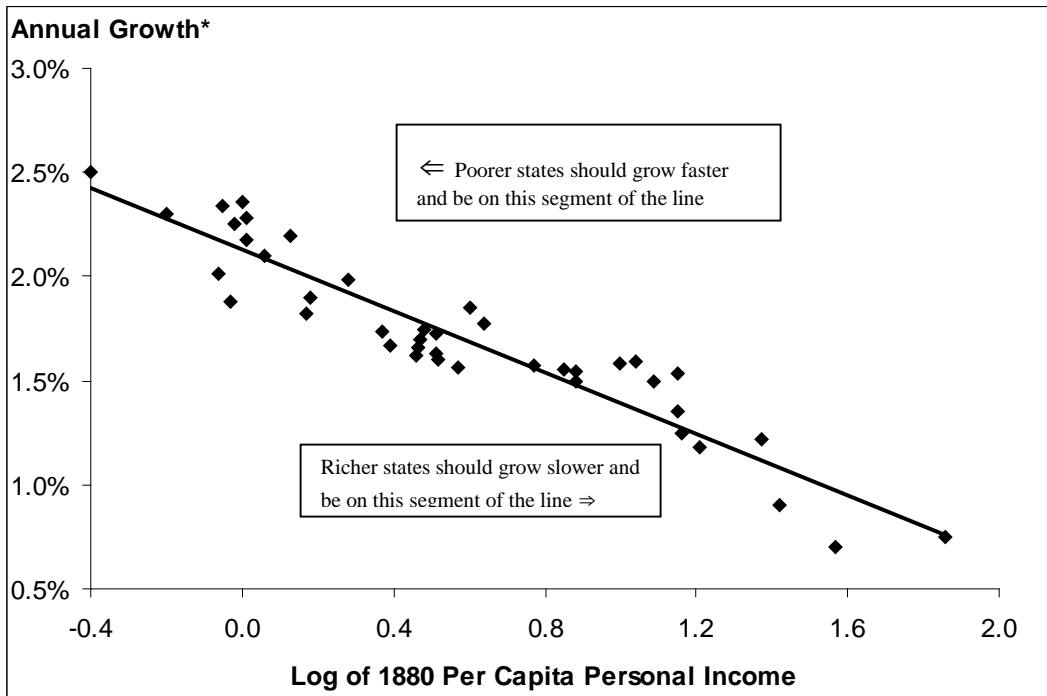
Source: Handbook of Economic Growth, Volume 1, Chapter 21.

production techniques so that the Solow model is applicable. As predicted, states do catch up, as shown in Chart 6.⁴ States that start richer (at more advanced technological development) grow slower just as advanced countries cannot grow at the same pace as “catch-up” countries, China for example. As states catch up in per capita terms, their growth advantage inevitably declines.

The growth model suggests that during the convergence process among states, labor will flow from both agriculture and manufacturing into the service sector. Seen in this light, job losses in agriculture and manufacturing during the transition period should not be viewed with the concern about a region’s economic future that they often receive in the popular press. Instead, they should be viewed as an inevitable byproduct of that regions’ successful process of creative destruction as development proceeds to a cutting-edge advanced economy. The growth model also suggests that innovation is critical for the states comprising the United States. At some point in the economic development of every state, not much can be gained from a “follow the leader” strategy. How can such a cutting-edge economy be achieved? Before this is question is addressed, the measurement of total factor productivity (TFP) is discussed.

⁴ This exhibit portrays catch up differently than Exhibit 4. In this diagram, U.S. states that start with relatively low per capita incomes (towards the origin on the horizontal axis) should experience faster growth rates (towards the top of the vertical axis) along the “catch-up line.”

CHART 6
INCOME CONVERGENCE OF U.S. STATES



* Annual average growth rate between 1880 and 2000

Source: Barro and Sala-i-Martin, *Economic Growth* (New York: McGraw Hill, 1995).

GROWTH EMPIRICS: MEASURING TFP

The Solow model, developed 50 years ago, offered little explanation of how efficiencies and technological progress occur. In the next section of this paper, economic research is reviewed that seeks to explain how economies can continue to grow through technological innovation, spurred by research and development, education, and the like. However it occurs, it should now be abundantly clear that the process of technological progress is the key to understanding growth. As an example of highly regarded research on this topic, Klenow and Rodriguez-Clare find that technological innovation accounts for more than 60 percent of the variation in income per worker across countries. Even more impressively, it accounts for 90 percent or so of cross-country differences in the *growth rate* of income per worker.

Before considering the factors that cause technological progress in the next section, it is necessary to come to terms with the definition and measurement of technological innovation.

The Production Function

What is technological progress, or total factor productivity, as economists generally call it? Vaguely speaking, TFP is the efficiency by which capital and labor are employed to produce output. Since efficiency cannot be directly observed, technological progress is by nature an ambiguous concept and as a result, unobservable as actual data. And yet, research, such as that of Klenow and Rodriguez-Clare, make use of data to arrive at their conclusions on its importance. As it turns out, economists have devised a way to approximate TFP, and once again, the starting point is the basic Solow growth model.

To calculate the amount of TFP in an economy, economists use an aggregate production function. Such a construct combines the economywide inputs of capital and labor to generate the economywide output. Loosely speaking, an aggregate production function represents the summation of all production techniques used by the individual firms in the economy. A functional form that is consistent with the stylized facts of growth is the so-called Cobb-Douglas production function:

$$(2) Y = A K^\alpha L^{1-\alpha}$$

where $Y = \text{GDP}$,

$A = \text{total factor productivity}$,

$K = \text{capital stock}$,

$L = \text{labor}$, and

$\alpha = \text{the fraction of national income paid for capital (in the United States this is a very durable number, which equals about 30 percent over long periods of time)}$.

