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The Search for the Sources of Growth: Areas of Ignorance, Old and New

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Many economic historians, like most economists, depend on standard growth accounts to provide some quantitative description of the proximate sources of growth, but this is misleading. American growth experience illustrates the difficulty. The seeming major contribution of tangible capital accumulation to nineteenth-century growth was the consequence of scale-dependent and capital-using technological progress. The large twentieth-century contributions of education and R&D conceal technology's new intangible capital-using bias. Additionally, reverse forces run from capital accumulation to technological progress. Without a greater understanding of these interactions, our knowledge of even the proximate sources of growth is incomplete.

I

As some readers may recognize, my title is a throwback to the very first paper I wrote with a clearly historical theme, a paper I prepared for an AEA session on growth in the December 1955 meetings.[1] My assignment—I now gasp to think of it—was to review the economic growth of this country since the Civil War—in 30 minutes. As I was a long-time National Bureau hand, I thought immediately of the work that Simon Kuznets and John Kendrick had under way, which—between the two of them—provided measures of output and of labor and capital growth since the latter nineteenth century. They let me use their data. To make some sense of the numbers, I thought of the device that John Kendrick had hit on to measure combined factor input and output per unit of combined input; so I borrowed that. The result was a calculation that seemed to show that over some eight decades, the combined per capita input of labor and capital accounted for only 10

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This article substantially reproduces the presidential address I gave at the 1992 Economic History Association meetings. I have elaborated some arguments and added some supporting tables and footnotes. The talk was based on views developed in collaboration with Paul David some 20 years ago; but he should not be charged with the faults that may afflict my formulation. I am grateful for his critical review of my earlier draft and for valuable comments and suggestions from my colleagues Nathan Rosenberg and Gavin Wright.

[1] Abramovitz, "Resource and Output Trends."

percent of the growth of net output per capita. What we now call total factor productivity (TFP) appeared to be responsible for the remaining 90 percent. In the analogous decomposition of labor productivity growth, the result was similar: capital per man hour, only 20 percent; total factor productivity, 80 percent.

This result, at least in the small share it assigned to capital intensity and in the dominant importance of TFP, was a surprise to me and, it seems, to most economists. After all, capital accumulation was a great subject in economics. In a vague way, we all thought it must play a large part in explaining growth, not just a small supporting role. So I thought I had hit on something new and substantial. But what exactly was it?

When I asked myself that question, I had no clear answer. What was this Residual, this total factor productivity growth, that seemed to hog the whole show? Technological progress was, of course, a part of the Residual, and the Residual's large value fitted in nicely with a common intuition that such progress was an important source of labor productivity growth. There was, therefore, an early tendency to identify that large primitive Residual with the advance of technology. It was a tendency encouraged by Robert Solow's paper, published only a few months later.[2] Solow found empirical results similar to my own about the size of the Residual; but in the context of his formal model the Residual was viewed as a measure of the rate of exogenous shift of an aggregate production function. I had seen at once, however, and my paper had pointed out, that the Residual in its early primitive form was a cover for many sources of growth besides technological advance, and some were clearly significant matters. So the Residual was really a grab-bag.

For this, there were several big reasons. One was that the measure of factor inputs was incomplete. The whole intangible side of total capital accumulation—education, on-the-job training, and research and development (R&D)—was neglected. And so were other categories of expenditure and forgone earnings by business, households, and government (for example, the costs of improving health) that have the effect, and often the purpose, of increasing future income. So also were the productivity gains attributable to better allocation of resources and to economies of scale. And all these missing elements were unmeasured and difficult to measure but still embedded in the Residual. It was clearly not a measure of the advance of applied knowledge alone.

With all that in mind, I called that big Residual "some sort of measure of ignorance" and thereby, all unwitting, coined a phrase that seemed to have a great deal of resonance. I must add that I am just that sort of contrary character who gets as much satisfaction from contemplating how much we do not know as he does from thinking about how much we

[2] Solow, "Technical Change."

do. Perhaps my fascination with what we do not know is a widely shared attribute of economists, if not of academics generally.

I hope so, because the old primitive Residual is really an understatement, a lower-bound measure of our ignorance about the sources of growth. By this I do not mean that beneath the growth-accounting sources lie deeper causes that govern the proximate causes, and below them still deeper ones, and so on. That goes without saying; that is why the elements of a growth account are called "proximate sources." My problem lies much closer to the surface. I mean that we know less about the proximate sources of growth than even a complete growth account—even one that makes good all the deficiencies of the first primitive accounts—may suggest. That is what I want to explain, and I want to use some history to illustrate my point.

Perhaps some of you are thinking "If we are already ignorant of 90 percent of the sources of per capita growth, how much worse can it be? Can it be worse than 100 percent?" In a sense it can. Remember Mr. Dooley: "It ain't what we don't know that bothers me so much; it's all the things we do know that ain't so." That is really the nub of the matter.

To set the scene properly I should point out that the growth accounts did not remain at the level of my early figures, or Solow's, or even the more detailed long-term accounts presented in John Kendrick's great book of 1961.[3] All these were primitive accounts, subject to all the deficiencies recited earlier. Edward Denison, however, lifted the accounts to a new level in a series of volumes beginning in 1962 and ending in 1985.[4]

At the same old crude level, Denison reached similar figures. Primitive TFP growth calculated from his tables was 83 percent of labor productivity growth from 1929 to 1982. But Denison found ingenious ways to measure the contributions of education and of other changes in labor quality. And he went further. He measured the gain from the shift of workers from low-productivity farming and from nonfarm self-employment to higher-productivity, nonfarm wage-and-salary jobs. And he estimated the gains from the enlargement of scale. So in the end he reached a final residual that accounted for not 80 percent of labor productivity growth, but only 44 percent.

Denison's work achieved at least two things. It showed that the elements that the early growth accounts had neglected were, indeed, important. And the apparent area of ignorance represented by the Residual seemed to have been sharply reduced. And yet, the unmeasured Residual, though smaller, remained far more important than any other single source; it was seemingly several times more important than

[3] Kendrick, *Productivity Trends.*

[4] Denison, *The Sources of Economic Growth* and *Trends in American Economic Growth.*

the growth of capital per worker, and it accounted for almost half of labor productivity growth. So the question remained: What is this Residual that still hogs such a large part of the show?

Denison returned an almost definite answer. He called this thinned-down Residual "the Advance of Knowledge Incorporated into Production and not elsewhere classified." He felt justified in giving his Residual this interpretation principally because he felt he had measured, or at least estimated, the more important alternative sources. So as I read Denison, the Residual, first and foremost, is supposed to represent the technological progress actually exploited or, as Denison says, "incorporated into production,"; the "not elsewhere classified" is a bow in the direction of possibly unidentified, but presumably minor, unmeasured sources and of the net of all the errors of estimate attaching to the measured sources.

There are, of course, other growth accounts, particularly those of Dale Jorgenson and his collaborators, in which the final residual is squeezed down still further.[5] They too, however, interpret their final residual as technological progress. It is this interpretation of the now-refined growth account residuals, as well as of the analogous numbers generated by regression studies based on the standard growth model, that has until very recently fixed itself in the minds of most economists who study growth in the contemporary world. By the same token, it is the interpretation that many historians of economic development also carry in their minds. So it is this interpretation that I want to discuss in the rest of my talk. I shall try to persuade you that this interpretation is one of the things we know that ain't so. My plan is to first tell you in general terms what I think the problem is and then go on to take up two historical developments that illustrate the trouble to which the common interpretation leads.

II

The trouble is really quite simple to state; once stated, I think it is hard to wave away.

Standard growth accounting is based on the notion that the several proximate sources of growth that it identifies operate independently of one another. The implication of this assumption is that the contributions attributable to each can be added up. And if the contribution of every substantial source other than technological progress has been estimated, whatever of growth is left over—that is, not accounted for by the sum of the measured sources—is the presumptive contribution of technological progress.

Once this is understood, the limitations of the standard growth

[5] Jorgenson, Gollop, and Fraumeni, *Productivity and U.S. Economic Growth*.

accounts and of many regression studies based on the same model stand out baldly. To reveal the growth contributions of the several proximate sources, the standard growth accounts may perhaps serve as a point of departure. They do provide a definite set of numbers whose derivation we understand. The model on which the numbers are based is, as they say, transparent. That said, however, the numbers based on the standard growth model become measurements from which to work away. After all, 80 years have already passed since Schumpeter's *Theory of Economic Development* argued that net capital accumulation would fall to zero in the absence of innovation. And surely there can be few economists who do not sense that there are two-way connections between technological progress, economies of scale, tangible capital accumulation, and human and other intangible capital accumulation.

We should have seen the contradiction between such interactive connections and the standard growth accounts at once. Indeed, not many years after the early accounts appeared, it was stated clearly by Richard Nelson, in a 1964 article that unfortunately is too little read to this day.[6] Nelson's main concern was with the embodiment or vintage question. Following an earlier study by Solow, he showed how an acceleration of the pace of capital accumulation, by reducing the age of the capital stock, speeds the rate at which embodied technical progress is incorporated into production. A standard growth account then yields a higher measure of total factor productivity.[7] But Nelson also discussed other forms of interaction between technological progress and both tangible and intangible capital, and he drew the right general moral:

> It is misleading to estimate the contribution of technological change by examining the residual after having estimated the contribution of education, shifting allocation of resources and so on. It also is misleading to assume that the contributions of the various factors leading to growth of total factor productivity are independent of the rate of growth of the capital stock.[8]

Paul David and I developed the same theme in papers published jointly in 1973 and separately in later years.[9] Our concern was the reverse of Nelson's. It had to do with the effect of technical progress—or rather, that of its character or bias—on the rate of capital accumulation. The basic proposition, going back to Hick's early work, is that capital-using technological progress, which increases the marginal productivity of capital more than that of labor, increases the

[6] Nelson, "Aggregate Production Functions."

[7] Solow, "Technical Progress" and "Investment." The embodiment effect is transient, though it may be important in periods of moderate length (10 to 15 years). The effect lasts, however, only so long as the age of capital declines. But if a new, higher rate of accumulation remains constant, the decline in age comes to a halt. A long-term speedup in the embodiment of technological progress requires a steadily accelerating rate of accumulation.

[8] Nelson, "Aggregate Production Functions," p. 596.

[9] Abramovitz and David, "Reinterpreting" and "Economic Growth in America"; David, "Invention and Accumulation"; and Abramovitz, "Manpower, Capital and Technology."

demand for capital relative to labor and so tends to raise the growth rate of the capital-labor ratio.

The lesson of interdependence has emerged in other ways as well, notably in Kenneth Arrow's hypothesis about learning by doing and in Nathan Rosenberg's learning by using.[10] These have to do with the contributions of experience with new methods to further advances, which is to say with the effects of past technical progress—if incorporated into production by investments in physical capital and marketing—on subsequent advance. The lesson of interaction, indeed, emerges in numerous historical and empirical studies of technical change, capital accumulation, R&D, education, and so on. And in the last few years the general theme of interdependence has become embedded in the new theories of economic growth. I shall mention these again later. So I think it may be of some interest if I recur to the theme of interdependence as it appears in two historical studies in which I had a hand.

III

I first encountered the problem in the course of work on long-term growth in the United States, on which Paul David and I embarked sometime in the mid-1960s. The projected book is unfinished and unpublished to this day, and I expect it will remain so. But parts of it have seen the light, and I start with one of them.

Our general plan for the book involved a comparison of the pace and character of growth in the nineteenth and twentieth centuries. The data we needed, at least for an account of aggregate growth in the twentieth century, were available in Kendrick, Denison, and later writers. Paul David himself undertook to put together the data we needed for the nineteenth century, beginning with his own original estimates of output and factor inputs up to 1840 and of labor inputs after that time.[11] He also used the output and capital accumulation estimates that had been made by Robert Gallman and his associates. These data permitted him to construct a growth account for the nineteenth century, the results of which were presented in the papers we published jointly in 1973 and in later papers by David alone.[12]

Table 1 uses these data to produce a primitive account of the sources of labor productivity growth across the two centuries and their major subdivisions. The figures in frame 1 are the David estimates for the nineteenth century, with revisions made since his 1977 paper. They are

[10] Arrow, "The Economic Implications of Learning by Doing"; and Rosenberg, "Learning by Using."

[11] David, "The Growth of Real Product."

[12] Abramovitz and David, "Reinterpreting" and "Economic Growth in America"; and David, "Invention and Accumulation."

TABLE 1
LABOR PRODUCTIVITY GROWTH AND ITS SOURCES: MEASURES ACROSS LONG PERIODS, 1800–1989

	Growth Rates (Percent per Year)			Contributions to Growth (Percentage Points per Year)		$\theta_c C/L$
	Y/L	C/L	θ_c	$\theta_c C/L$	TFP	Y/L
Frame 1						
1800–1855	0.42	0.63	0.34	0.22	0.20	0.52
1855–1890	1.06	1.54	0.45	0.70	0.36	0.66
1890–1927	2.01	1.34	0.46	0.62	1.40	0.31
Frame 2						
1890–1927	2.00	1.22	0.43	0.51	1.49	0.26
1929–1966	2.67	1.66	0.35	0.56	2.14	0.21
Frame 3						
1966–1989	1.40	1.75	0.35	0.62	0.78	0.46

Notes and Sources: Y/L is gross output per full-time equivalent labor hour; C/L is capital per full-time equivalent labor hour; θ_c is capital's share in gross income; $\theta_c C/L$ is the growth rate of C/L multiplied by capital's share; TFP is $Y/L - \theta_c C/L$; and $\theta_c C/L$ / Y/L is the share of capital intensity in the growth of labor productivity. See the Appendix for sources and procedures.

extended through the first quarter of the present century to provide an overlap with the figures in frame 2, which carries the analysis forward in estimates running from 1890 to 1966. These are drawn from John Kendrick's publications. Frame 3, finally, carries the account forward to 1989. This frame is, in effect, a rough extension of the Kendrick data based on the output data in the National Income and Product Accounts, the labor input figures of the Bureau of Labor Statistics (BLS), and the capital stock figures of the Office of Business Economics. Our Appendix provides a more detailed description of data sources, and a more extensive description and discussion of the data will accompany a chapter we are preparing for the forthcoming *Cambridge Economic History of the United States*.

In Table 1, the analysis of labor productivity growth covers relatively long periods. The purpose is to focus attention on growth measures freed as much as possible from the influences of reversible fluctuations (business cycles and "long swings"), political disturbances (particularly the major wars of the two centuries), and sheer measurement error.

Our nineteenth-century growth account as depicted in Table 1 holds another surprise: the sources of growth are quite at variance with the twentieth-century results. It finds that the growth of capital intensity was a much larger source of labor productivity growth in the nineteenth century than in the twentieth. In the first half of the nineteenth century, capital intensity on the average accounted for about one-half the growth of labor productivity; in the second half, up to 1890, it accounted for two-thirds. Capital intensity was also the apparent main source (75 percent) of the acceleration of labor productivity growth between the first and second halves of the century. And finally, the rates of total factor productivity growth were very low: 0.22 percent a year on the average in the century's first half, 0.36 percent in the second.