To understand why TFP in equation (2) represents the efficiency with which the economy combines the inputs of capital and labor, consider two economies. Both economies use the same amount of inputs and have the same α , but the first one has twice the TFP of the second one. Then the first economy will produce twice the output of the second economy. Note that Y , K , L and α all can be measures from the national income accounts. Given this information, A can be backed out of equation (2) with a technique that has become known as growth accounting.

Growth Accounting

Solow developed the basics of growth accounting by noting that equation (2) can be used to decompose the observed output *growth* of economies into its different sources. Growth accounting allows the sources of growth to be identified among the accumulation of capital, labor and changes in TFP. To see this, production function (2) can be expressed in rates of change (growth), instead of in levels:

$$(3) \Delta Y/Y = \alpha(\Delta K/K) + (1 - \alpha)(\Delta L/L) + \Delta A/A$$

According to expression (3), the growth in output is due to weighted growth in the capital stock, weighted growth in the labor input, and growth in total factor productivity. Given the values of GDP, capital, and labor from the national income accounts, expression (3) can be solved for the rate of change of TFP, $\Delta A/A$:

$$(4) \Delta A/A = \Delta Y/Y - \alpha(\Delta K/K) - (1 - \alpha)(\Delta L/L)$$

Thus, TFP growth captures the part of output growth that cannot be accounted for by the accumulation of capital and labor. It often is called the “Solow Residual.”

Growth Accounting in Practice: Where Does the Growth Come From?

Displayed below in Table 2 is a decomposition of GDP growth of the form in equation (3), measured in terms of nonfarm business output per hour for the United States between cyclical peaks. The time periods represent a rather robust period of growth in the 1960s, almost two decades of slower growth in the 1970s and 1980s, and a rebound in growth in the 1990s.

**TABLE 2
ECONOMIC GROWTH IN THE UNITED STATES BY COMPONENT**

	1960 to 1973	1973 to 1995	1995 to 2001
Nonfarm Business Output Growth	4.6%	3.1%	3.9%
Less (percentage point contributions):			
Nonfarm Business Hours	1.7	1.7	1.3
Equals (percentage point contributions):			
Output per hour	2.9	1.4	2.6
Cyclical	0.0*	0.0	-0.5
Capital Services	1.4*	0.7	1.3
Equals (percentage point contributions):			
TFP **	1.5*	0.7	1.8
(computer sector TFP)	NA	0.2	0.4

* Authors' estimate

** TFP includes small measurable changes in labor quality

Source: Council of Economic Advisers.

Quite clearly, differences in growth in labor had little or no effect on differences in economic growth between these time periods. Specifically, the contribution from labor (“nonfarm business hours”) was nearly identical in the three time periods; 1.7 percent, 1.7 percent and 1.3 percent. According to Table 2, the slowdown in U.S. economic growth in the middle time period was due to a slowdown in the growth of capital accumulation and TFP. This is particularly pronounced in terms of output per hour as the measure of growth.⁵

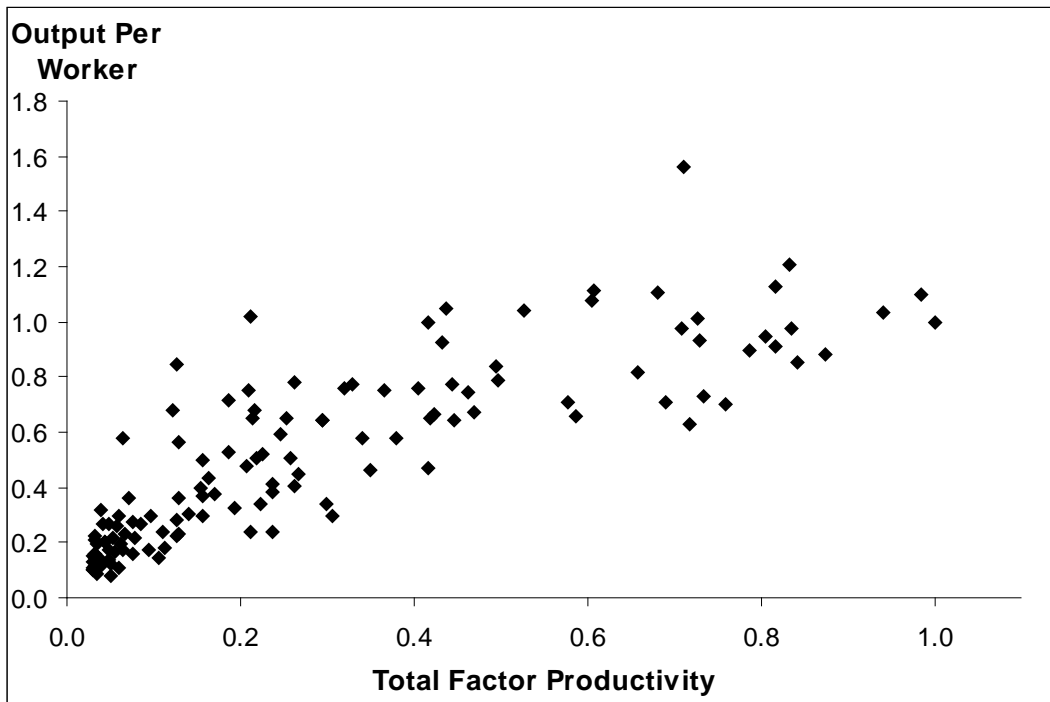
Why did labor productivity rebound in the 1990s to the healthy productivity growth enjoyed in the earlier time period? The data in Table 2 point to two factors in the rebound in the last half of the 1990s — rapid improvements in capital services and TFP. Is this evidence of a “new economy” as was often conjectured? The use of this term could be justified in the sense that innovation in TFP appears to be technology led — the TFP in the computer sector alone is significant. Furthermore, of the 1.3 percent increase in capital services in this time period, information capital contributes 1.01 percentage points, or 78 percent of the capital accumulation that occurred in the time period. Final judgment will have to wait, however, to establish a sufficiently long trend before calling this era a new economy.

Clearly, technology was a key to the U.S. rebound in the latter half of the 1990s, no matter how brief this may be. Nevertheless, it is tempting to conclude this is much ado about nothing. After all, the differences in TFP growth between time periods is only one percentage point, more or less. To provide perspective, it is worth recalling the lesson from Table 1 — small differences in growth rates compound to make large differences in standards of living after several decades. Similar calculations have been made across other leading economies. See Chart 7. There is a growing consensus that TFP is a vital ingredient to economic growth.

The next order of business is therefore to explore how TFP can grow. Special attention is given to leading economies that do not have the opportunity to copy from more advanced economies.

⁵ To understand the calculations, start with nonfarm business output; subtract hours to get output per hour; and then subtract capital services to get TFP. TFP is simply the residual after accounting for labor and capital growth as in equation (4).

CHART 7
OUTPUT PER WORKER AND TOTAL FACTOR PRODUCTIVITY
IN OTHER COUNTRIES RELATIVE TO THE UNITED STATES



Source: Penn World Tables

DETERMINANTS OF TOTAL FACTOR PRODUCTIVITY

Economists agree that to sustain TFP growth, leading economies must develop new technologies and new products. It is necessary, therefore to understand how this happens and how policies and institutions may affect this process. An influential perspective on the importance of innovation was developed more than 70 years ago but has received considerable modern attention. It is the process called “creative destruction,” which is discussed next in some detail.

The Schumpeterian Paradigm: “Creative Destruction”

The key ideas in the “Schumpeterian Paradigm” are that output growth requires the processes of invention and innovation; and that creative destruction must occur to allow for the implementation of these new processes. The reference to Joseph Schumpeter, who after immigrating from prewar Germany became a professor of economics at Harvard University in 1932, comes from the specification of the innovation process, which puts the entrepreneur at center stage:

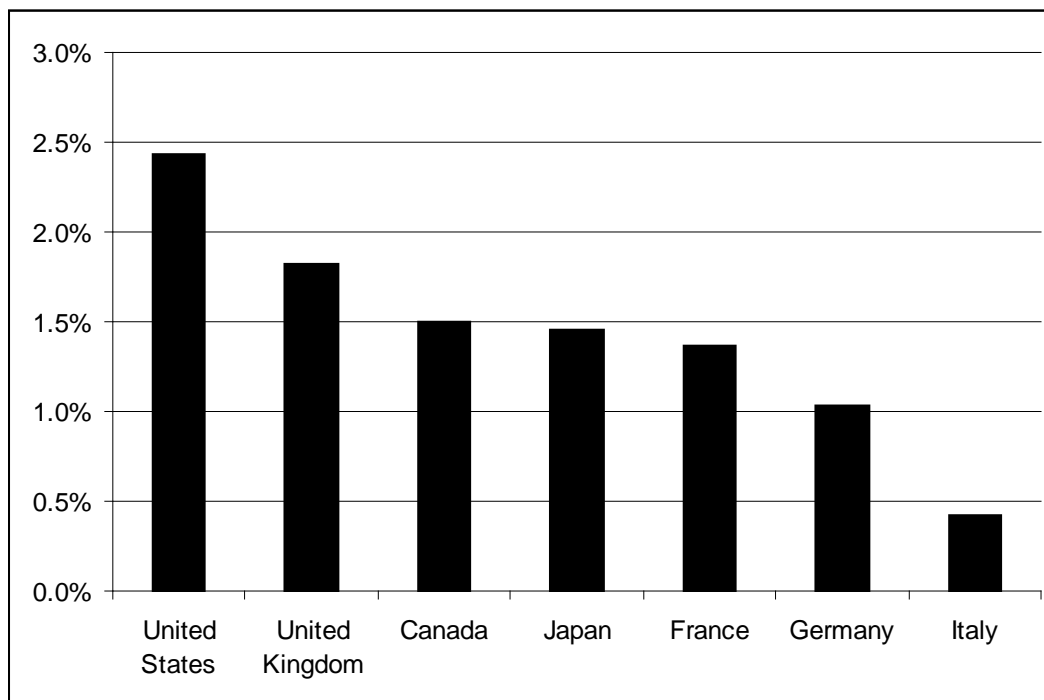
The function of entrepreneurs is to reform or revolutionize the pattern of production by exploiting invention or, more generally, an untried technological possibility for producing new commodities or producing an old one in a new way.

According to Schumpeter, the innovation process involves new techniques, inventions, and new products. It is important to realize that during this process, jobs, firms, and products are both created and destroyed. Specifically, entrepreneurs who plan to innovate start new firms or produce new goods. As these new firms (or new products) enter, existing firms (or existing products) lose market share and eventually exit. In this process, new jobs are created in new industries and old ones are destroyed.

To give an example of creative destruction, consider these facts about the U.S. economy. Almost half of annual productivity growth is accounted for by the movement of labor from less-productive to more-productive firms. For five-year changes, Baldwin, Dunne, and Haltiwanger report that about 40 percent of job creation and destruction are accounted for by entry and exit of firms. Achieving all this reallocation means that good firms must be allowed to expand and bad firms must be allowed to shut down. Well-functioning markets provide the mechanism by which resources flow freely to the new advancing industries and firms. As “catch-up” countries compete successfully at lower costs for the older established industries, firms in these industries in the advanced economy exit the market.