These results, on their face, present us with a dilemma. If we think that labor quality, rural-urban migration, and, still more, the scale economies from a rapidly growing aggregate output in an increasingly unified economy made a significant positive contribution, there is little room for technological progress itself. Or, if we feel we must preserve some space for technological progress—even for the minuscule apparent rate in the post–Civil War years—there is no room for education, better resource allocation, and scale.

What are we to make of all this? Was technological progress really so unimportant in the nineteenth century? Of course, the underlying data and the account that David and I based on them may be in error. But we do not think this is the main trouble: we believe there was a real difference between the two centuries. The difference, however, is probably not only in the pace of technological progress, though that may well have accelerated. It lies also in a difference in the character of technological advance. It is this, we think, that caused conventional capital accumulation to play such a large role in aggregate growth-accounting calculations for the nineteenth century and a much smaller role in the twentieth-century accounts. Unless one takes account of that difference, one cannot understand this and other major features of our economic development.

The particular difference in the character of technological progress that concerns us here will hardly sound strange; it is simply this. In the nineteenth century, technological progress was heavily biased in a *physical* capital-using direction. It could be incorporated into production only by the agency of a large expansion in physical capital per worker. And I attribute the dominant importance of nineteenth-century capital accumulation as a source of productivity growth in a standard growth account to this fact. In the twentieth century, however, the physical capital-using bias weakened; it may have disappeared altogether. The bias shifted in an intangible (human and knowledge) capital-using direction and produced the substantial contribution of education and of other intangible capital accumulation to this century's productivity growth, as this appears in the standard accounts. That said, it is important to distinguish raw labor power from labor augmented by education and the cumulative investment in the advance of knowledge. It may well be true that, as between raw labor and tangible capital, technological progress remains labor saving and capital using. The important shift has been within the two asset classes, tangible and intangible, that make up the stock of "capital," broadly conceived. Here the bias of technological advance in the present century worked to reduce the relative marginal productivity of tangible capital compared with that of intangible capital, much of the latter embodied in labor.[13]

How do we know? The quantitative evidence is not conclusive, but it is good enough to create at least a presumption in favor of the case. As regards the nineteenth-century bias toward physical capital, the key statistic is capital's share of income. Had the growth of the capital-labor ratio been caused by an increase of thrift alone, with technology and scale unchanged, the rate of return to capital would have declined relative to the return to labor. How fast the relative return to capital would have fallen per unit increase in the capital-labor ratio is what is measured by the elasticity of substitution. Successive studies for the present century confirm that the elasticity of substitution is much less than unity, and Paul David's estimates suggest that this was true of the last century as well.[14] But if the elasticity was less than unity, and if technological progress had been neutral, the national-income share of capital, the fast-growing factor, would have declined. And even unit elasticity would have left capital's income share unchanged. In the nineteenth century, however, capital's share rose substantially—by 19 percent during the first half and by another 19 percent during the second half, a 41 percent increase overall (see Table 2). It is this result that creates, as I say, at least a presumption that technology was advancing, not in the neutral fashion that the growth accounts assume, but in a capital-using fashion.[15]

A series of powerful forces, each manifestly connected with technological progress, worked in this direction. First, the great expansion in the total size of the domestic market and its increasingly unified character encouraged production on a larger scale and heavier investment in the application of steam power and in more specialized capital equipment. This, indeed, is the message of all the great economists of the nineteenth and early twentieth centuries, in a line stemming from Adam Smith, running through Böhm-Bawerk, Sidgwick, and Taussig, and stretching to Allyn Young. But these men did not see the economies

[13] The argument is set forth at greater length and with more precision in Abramovitz and David, "Economic Growth in America"; and David, "Invention and Accumulation."

[14] David and van de Klundert ("Biased Efficiency Growth") estimated a CES production function for the corporate sector, allowing for bias in technical change; they found an elasticity of substitution of 0.3 for 1900 to 1960. This follows earlier findings by Irving Kravis, Kenneth Arrow, and John Kendrick and R. Sato, whose publications are cited in Abramovitz and David, "Economic Growth in America." That paper also reported a very low elasticity of substitution for 1805 to 1907.

[15] The share figures in the David account are constructed from the side of tangible capital. They are the product of estimates of (1) the tangible reproducible capital stock and (2) a gross rate of return derived from interest indices for the real net rate plus depreciation rates that reflect the assumed service lives of structures and equipment that underlie Robert Gallman's estimates of capital accumulation, supplemented by an imputed net rate of return on the nonreproducible capital stock. This method implicitly assigns entrepreneurial earnings and the returns to human capital generally to labor.

of scale as a source of growth separate from technological progress itself. Rather, they thought of the advances they saw with their own eyes as an emerging technology that was both capital and scale intensive. It was increasingly specialized and roundabout in its organization; required increasing amounts of capital per worker to employ it; and therefore demanded larger-scale operations in its plants and in the aggregate to make the heavier use of capital economical.

There is more to the story of nineteenth-century technological bias. The unification of the national market was itself created by a most dramatic example of scale-intensive and capital-intensive technological progress, the steam railroads. Indeed, Simon Kuznets's estimates of national wealth tell us that by 1890, the cumulative investment in the structures and equipment of the railroads was greater than that in all nonagricultural industry put together.[16]

The rise of the cities, itself a requirement of scale-intensive production, was another capital-intensive development. It required heavy investment in structures for housing, trade, finance, government, and schools and, especially in its early stages, for streets, water supplies, sewage disposal, and urban transport.

Still another major development, not directly implied by the emergent scale-intensive and capital-intensive technology, nevertheless facilitated and strengthened its effect on the demand for physical capital. This was the expansion of the country into the prairies and plains between the Appalachians and the Rockies. Its most immediate effect was to sustain the rate of accumulation in land clearance and farm improvement. But because of the character of the western terrain, it enlarged the area over which the new mechanized farm technology could be applied.[17]

The westward movement had other, still broader, implications. The process of territorial expansion and settlement, by attracting immigrants, enlarged the effective aggregate scale of the economy. In this way and by redistributing the whole population, it increased the need for transport and raised the volume of railway traffic in both prospect and

[16] The reported value of the real estate improvements of the steam railroads in 1890 was 62 percent greater than the total in Manufacturing, Mining, and Other Industrial capital. It was 93 percent as large as in Manufacturing, Mining, Other Industrial, and Agriculture. See Kuznets, *National Product Since 1869*, table IV-2. Needless to say, there were also capital-saving inventions. Alex Field's ("The Magnetic Telegraph") firm-level studies of the effect of the magnetic telegraph on the management and capital structure of railroads and of the dressed meat, chilled fruits, and vegetable industries are cases in point. The direct capital-saving effect of the telegraph in these cases is clear enough. The telegraph made single-track rather than double-track operation of railroads possible, and it improved the control and therefore the efficiency of rolling stock at any given scale of the industry. By increasing the volume of traffic per mile of track, single-track operation raised the rate of return to railroad capital. It therefore encouraged the growth of an industry that was capital intensive relative to the rest of the economy. And the telegraph's macroeconomic effects through the meat-packing industry pose a similar question.

[17] Parker, "Productivity Growth in American Grain Farming."

fact. It therefore supported railroad construction, with its contribution to market unification. At the same time, the settlement of the West carried with it a demand for the urban development and urban construction needed not only to carry on a market-oriented economy but also to provide the distribution, transportation, communication, and finance required by a scale- and capital-intensive technology.