It follows from the notion of creative destruction that there are characteristics of an economy that should aid the process. First, clearly there needs to be activity in terms of invention and innovation. Research and development are directly linked to activity in terms of invention. It is easy to imagine that education, especially higher education, also is important to the invention and innovation processes. Thirdly, for creative destruction to operate, the market structure of an economy must be adaptable — “flexible” is the term most used by economists. Consider for example the seven large countries once again. Having mostly caught up to the United States in productivity terms by the 1990s, they have fallen behind since then, as shown in Chart 8. Many economists attribute the relative decline of productivity growth within these countries to the relative inflexibility of their markets compared to the United States. Such inflexibility concerns

CHART 8
ANNUAL AVERAGE GROWTH OF LABOR PRODUCTIVITY, 1995 THROUGH 2006



Source: Organisation for Economic Co-Operation and Development, *Economic Outlook*, 2005.

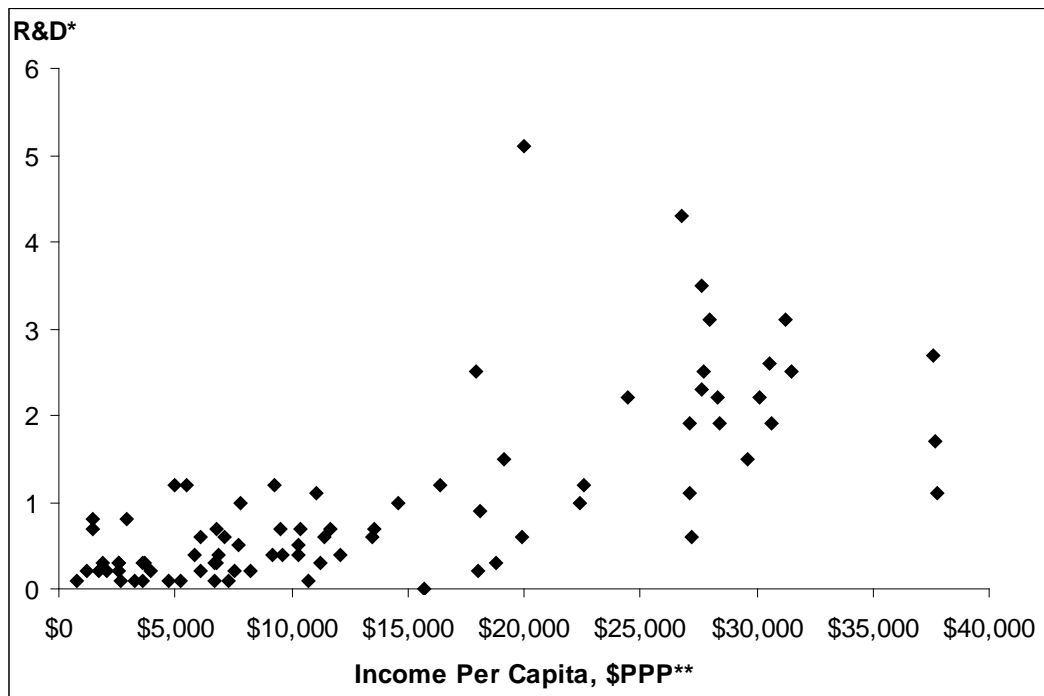
institutional features of their labor markets, public policies, and the protection of their industries that retard the process of creative destruction. Another contributing factor is a far lower proportion of the labor force that has college degrees relative to the United States, making it more difficult to adapt the skill profiles of their workers to the most recent skills in demand. Resisting the forces of creative destruction apparently comes with a cost — lower productivity growth, and hence, lower standards of living.

R&D and Invention

According to some theories of technological progress, research and development (R&D) has the obvious direct effect on innovation, and hence productivity, and an indirect effect of causing accumulation of new technologically efficient capital. The secondary effect can be very large. Furthermore, advances in R&D create new knowledge that becomes available to others at no cost, inducing still more innovations at lower cost than the original discovery. As already discussed, R&D is especially crucial for the invention process of leading economies. In contrast, emerging economies can simply adopt the leading technologies from the developer of the technology. And indeed, nearly 95 percent of all R&D is conducted by a handful of countries. Chart 9 shows clearly the expected pattern of R&D production by income levels of countries.

Chart 10 shows impressive growth in R&D expenditures for the United States since the late 1980s, with a particularly sharp increase since the mid 1990s. This is particularly the case for the

**CHART 9
RESEARCH AND DEVELOPMENT AND INCOME BY NATION**



* Research and development as a percentage of gross domestic product.

** PPP is purchasing power parity.

Source: United Nations *Human Development Report* (2005).

private sector seeking to maintain its competitive advantages in the global economy. The propensity to convert R&D into patents follows the same pattern and is shown in Chart 11.

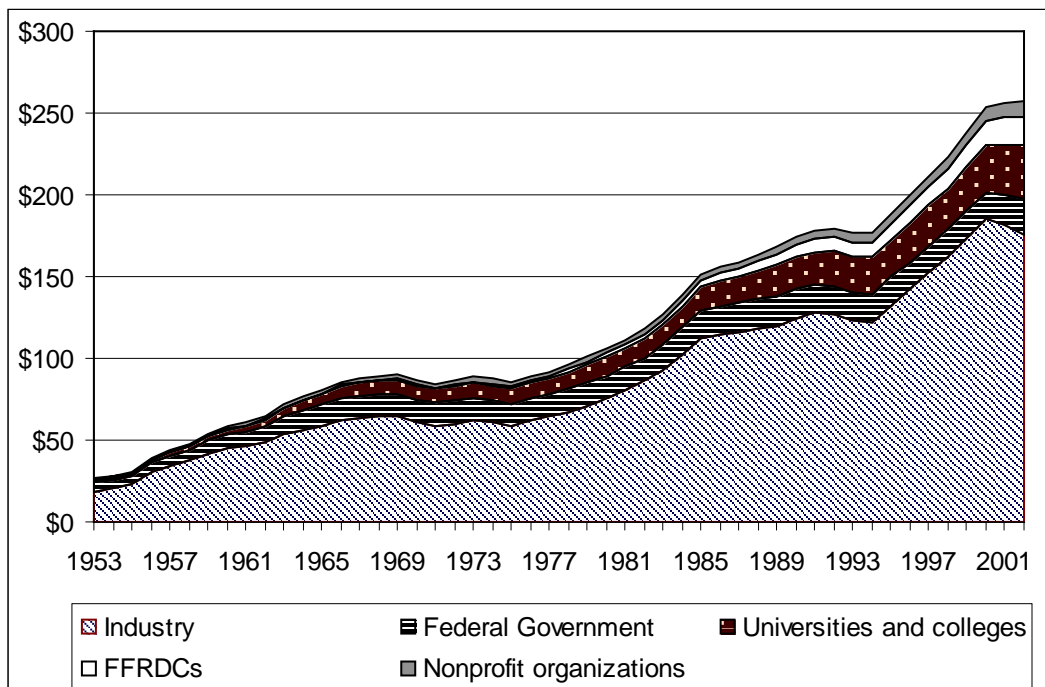
At least in terms of expenditures on R&D and patents, the last decade or so has been a remarkable period of invention in the United States. Recall that this corresponds to an impressive rebound in TFP growth for the nation (Table 2).

More sophisticated analysis supports this casual evidence. For instance, Jones (2002) found that 70 percent of the improvement in productivity of the United States between 1950 and 1993 can be attributed to the direct and indirect effects of new knowledge. Other researchers have found comparable evidence that R&D is a powerful driver of growth in the highly industrialized economies.

Innovation and Human Capital

To the extent that the productivity changes are caused by technological change, skilled labor becomes relatively more important, and the need for human capital development becomes a crucial factor of continued growth. An educated work force is more adaptable to innovations on the job.

CHART 10
RESEARCH AND DEVELOPMENT EXPENDITURES IN THE UNITED STATES
(In Billions of 1996 Dollars)

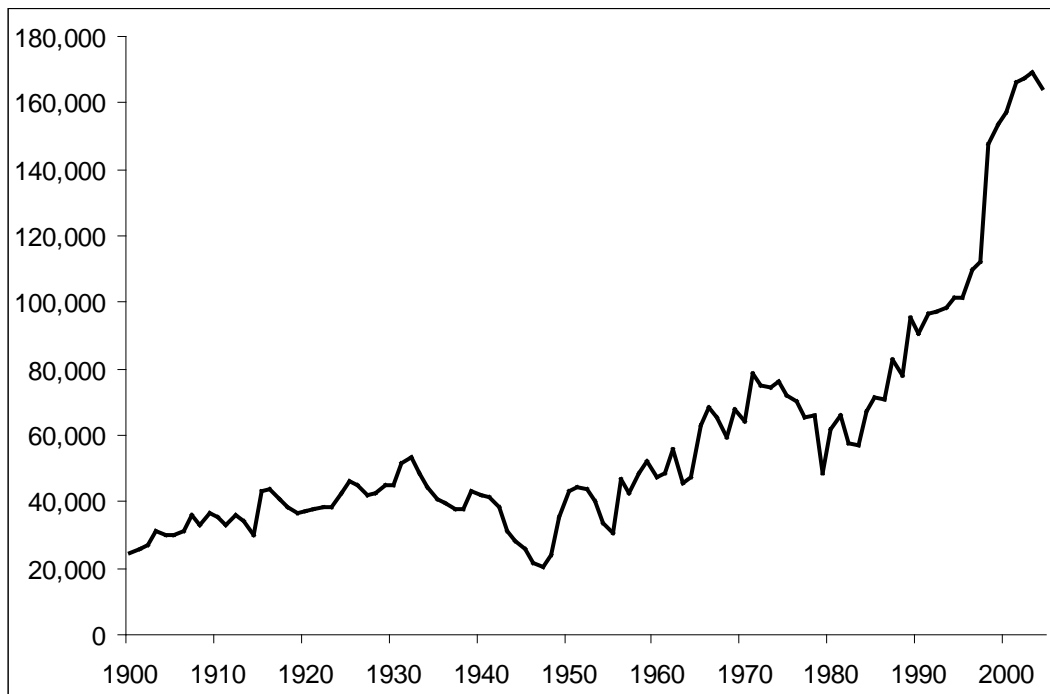


Source: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources, annual series.

Human capital is the accumulated knowledge and skills of the work force. The means of acquiring knowledge and skills are formal education, on-the-job training, and learning-by-doing. In general, education should have large public benefits in an advanced economy. This notion is confirmed by the estimates of the Seidman Institute (2005). More specifically, education should be important for the invention and innovation process. The United States leads most other nations in terms of educational attainment. Barro and Lee (2003) report average years of schooling in 2000 across various countries as follows: U.S. is 12.1, Canada 11.6, Australia 10.9, Germany 10.2, Japan 9.6, U.K. 9.4, France 7.9 and Italy 7.2. A similar pattern is found if measuring the percent of a population with a degree in higher education: 37.3 percent in the U.S. while only 23.8 percent in the EU. All of these countries have fallen behind the United States once the catch-up phase was completed.