The story, as I have told it, depends on the particular definition of periods used in Table 1. In particular, it depends on our decision to treat the "long swing" running across the Civil War (1855 to 1871) and the following long swing (1871 to 1890) as a single long period. The first of these subperiods included not only the wartime years of physical destruction and disruption but also the years of severe inflation during the war and the subsequent postwar disinflation. It included military demobilization, the gradual resumption of peacetime activity, and the beginnings of Reconstruction in the South. The upshot was a sharp decline of labor productivity growth.

The second subperiod saw a sharp rebound from these disturbances. It included the incorporation into production of many physical projects that might have been carried out earlier if war had not intervened. In the same way, the second period saw a large increase in immigration, the resumption of westward expansion, the extension of the railway net, and the reorganization of corporate scale and structure to exploit the potential in scale-intensive and capital-intensive progress—all of which was, in part, the more concentrated unfolding of developments that had been delayed by war and financial disruption. So I believe that the combination of the two subperiods is a useful way to depict the long-term developments underlying the trend of economic growth.

My reason for combining the two long swings before the Civil War (1800 to 1835 and 1835 to 1855) is simply that the estimates lying behind our growth account in these years are subject to particularly large margins of error. It is likely, therefore, that the long-term trend is better revealed by measures that run across a long span of time. The result of these decisions is displayed in Table 1 and is the basis for the story I have told.

It is true, nonetheless, that the long-period estimates of Table 1 do not do justice to the fluctuations from which they emerge. Those who prefer to form their view from the shorter long swings would look instead to the figures in Table 2. One might then tell a somewhat different tale. One might then say that the years when the growth of capital intensity was the dominant contribution to labor productivity growth were the mid-century years, from 1835 to 1871. One might argue that a transition toward a development pattern resembling that of the present century began during the last quarter of the last century. And one would be supported in this view by the facts that in those years TFP became much

TABLE 2
LABOR PRODUCTIVITY GROWTH AND ITS SOURCES:
MEASURES ACROSS "LONG SWINGS," 1800–1989

	Growth Rates (Percent per Year)			Contributions to Growth (Percentage Points per Year)		$\theta_c C/L$
	Y/L	C/L	θ_c	$\theta_c C/L$	TFP	Y/L
Frame 1						
1800–1835	0.48	0.47	0.32	0.15	0.33	0.31
1835–1855	0.33	0.90	0.38	0.34	−0.01	1.03
1855–1871	0.14	1.15	0.46	0.53	−0.40	3.79
1871–1890	1.84	1.87	0.45	0.84	1.00	0.46
1890–1905	1.36	0.97	0.46	0.45	0.91	0.33
1905–1927	2.46	1.59	0.46	0.73	1.73	0.30
Frame 2						
1890–1905	1.93	1.26	0.44	0.55	1.38	0.28
1905–1927	2.05	1.19	0.40	0.48	1.57	0.23
1929–1948	2.04	0.70	0.38	0.27	1.79	0.13
1948–1966	3.33	2.68	0.32	0.86	2.51	0.26
Frame 3						
1948–1966	3.20	2.67	0.37	0.98	2.22	0.31
1966–1989	1.40	1.75	0.35	0.62	0.78	0.56

Notes and Sources: See Table 1.

larger and the contribution of capital-intensity growth sank to just under half of labor productivity growth.

I have no solid basis for choosing between this view and the one that emerged from Table 1. They both may hold a part of the truth. I would note, however, that capital intensity continued to rise throughout the latter part of the century. Between 1855 and 1871 and between 1871 and 1890 the rate of rise accelerated by 63 percent, yet capital's share of gross income did not decline. Even on the shorter-term view of late nineteenth-century development, therefore, one may continue to say that the century's last quarter was a time of strong scale-intensive and capital-using technological progress. It revealed itself, however, in both rapid capital accumulation and a large Residual growth.

I come back now to the main current of my argument. The implication of all I have just said is that in a growth-accounting framework the undoubtedly large contribution of technological progress to nineteenth-century growth is to be found not only in the infamous Residual, but also hidden behind the technology-dependent rubric of capital accumulation.

IV

When we turn to the present century, there is a dramatic change. The acceleration of labor productivity growth that had started in the nineteenth century continued through the first two-thirds of the present century. The apparent sources of that growth and of its acceleration, however, shifted radically. In the last century the major source of labor productivity growth, according to the standard model, had been the enlargement of the tangible capital stock in relation to labor input. Beginning in the first third of the present century (1890 to 1927), the share of labor productivity growth attributable to crude TFP reached 70 percent (or 75 percent, according to the Kendrick-based estimates of frame 2), whereas in the second third (1929 to 1966) it reached the 80 percent level familiar from standard growth accounts. In the same way, crude TFP—which in a growth-accounting sense had been the source of only a minor part of nineteenth-century labor productivity acceleration—came to be almost the sole source of the speedup of labor productivity growth in the present century.

I argued in the last section that, in the 1800s, a tangible capital-using bias of technological progress supported a high and rising rate of capital accumulation per worker hour. In the present century, the bias of technological advance shifted toward intangible capital. Technological change tended to raise the relative marginal productivity of capital in the form of the education and training of the labor force at all levels; in the form of practical knowledge acquired by deliberate investment of resources in research and development; and in other forms of intangible capital, such as the creation and support of corporate managerial structures and cultures and the development of product markets, which are the infrastructure of the economies of scale and scope.[18]

This shift was reflected in a change in the national income shares of "labor" and "capital." The rising nineteenth-century trend of "capital's" share gave way to a decline. Between the 1890s and the 1950s, according to Kendrick, "capital's" gross share declined by about a third. Since then, it has remained approximately constant.[19]

The sharp contrast between the nineteenth century's rising trend in capital's share and its decline and subsequent constancy in the present century is a warning that something important had happened to the factor bias of technological advance. The shift of trend, however, does not bear any simple interpretation. In particular, it is not evidence that the older tangible capital-using bias relative to raw labor has disappeared or even weakened. That is because the compensations of both "capital" and "labor" now contain elements of returns properly attributable to intangible capital. On one hand, intangible capital in the form of education and training is embodied in labor, and the return to that capital forms a large part of "labor's" earnings. On the other side,

[18] Chandler, *Scale and Scope*.

[19] The figures for capital's share in Table 1, which are averages over long periods and do not constitute a continuous series, give only a muted picture of the decline in capital's share. The figures in the text are based on a chain index constructed from Kendrick's estimates for the private domestic economy for the years from 1899/1909 to 1948/53 (Kendrick, *Productivity Trends*, table A-10, and *Postwar Productivity Trends*, table A-v). BLS data for the private business economy suggest that the share has remained approximately constant since the late fifties (Bureau of Labor Statistics, "Trends").

accumulations of intangible capital in the form of knowledge acquired by R&D and in the form of business capability acquired by investments in the corporate structures of management and administration and in market development yield significant parts of the compensation that our measures attribute to "capital." The quotation marks in this and earlier paragraphs are meant to draw attention to the degree that returns to intangible capital have invaded the measured compensation aggregates of both labor and capital.

Recognizing these complications, we cannot think of the decline of capital's share as even presumptive evidence of a weakening of the older tangible capital-using bias of technological progress relative to raw labor. What emerges, rather—but not from the existing share data alone—is that the income share attributable to education and training (that is, human capital) that adds to the share of "labor" compensation and the share attributable to other intangible accumulations that bolsters the income share of "capital" have both increased relative to that of raw labor and probably to that of tangible capital as well.[20]

The hypothesis to which these observations point is that the twentieth-century bias of technological progress has been *intangible* capital using, and that this new bias lies behind the great rise in the educational level of the labor force, the increasing scale of investment in R&D, and other important features of our economic development. I try to develop this theme in the remainder of this section. Because the resource costs of education are so very large, I concentrate on that subject, but other, related aspects of the matter appear as well.