A natural empirical question arises: Can lower educational achievement in Europe partially account for the recent inability of Europe to keep pace with the United States? Unfortunately, as is often the case in economics, the initial rigorous tests of this hypothesis have delivered somewhat mixed results. Benhabib and Spiegel (1994) find support for the view that the stock of human capital (total years of education) is positively related to economic growth when testing across countries. Krueger and Lindahl (2001) also find this relationship in a data set of 110 countries between 1960 and 1990; however, the relationship loses statistical significance when the set of countries is restricted to the OECD. A purer test is provided by Vandebussche,

CHART 11
NUMBER OF UTILITY PATENTS GRANTED IN THE UNITED STATES



Source: United States Patents Office (www.uspto.gov).

Aghion and Meghir (2004). They hypothesize that different types of education have different impacts on growth. Specifically, achievements in higher education should have the largest effect on countries closest to the technology frontier. Although complex, their tests support the contention that years of higher education positively contribute to growth and that this gets stronger the closer a country is to the frontier.

Market Flexibility

The Schumpeterian Paradigm implies that policies and institutions that promote competition and facilitate entry and exit are instrumental. Moreover, markets that work well allocate resources freely across competing uses to the ones that are most likely to result in growth. An extension of this principle is the Schumpeterian notion of creative destruction. Conversely, subsidization (protection) of industries, firms, products, and jobs reduces efficient turnover and the process of creative destruction.

Much of the literature on this topic is focused on the labor market, and specifically, the relative flexibility of the labor market in the United States compared to Europe. There is considerable evidence that the labor market rules enforced in Europe are another major factor in the slower growth experienced by Europe in recent years (Chart 8) and their higher unemployment rates. European economies are characterized by higher unemployment insurance benefits, severance restrictions, centralized bargaining, and other forms of protection such as restrictions on the adoption of new technologies. These policies emphasize the short-run losses to individuals

during the innovation process at the expense of the long-run gains in living standards and long-run employment.

A review of the literature indicates that the following institutional arrangements favor high growth.⁶

- Promotion of free trade makes domestic industries more competitive and is a source of technological progress for countries not on the technological frontier.
- Enforcement of the rule of law provides incentives to accumulate physical and human capital. It also provides protection of private property, enforcement of contracts, intellectual property protection, and an independent court system that is free of corruption while preserving individual freedoms.
- High-quality regulatory practices curb excessive bureaucracy, remove price distortions (such as monopoly pricing), and generally preserve market incentives.

An index compiled by the World Bank aggregates the qualities found in the latter two categories of institutional structure detailed above. Their index is highly correlated with GDP per capita, as shown in Chart 12. It also is true that specific measures of these individual qualities (rule of law, globalization, quality of regulation, anticorruption, and so forth) generally are strongly correlated with economic growth.

What Role Should Government Policy Play?

Many factors influence the rate of innovation in a country or geographic area. A maintained hypothesis is that *complete* markets are the superior mechanism to achieve a competitive environment and to allocate resources across entering-exiting firms. However, markets are not always complete (perfect). If markets are incomplete then inefficiencies can arise and reduce the rate of technological progress when not addressed. The private market, left to its own, will then underproduce the good from a social (and efficiency) perspective because the social benefit (the sum of the private and public benefit) exceeds the private return.

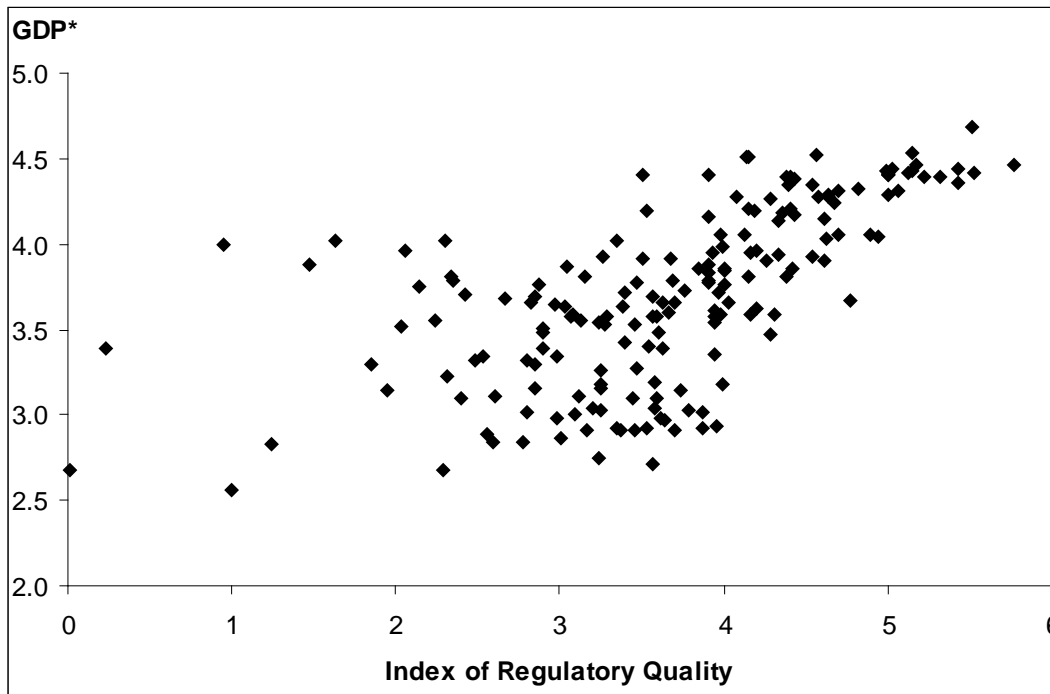
This introduces a possible role for limited government. Of course, it is possible for the government to overproduce the good, so careful consideration must be given to the relative sizes of the public and private benefits. But, when properly considered, there is a role for government to make the market “complete.”

Competition and Regulatory Policy

The act of diverting resources from the private sector and high tax rates go hand-in-hand. Economies characterized with high diversion rates and high tax rates tend to have slow rates of growth of TFP. The corollary is that economies that rely more on competitive private markets are more productive. The key is competition, and once again, there is the delicate tradeoff between leaving markets completely unhindered versus the promotion of market competition through regulatory activities such as antitrust laws, information disclosure laws, environmental protection in the presence of pollution externalities, and so forth. Governments that do this well show considerable restraint in their regulatory activities; and when used for purposes of correcting a market imperfection, they preserve market incentives in their regulatory practices. As an

⁶ See Prescott and Parente for the importance of trade, Herrendorf and Teixeira (2007) for the damaging effect of monopolies and Hall and Jones (1999) for a discussion of institutional quality generally.

CHART 12
REGULATORY QUALITY AND GROSS DOMESTIC PRODUCT
BY COUNTRY IN 2000



* Real gross domestic product per capita, using a log scale.

Source: International Monetary Fund, *World Economic Outlook 2003*, and Penn World Tables.

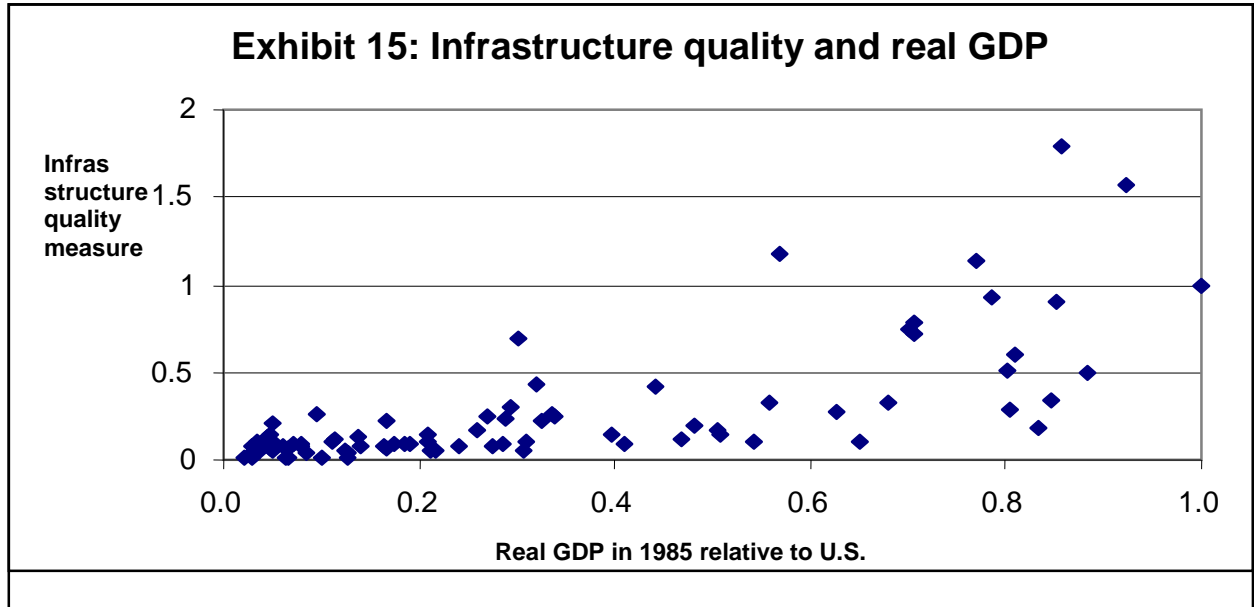
example, pollution can be regulated through economic incentives when setting up markets in which pollution rights are sold.

Infrastructure

As related to growth, the term infrastructure encompasses a great many things. It includes transportation networks, communication networks, the health and educational system, and legal structure. For advanced economies, the research and development infrastructure also matters a great deal. Infrastructure quality is correlated with GDP across nations, as shown in Chart 13.

The markets for infrastructure are considered incomplete in varying degree. Transportation on many roads, flights between cities and communication across many networks is more efficient when roads and networks are integrated seamlessly. There are network “externalities” that make their true value greater as a whole than sold-off in parts. This is not always true, so toll roads can work efficiently in places as can cable television networks. Nevertheless, on a whole, there seems to be a role for government involvement with respect to efficient transportation and communication networks, including cost-effective access to private or public “rights of way” in corridors, trenches, conduits, tower sites, and so forth.

CHART 13
INFRASTRUCTURE QUALITY AND GROSS DOMESTIC PRODUCT
BY COUNTRY



Source: Adamopoulos (2005) "Transportation Costs, Agricultural Productivity, and Cross-Country Income Differences", University of York.

Human Capital

The market for education can be incomplete because individuals do not have access to it. Human capital is different than physical capital in that human capital only can be rented, never sold: it is illegal to own other people. The inability to sell or collateralize the asset makes the market incomplete. It is more costly to take a loan without collateral, and thus, there is lower access to human capital markets for everyone, but especially low-income families. Consider, for example, someone with the ability to earn a 10 percent return on their educational investment, but because of economically inefficient access to the market, must pay 15 percent interest on the student loan. An economically rational person will not pay 15 percent interest to earn a 10 percent return, and thus, education will be underproduced from a socially efficient perspective. It is for this reason that some student loans are guaranteed by the government and/or direct financial aid is provided on the basis of need. Without the aid, the market will underproduce educational services, human capital accumulation will be inefficiently low, and growth in living standards will suffer. The government has a role here in providing economically efficient access to the market for education.