The "education" I consider here is not the whole total of what might reasonably be considered under that heading. My discussion deals only with education in "regular" schools: public and private elementary and secondary schools and institutions for postsecondary education, the colleges and universities. It does not deal with on-the-job training or with the flow of information that reaches people of all ages through the press and over the air. These would be large fractions of an augmented total, but I cannot consider them here.

There is more. The costs of education, even in an augmented sense, do not exhaust our investment in "intangible" capital. There is also

[20] An argument for the reversal, together with supporting calculations by Paul A. David, appears in Abramovitz and David, "Economic Growth in America." A symptom of the change can be seen in the movement of capital-output ratios. Between 1800 and 1890, the ratio in the domestic economy increased by 48 percent; between 1890 and 1966, it declined in the private domestic economy by some 48 percent. (For the nineteenth century, see ibid., tables 1, 2. For the present century see Kendrick, *Productivity Trends*, tables A-15, A-22, and *Postwar Productivity Trends*, tables A-15, A-19.) With the pronounced retardation in growth after 1966, the ratio rose again. (Stock data: Commerce, *Survey*, Nov. 1987 and Sept. 1990; output data: BLS, Multifactor Productivity Measures, table 4.) See also David, "The Computer and the Dynamo," which presents further argument bearing on the reversal, with special attention to the capital-saving effects in the present century of the development and application of electric power.

research, both basic and applied; practical invention; and the costs of commercial development, including the expense of creating and maintaining markets for new products. The hypothesis that twentieth-century technological progress has been intangible capital-using applies, I believe, to these forms of capital as well, but I must leave them aside.

The broad facts about the rise of education in regular schools are familiar. In 1900, very few members of the labor force had even a high school education. By 1988, 85 percent of the labor force had at least a high school diploma, 45 percent had some postsecondary schooling, and 58 percent of those had four years of college or more.

As a consequence, the annual resource costs of schooling vaulted. Over the course of the century, the ratio of direct expenditures for regular schools at all levels plus the forgone earnings of students rose by a factor of six; from the equivalent of about 2 percent of GNP to more than 13 percent. (Compared with GNP augmented by forgone earnings, the rise would have been from some 2 percent to 12.7 percent.[21])

The upshot of these developments appears in Denison's growth accounts. After discounting the earnings differentials between workers with different levels of schooling by about 40 percent (to allow for the effect on earnings of IQ and other labor quality differences correlated with education), he attributes 27 percent of the growth of output per person employed to the rise of school levels between 1929 and 1982.[22]

To grasp the real meaning of this number, however, we have to know how the extension of education came about and what its connection may have been with the other proximate sources of growth. My hypothesis is that school levels rose only in part because the growth of national income per head made it easier for families to meet the private costs of schooling or to obtain finance if they could not. I believe, however, that if that had been the main force at work, the extension of education would have been far more limited than it actually was. Instead, in my view, a new human capital-using bias in the composition of output and in the industrial locus and nature of technological advance was an important part of the process. It increased the demand for workers with longer schooling.

My insistence on the importance of the human capital-using bias of these developments stems from a few simple considerations. First, when schooling was extended to the secondary and higher levels, the private costs of schooling to families became very heavy. Paul David

[21] My figures are based on a series representing the sum of direct expenditures by households, government, and nonprofit organizations and of the forgone earnings of students. From 1900 through 1940, the estimates are those of Schultz, "Capital Formation." For 1948 and 1962, they are based on estimates by myself and Paul David, following Schultz's sources and methods. I then extended the series to 1981 on the basis of the movement of figures in Eisner, *The Total Incomes System of Accounts*, tables 3, 5, 6.

[22] Denison, *Trends in American Economic Growth*, table 8-3.

and I have calculated that in both 1940 and 1960, the private costs per high school student (largely forgone earnings) were about 18 percent of the average family income; for college students, they were about 44 percent.

Second, though schooling is in part a consumption good and a contributor to social status, it is hard to believe that most families would willingly have borne such costs without the prospect of an attractive financial return. Nor would they have supported compulsory education laws and the higher taxes associated with enlarged public educational expenditures and subsidies if the financial return to their own private costs had been meager and if they did not sense that, in the context of twentieth-century technology and economic organization, schooling supported the growth of incomes generally.

Finally, in the absence of a substantial increase in the market demand for workers with longer schooling, the prospects for a generous financial return could not have been maintained. As the number of workers with more schooling rose relative to those with less, the earnings advantage of the former would, assuming constant relative demand, have declined. Financial returns to the costs of schooling would have fallen, and career prospects would have been dampened. I believe the result would have been a much slower expansion of education.

In the event, however, no such thing happened—at least over the half-century between 1940 and 1990. The earnings premium for education remained high and, over the last three decades, even increased.[23] The obvious implication is that the market demand for workers with longer education did, in fact, increase by enough to offset the decline in relative earnings that supply forces, responding to the rise in incomes and better access to finance, would otherwise have caused.

The stability, or even increase, in the earnings premium for education, however, is not in itself conclusive evidence that the relative marginal *social* product of schooling has been tending to rise. If employers view education as a signal that workers have other desirable qualities—high IQ, ambition, energy, good home background, and so on—the demand for schooled workers will rise with the extension of education regardless of its contribution to labor quality. When more job candidates have gone to school for 12 years, employers may feel they must have workers with 14 years of schooling to maintain the overall quality of their staffs. The private returns to education may be tending to increase, but not the social return. This is a possibility that makes the interpretation of the returns to education problematic; I will return to it.

Finally, the great expansion in the relative numbers of educated workers, together with the stable earnings premium, means that the

[23] This conclusion is based, from 1940 to 1962, on calculations by Abramovitz and David using figures from *Current Population Surveys*. For later years, figures are from Katz and Murphy, "Changes in Relative Wages"; and Levy and Murnane, "U.S. Earnings Levels."

income share attributable to human capital has increased rapidly. Subject to provisos about the possibility of a greater-than-unity elasticity of substitution and about the correlates of schooling, there is a strong presumption that technological progress and other developments associated with economic growth have had a human capital-using bias.

A full report on the sources of the human capital-using bias that I now postulate would be a long story. I must tell it here, as Schumpeter loved to say, "in desperate brevity."

An important indicator is the change in the occupational composition of the work force. Roughly speaking, we are dealing with a shift from blue-collar to white-collar jobs. Since 1950 the census has told us the average years of education that characterize a large number of occupational groups. Using only a grouping by broad occupational classes, Paul David and I calculated by how much the average level of schooling of the whole work force would have increased if the school levels of the different occupations had remained unchanged at 1950 levels and only the occupational composition had shifted. So calculated, the occupational shift factor accounted for just about half the actual rise in school level between 1900 and 1960.[24] I may add that a rough comparison of the occupational composition of the employed work force in 1988 with that in 1960 confirms what is palpably the case: the shift of workers toward education-intensive occupations has continued until recent years.[25]

Could this shift have been due to a relative cheapening of educated

[24] The hypothetical levels of education cited in the text were computed as weighted averages of the average years of school completed for each occupation and sex category in 1950, weighting by the numbers of persons in each occupation-sex category in given years. The numbers in each occupation group by sex were obtained for census years from 1900 to 1950 from Kaplan and Casey, *Occupational Trends in the U.S., 1900–1950*, table 2. The 1960 figures were drawn from *Statistical Abstract of the U.S., 1964*, table 308. The average years of school completed in 1950 was taken to be represented by the numbers in the labor force aged 35 to 44, classified by occupation and sex. These were obtained from U.S. Census, 1950, "Education," table 11. The actual years of education for 1900 to 1950—the denominator of the ratios cited in the text—are taken from Schultz, "Education and Economic Growth," chap. 3, table 2. For 1950 and 1960 they are based on figures from Denison, *Why Growth Rates Differ*, table F-9.

The ratios of changes in the hypothetical levels of schooling to the actual levels were (1900–1950) 0.51 and (1950–1960) 0.49. Such ratios can also be computed for 1920 to 1950 in which the denominators of the ratios—the change in the actual level of education—can be obtained from both Schultz ("Education and Economic Growth") and Denison (*The Residual Factor*, chap. 1). For these years, the ratios are lower and differ somewhat from each other: Schultz has 0.37, Denison, 0.346.

[25] I have estimated the occupational composition of employed civilian workers in 1988 (as they appear in the *Statistical Abstract, 1990*) with the census figures for 1960. I cannot be confident about the precision of the comparison, because I have not been able to put both sets of figures into utterly uniform classes. But the results for 11 broad groups are unmistakable. All the "White-collar" occupations, the most education-intensive ones, become more important. So do the "Service" occupations (except household workers, who are poorly schooled). All the other groups (which are less education intensive) become less important, except "Craftsmen, foremen, and precision workers," who are relatively well schooled. The rank correlation between groups' years of schooling in 1950 and their growth (in percentage points) between 1960 and 1988 is +.73.

workers? No. Since 1940, at any rate, when earnings data by level of education became available, there has been no such cheapening.[26]

The sources of the demand-side effect can be seen more clearly by decomposing the effect of the shift in occupational composition into a part associated with the changes in employment by industry and that connected with the change in occupations within industries. They have been about equally important in their effects on the overall level of schooling.

The change in employment by industry is familiar ground. It is essentially the shift from agriculture (where educational levels are low) to manufacturing, mining, and construction (where they are intermediate) to services (where they are relatively high). The shift was driven by three main forces. First was the rise in per capita incomes and its associated Engle effects on the structure of final consumer demand. Second was the relative growth of industries in the service sector whose functions are required for the exploitation of scale-intensive technological progress. I mean trade; communications; finance; the legal, accounting, and engineering professions; and much of government itself, both local and national. Third was the industry bias of technical advance, which raised the productivity of labor far more in agriculture and industry than in the service sector.[27]

The shift toward education-intensive occupations within industries was driven in turn by a compound of the second and third forces just mentioned. The expansion of service functions for business that scale-intensive technological progress demanded took place within industrial and agricultural firms as well as in the service sector proper. Large firms developed an elaborate managerial and administrative hierarchy, complete with engineering, accounting, legal, financial, and research components; and they integrated forward into trade, merchandising, and advertising and into the provision of service and maintenance for customers.[28] And the same laggard productivity growth characteristics of these service occupations made their relative employment growth greater than their relative output growth. An important generalization about economic growth, therefore, is that the scale-intensive technological progress that made productivity growth in the basic agricultural

[26] There is a qualification. Between 1970 and 1980, when a great wave of college-educated young people—the baby boomers of the 1950s—entered the labor market, the earnings premiums associated with a college education declined. (Freeman, *The Overeducated American*; and Welch, "The Effects of Cohort Size on Earnings.") All this was reversed in the 1980s, however, when the new cohort of college graduates was smaller (Levy and Murnane, "U.S. Earnings Levels," table 7).

[27] Productivity figures do, indeed, understate the productivity increase in the service sector, especially as output growth in some branches is measured by the growth of labor input. If one could correct this deficiency, the industry bias of productivity growth would be less marked, but output growth in services, by the same token, would be more rapid. The Engle effect would appear to be stronger, and so would the output growth of business services.

[28] See Chandler, *Scale and Scope*.

and industrial occupations so rapid was gained only by an expansion of employment in education-intensive occupations that, considered in isolation, exhibited much slower productivity growth.[29]

So much for the effect of occupational shift. A very large part of the story, however, has to do with the rise of educational levels within occupations. Here I have only a few suggestions. It is true that the nature of many jobs has not changed substantially. Yet, as the fractions of all workers with secondary or postsecondary education increased, entry into many of those jobs became conditional on higher levels of schooling—not because workers' skills had been raised by training at school, but because time at school or the possession of a diploma came to be used as a crude indicator of intelligence, industry, or other personal characteristics sought by employers. This is the so-called screening function of education and school credentials. To the extent that this operates, the social return to additional schooling is lower than the private; and the stability, or even rise, in the private return may mask a decline in the real social return.[30] In any event, the presumptive increase in private demand exaggerates the increase in social demand. I cannot say how important this consideration may have been. I can say, however, that there are limits to the argument. There was a real social basis for the increasing demand for schooling.

First, the screening argument does not apply to the large part of the extension of education that is associated with the shift of workers toward education-intensive occupations. Second, the screening function served by school credentials is itself of social value. More important, the nature of many jobs has changed without a corresponding change in occupational titles. The machines that workers use have become more complex and sophisticated and require more school skills and, in some cases, even some theoretical knowledge to operate and maintain them. The enlargement of the scale of firms produces a generalized demand for paperwork. Not only clerks but machine operators as well keep records and file reports. And this is all the more true at higher occupational levels, in which administration has necessarily assumed the form of consultation and decision on the basis of records, reports, analyses, committees, and impersonal as well as interpersonal communication. So schooling counts for more.

The greater frequency of change in the techniques and organization of production and distribution has progressively increased the need for personnel who can function as problem solvers and for a work force

[29] One implication of this proposition is that the enlarged costs of management, administration, professional services, and other education-intensive functions have paid for themselves, at least in part, by larger "throughput," which is in itself tangible capital saving. It helps justify the use of more capital per unit of labor input by raising the output intensity with which capital is employed (see Field, "Modern Business Enterprise").

[30] Berg, *Education and Jobs*.

that, in general, can adapt easily and quickly to changed routines. Both basic and more advanced schooling appears to make people capable of learning new routines more easily. These capabilities contribute to their private as well as social marginal productivity. Similar capabilities, enlarged by education, enable people as consumers to accept and absorb new products and services. This supports the rapid rate of technical progress and so, by indirection, the demand for schooled people. In this respect, the social marginal product of schooling is greater than the private.

Technological advances in medicine, including in public hygiene and nutrition, have added to the life span and reduced morbidity. And as the expected duration of effective working life increases, any given educational earnings premium translates into a higher expected lifetime rate of return. And this is all the more important because the returns to advanced schooling grow larger as its possessors grow older. The large premiums are gained relatively late in a working career.

Still another kind of technological change increased the demand for schooling. The curricula of schools at all levels have come to include more that is of direct vocational and commercial interest and use. In part schools and colleges were attempting thereby to satisfy a latent public demand, but it was also a consequence of the growth of knowledge and of the increasing degree to which industry has come to depend on applied science. So new subjects were established in university curricula, such as forestry, mining, public health, business administration, and education itself. And older curricula like medicine, law, and engineering—not to mention economics and economic history—became more rigorous and complex and, therefore, longer.[31]

V

So now it is time to come to a conclusion—or, at least, to an end. My general theme has been the interdependence of what we have come to call the "proximate sources" of growth. The historical examples I have offered, however, trace only one line of dependence, the dependence of both tangible and human capital accumulation on the pace and character of technological progress. I have neglected the connection between the prospective returns held out by the emerging states of science and technology and the great upsurge of intangible capital accumulation in the form of investment in R&D. There is a similar story to tell there. My examples support the view that we cannot gain a truly meaningful idea

[31] A recent historical study shows how late nineteenth-century investment in the scientific characterization of geological formations and the training of mining engineers to apply that new knowledge enlarged this country's endowment of potentially valuable mineral resources in ways that a new mineral-using technology could exploit productively. (David and Wright, "Resource Abundance and American Economic Leadership.")

of the effects of technological progress by first estimating the contributions of tangible and intangible capital accumulation as well as those of the other (apparently measurable) sources, and then seeing what is left over.