Research and Development

R&D is not like normal products because it involves ideas. Knowledge cannot easily be restricted. Its ownership is difficult to determine and even more difficult to confine. As such, the development of R&D benefits more than just the inventor and provides spillover benefits to other users of the ideas, and hence, the economy. It follows that the developers of R&D cannot obtain

the full rate of return for the invention because of the spillover. Since inventors have less private market incentive relative to the true rate of return, the market will underproduce R&D from the perspective of society. As such, the government can be justified in intervening in the market. Product protection and intellectual property rights are forms of government intervention providing temporary monopoly rights to the inventor. To the extent that a “product” is involved, the results of R&D can be patented. But the knowledge aspect of it is less easily protected, even with IP laws. Thus, direct subsidy of basic research is another form of intervention, often performed at universities and other nonprofit research institutions. The subsidy is meant to offset the wedge between the market rate of return to society and the rate of return to the inventor.

Lessons for Regional Growth

What lessons can be taken from the evidence provided above and be applied to regional growth? In particular: How can U.S. regions or states maintain growth leadership in the global economy?

So far, evidence has been given that the growth patterns of the 50 states behave much as countries do. In particular, it appears that growth rates of states do converge. States with the highest per capita incomes tend to grow slower than those starting further behind. Another lesson is that, as the catch-up phase ends, the stage of advanced growth requires the proper institutions, policies, infrastructure, and so forth to provide incentives for technological progress. In terms of fiscal policy, there must be enough taxes to pay for the institutions and infrastructure that promote growth. However, excessive taxes become a barrier to growth. State and local governments also must take care to promote competition and facilitate entry and exit. Finally, states that wish to continue to grow must rely on the same things that advanced countries do — cutting-edge technology, including the R&D sector and educational sector, particularly higher education. Without inefficient subsidies and industrial protection, low-tech production will increasingly leave the United States. States that do not wish to decline with these industries will need strong education at all levels to support and attract local R&D. Research universities will be very valuable for the R&D that they produce and the production of education that provides infrastructure support for all forms of technologically advanced industries.

While an extensive body of literature exists analyzing growth across countries, regional growth has not received the same attention. There is at least one reason to suspect regional growth is somewhat different than country growth. The ability of resources to move freely across state borders is much greater than across country borders. In other words, it is possible to attract a highly educated workforce without producing it within the state. Likewise, it is possible to attract the latest R&D without producing it in the state. Thus, this becomes essentially an empirical question. For example, if these resources are slow to move to places in the deep South, which seems to be the case, then the deep South will have to produce much of it themselves. In such cases, empirical studies will find that the location of research universities are a predictor of high levels of productivity (as proxied by gross state product per worker), but not necessarily growth in productivity. Conversely, if resources move quickly, it is possible that universities have no impact on productivity within a state. The reason that universities might affect levels of productivity, but not growth rates of productivity, is that states can catch up at fast growth rates the further they are behind the technological frontier.

Aghion, Boustan, Hoxby and Vandenbussche (2005) provide evidence on this question. They find that the closer states are to the technological frontier, the faster they grow per expenditure on research universities.⁷ Note that higher education also improves a state's performance because education is required for many high-skilled jobs, and it gives workers the flexibility to adjust to the process of creative destruction. Education is required not only for producing cutting-edge technology, it also provides the ability to adjust to technological innovation. The conclusion is that states that wish to compete at the advanced stages of growth need research universities and the other infrastructure required for the R&D sector.

It might be tempting to suggest that it is better and cheaper for a state government to allow other states to remain growth leaders, incurring the necessary costly education and R&D, while maintaining one's own economy perpetually in the catch-up phase by simply adopting the growth leader's technology from 20 or 30 years ago. Maintaining a stable position in the catch-up stage might imply (if it can be done at all) that an economy is perpetually 20 years behind the standard of living of the growth leader. Imagine setting the goal of attaining a standard of living in 2006 that California had in 1985, for instance. Moreover, even if this strategy is appealing, one has to realize that it implicitly assumes that a state's comparative advantage can be maintained in the less-productive sectors. There is reason to be concerned about such a strategy because to succeed in these sectors the state at question will have to compete with low-cost leaders such as China, India and the next set of countries that will emerge. The state would have to be a low cost-low wage state, which does not seem attractive. It is likely that its people would try to leave it to move to high-wage states, much as many immigrants leave their home country to come to work in the United States. An additional concern arises when time is introduced into this strategy.

Given the evidence presented above, the following statement from Allan Greenspan comes as no surprise:

In a global environment in which prospects for economic growth now depend importantly on [the] capacity to develop and apply new technology, the research facilities of our universities are envied throughout the world...Here, perhaps the most frequently cited measures of our success have been the emergence of significant centers of commercial innovation and entrepreneurship...where creative ideas flow freely between local scholars and those in industry. (*The Region*, March 1999, page 9)

The notion that regions can grow isolated from the rest of the country and the rest of the world has become ridiculous. Competition will come from above and below. It is important for regions within the United States to push on the technological frontier, not just because of the potential gains from innovation, but because low-cost competition from emerging countries will erode the economic foundation of increasingly low-tech regions that do not innovate.

⁷ The authors control for endogeneity with a two-stage procedure. This provides statistical validation that causation runs from education to productivity, and not the reverse (states with high productivity, and hence high wages, have a citizenry that simply demands more higher education).

CONCLUSION

Economic growth is critically important for individual well-being. Specifically, even small differences in growth rates over long horizons lead to large differences in living standard.

A country or a region can grow in two ways: It can either catch up with the leading economies or it can be a leading economy itself. The first paradigm applies to many developing countries, whereas the second paradigm applies to U.S. states or regions. Of particular importance are good institutions and infrastructure, education and R&D; research universities are a natural way of supporting these.

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