In truth, however, the interdependence of the proximate sources runs both ways. Although technological progress (actual and prospective) supports capital accumulation, both tangible and intangible capital accumulation also influence technological progress—in the shorter term through the embodiment process, in the long term by investment in R&D, through learning by doing and by using, and by the contribution of education to the absorption of new products and processes and through other channels. My discussion has had to leave all that aside. It is these lines of influence, however, *from* capital accumulation *to* technological progress, that are the heart of the "new growth theories" associated with Robert Lucas, Paul Romer, and their associates. Their almost total concentration on that line of influence seems to me to be overdone. It calls for qualification. The nineteenth-century tangible capital-using bias of technological progress and the present century's intangible capital-using bias were not the consequence—certainly not the exclusive consequence—of capital accumulation. It is doubtless true that the terms on which capital is supplied has some, perhaps much, influence on the direction as well as the pace of technological progress. The bias of technological advance may in part be so induced. But it may also derive from an evolution of scientific and technological knowledge quite unrelated to the terms of factor supply. There is still far too much that is poorly understood about the influence of relative factor costs, about the evolution of science and technology, and about the political and economic institutions and modes of organization on which the discovery or acquisition of new knowledge depend. We cannot reduce the actual advance of technology, its direction as well as its pace, to a stable function of the supply of savings and the costs of finance alone. Capital accumulation and the advance of knowledge arising in part from independent or poorly understood sources work together to produce joint effects. And that is the moral of this sermon.

So I come back to the beginning of my talk. For those of us who take a perverse satisfaction in contemplating our ignorance, I offer a happy ending. We know all too little about the interactions among our infamous "proximate causes." They constitute an area of ignorance even larger than the old primitive Residual.

There is one thing more. When I characterized that old Residual as "some sort of measure of our ignorance," I coupled it with another characterization: "some sort of indication of where we need to concentrate our attention." Of course, the same applies in the present case. To which I would add this for the benefit of an audience of historians: what we cannot reduce to stable and well-understood functions of endogenous factors remains in the realm of history. And historical studies of technology and other aspects of growth are full of examples of a proper appreciation of the joint and interdependent action of the main sources of growth. I expect such historical studies to make major contributions in the future. And that is as close as I can come to ending on a properly inspirational note.

Appendix

DATA SOURCES, FRAME 1

The estimates presented in frame 1 rest on the Abramovitz-David figures first published in 1973 and, after minor revision, in David, "Invention and Accumulation." Those estimates, which in the earlier papers referred to the Domestic Economy, are now revised to refer to the Private Domestic Economy; and other revisions have been made since then as well. The new estimates draw on figures David and I have prepared for our joint contribution to the forthcoming *Cambridge Economic History of the United States*, which will include a more extensive description of the estimates than appears here. The following paragraphs provide a compressed description of the estimates underlying the growth account in Tables 1 and 2.

Real Gross Private Domestic Product (RGPDP): Y

The growth rates were computed from an underlying constant dollar series, expressed alternatively in 1860 dollars or 1960 dollars, which was formed from chained Laspeyres output indices, using 1840 (census year) price weights for the period 1800/40, 1860 (census year) price weights for 1840/1909, and 1929 price weights for 1909/29.

RGPDP was estimated by subtracting estimates of real government product (in corresponding constant prices) from estimates of real gross domestic product (RGDP). The latter series consists of the 1977 vintage Abramovitz-David estimates, on a comprehensive scope (so-called Variant II) basis, which includes the estimated value of home manufactures and improvements made to farmland. The latter series are those that underlie the tables in David, "Invention and Accumulation." They differ notably in the 1800 to 1834/36 interval from the estimates reported for real gross domestic product in Abramovitz and David, "Reinterpreting," due to revisions in the method of constructing estimates for the pre-1840 era—principally the substitution of estimates of labor inputs on a full-time equivalent man-hours basis for those on a gainful worker basis.

Estimates of real government product, expressed in 1960 constant dollars, were derived from a chained Laspeyres index. The constituent series for the period 1890/1929, in 1929 prices, is from Kendrick, *Productivity Trends in the United States*, table A-III, col. 5 ("Government Purchases"). These were extrapolated from 1890 to 1840 on estimates of constant dollar government expenditures, in 1860 (census year) prices. The latter series was derived by deflating the sum of current dollar estimated federal government expenditures and expenditures on public education, from Davis et al., *American Economic Growth*, tables 17.1, 17.2. The deflator used for this was the David-Solar CPI from table 5.A in "A Bicentenary Contribution." The resulting series was extrapolated from 1840 to 1800 on estimates of constant dollar gross purchases of the federal government, derived by employing the David-Solar CPI to deflate current

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dollar estimates from Trescott, "The U.S. Government and National Income," table 2, p. 339.

Full-Time Equivalent Man-hours in Private Domestic Economy: L

Estimates of FTE man-hours of labor input have been derived by subtracting estimated man-hour employment estimates for government, military, and education sectors from the FTE man-hours estimates underlying the tables in Abramovitz and David, "Reinterpreting." The latter estimates were obtained from estimates of the distribution of the gainfully occupied work force among ten one-digit standard industrial classification sectors, assuming that constant within-sector ratios between FTE man-hours and gainful workers were maintained between 1800 and 1900. The level of the resulting series for the total national (also domestic) economy was linked in 1900 to the FTE man-hours estimates in Kendrick, *Productivity Trends*, table A-x.

The underlying Abramovitz-David sectoral estimates of the gainful work force, which were built on the earlier estimates of Lebergott and of Gallman and Weiss contain adjustments designed to reduce the noncomparability between census observations up to 1860 and those after 1860. The adjustments were needed due to the U.S. convention of not including free married women as part of the farm work force, which resulted in the complete elimination of female former slaves from the agricultural work force counts. For dates from 1869 onward, estimates of black female workers on farms were added to the agricultural work force figures. For the period before 1840 only three major occupational sectors could be distinguished on a gainful worker basis: farm, nonfarm commodity production (with estimated internal weights for forestry and fishing, mining, construction, and manufacturing), and noncommodity production. The man-hours per gainful worker coefficients for those aggregates in 1840 were applied in extrapolating the estimates backward to 1800. To obtain man-hours estimates for the private economy for the pre-1840 period, the difference in the national and private economy man-hours trend over the interval 1840/60 was assumed to have applied in the entire 1800/60 period.

Real Reproducible and Nonreproducible Capital Stock Index: C

Indices of the constant dollar net stock of reproducible tangible capital (inclusive of improvements to farmland), K, and of the constant dollar nonreproducible stock (unimproved farmland), R, were aggregated to form a weighted geometric index of real capital inputs for each trend period. The factor share weights used were the imputed returns to each type of property as a fraction of the gross income from all (domestic) tangible assets. The weights, and the per annum growth rates of K and R, respectively, are those given in Abramovitz and David, "Reinterpreting," table 2, p. 431. The growth rate of the resulting aggregate index is equivalent to a Divisia index, as the weights change each subperiod. The entries for C in Table 1 were obtained by the following operation: $1 + C = antiln[\theta_R \{ln(1 + R)\} \theta_K \{ln(1 + K)\}]$; they differ slightly from those shown for the same variable in Abramovitz and David, "Reinterpreting," where the percentage growth rates were erroneously directly aggregated using the indicated weights.

Gross Income Share of Tangible Property: θ_c

Average gross factor shares for reproducible tangible capital inclusive of farm improvements (net stock basis), K, and for land exclusive of farm improvements (R), from Abramovitz and David, "Reinterpreting," table 2, were summed to obtain the gross share of tangible property in gross domestic income. Trend period averages were computed as geometric means of gross factor share estimates for the terminal dates.

The estimates cited here were made by imputation, using average real net rates of return and depreciation rates for private reproducible assets, and real net rates of return on private nonreproducible assets, multiplying each by the corresponding ratio of the real net stock of capital to gross *private* domestic income. They are, therefore, entirely consistent with the GPDP basis for the computations reported in Tables 1 and 2.

The estimates for the nineteenth century described here are clearly not the only treatments of the available evidence that deserve consideration. Paul David and I intend to discuss the alternatives that have been proposed, particularly those for the first half of the century, in our contribution to the forthcoming *Cambridge Economic History of the United States*.

DATA SOURCES, FRAME 2

1890–1927

Gross output per hour and total worker hours are from Kendrick, *Productivity Trends*, table A-xxii; capital stock, net of depreciation, is from table A-xxii, supplement. Capital's gross factor shares were obtained by adding 9 percentage points to capital's net share from table A-10 of the same source. This allowance for depreciation is the difference between capital's gross and net share for 1929/37 from Kendrick, *Postwar Productivity*, table A-v.

1929/48 and 1948/66

Gross output per hour and aggregate hours are from Kendrick, *Postwar Productivity*, table A-19; gross capital stock is from table A-16, col. 6. Capital's share in gross output is from table A-v in the same source. For 1929/48, the figure is a weighted average of the figure for 1929/37 and 1937/48. For 1948/66, the figure is a weighted average of Kendrick's figures for 1948/53 and 1958.

DATA SOURCES, FRAME 3

Output in the private domestic economy is obtained from figures for GNP from *Economic Report of the President, Feb. 1991*, table B-2, less government products and net factor income from abroad from national income and product tables in the July issues of the *Survey of Current Business*. Hours worked are from the BLS in *Economic Report of the President*, table B-46. This assumes that the growth rate of labor hours in the private domestic economy is the same as that in the private domestic business economy. The growth rate of the capital stock is calculated from OBE estimates of the constant cost (1982 dollars) of private fixed gross capital stock (residential plus nonresidential). Inventories are not included. (From "Fixed Reproducible Capital Wealth in the United States," *Survey of Current Business*, Nov. 1987, and later issues of the *Survey*.) Capital's share of gross income was calculated as the average of annual estimates made by Bureau of Labor Statistics, "Trends," table 6, for 1948 to 1979 and by extending the average for 1973/79 to the following years. The BLS estimates refer to the private domestic business economy.

PERIODS

The periods for which measures were originally calculated are those shown in Table 2. They are meant to be measures between comparable phases of successive "long swings." The earliest date, 1800, is simply the initial year of our data. In the rest of frame 1, with one exception, growth rates were calculated from the average standing of each series during the five years immediately preceding the onset of major business depressions. Thus "1855" refers to the midyear of the five-year period from 1853 to 1857, 1871 stands for 1869 to 1873, and so on. 1835, however, represents a three-year period, from 1834 to 1836. The same system was followed in frame 2 through 1927 (1925 to 1929). Thereafter, growth rates are calculated between single years that lie on boundaries between major changes in macroeconomic conditions. Thus 1929 was the year preceding the protracted period dominated by depression and war; 1948 marks the end of postwar reconversion and the beginning of the postwar growth boom; 1966 immediately preceded the long slowdown of productivity growth and of business and financial disturbance associated with successive energy shocks, stagflation, disinflation, and the fiscal and monetary stimulation of the Reagan years. The terminal date of the tables, 1989, is simply the peak year of the business cycle preceding the recent cyclical contraction.

The growth rates over the "long swings" so distinguished in Table 2 were then combined to form the longer periods of Table 1. The rationale behind these combinations as they apply to the nineteenth century is set forth in the text. In the present century, the major decision was that of combining the two subperiods 1929/48 and 1948/66. The justification is analogous to that for combining 1855/71 and 1871/90. The Great Depression brought a serious decline of new investment and the postponement of much innovation in product and process technology. The major war that followed had the same effect on civilian investment and innovation. It is, therefore, reasonable to suppose that the rapid rate of capital accumulation and the record growth rate of TFP during the postwar growth boom that followed represented, in part, the release of a backlogged potential for investment and innovation. A better view of long-term growth trends, therefore, should emerge from the experience of the longer span running from 1929 to 1966.

The long period running from 1890 to 1927 is the era of electrification. It combines an early subperiod (1890 to 1905), when the potentials of electric power and internal combustion were only being slowly realized and applied, with a later subperiod (1905 to 1927), when American manufacturing was being rapidly electrified (David, "The Computer and the Dynamo") and when gasoline-powered tractors, automobiles, and trucks came into their own. Finally, there are the years since 1966, the years of productivity slowdown. It remains to be seen whether these years were also a time of backlogged potential, like 1929 to 1948, to be followed again by a sustained period of rapid realization.

REFERENCES

Abramovitz, Moses, "Resource and Output Trends in the United States Since 1870," *American Economics Review*, 46 (May 1956), pp. 5–23.

Abramovitz, Moses, "Manpower, Capital and Technology," in Ivar Berg, ed., *Human Resources and Economic Growth* (New York, 1972), pp. 50–70.

Abramovitz, Moses, and Paul A. David, "Reinterpreting American Economic Growth: Parables and Realities," *American Economic Review*, 63 (May 1973), pp. 428–37.

Abramovitz, Moses, and Paul A. David, "Economic Growth in America: Historical Parables and Realities," *De Economist*, 121:3 (1973), pp. 251–72.

Arrow, Kenneth, "The Economic Implications of Learning by Doing," *Review of Economic Studies*, 29 (June 1962), pp. 155–73.

Berg, Ivar, *Education and Jobs: The Great Training Robbery* (New York, 1970).

Chandler, Alfred D., Jr., *Scale and Scope: The Dynamics of Industrial Capitalism* (Cambridge, MA, 1990).
David, Paul A., "The Growth of Real Product in the United States Before 1840: New Evidence, Controlled Conjectures," this JOURNAL, 27 (June 1967), pp. 151–97.
David, Paul A., "Invention and Accumulation in America's Economic Growth: A Nineteenth Century Parable," in Karl Brunner and Allan H. Meltzer, eds., *International Organization, National Policies and Economic Development* (Amsterdam, 1977), pp. 179–228.
David, Paul A., "The Computer and the Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror," in OECD, *Technology and Productivity: The Challenge for Economic Policy* (Paris, 1991), pp. 315–48.
David, Paul A., and Peter Solar, "A Bicentenary Contribution to the History of the Cost of Living in America," in Paul Uselding, ed., *Research in Economic History*, Vol. 2 (Greenwich, CT, 1977), pp. 1–80.
David, Paul A., and Theo van de Klundert, "Biased Efficiency Growth and Capital-Labor Substitution in the United States, 1899–1960," *American Economic Review*, 55 (June 1965), pp. 357–94.
David, Paul A., and Gavin Wright, "Resource Abundance and American Economic Leadership" (Center for Economic Policy Research Paper No. 267, Stanford University, Aug. 1992).
Davis, Lance E., et al., *American Economic Growth: An Economist's History of the United States* (New York, 1972).
Denison, Edward F., *The Sources of Economic Growth in the United States and the Alternatives Before US* (New York, 1962).
Denison, Edward F., "Measuring the Contributions of Education (and the Residual) to Economic Growth," in OECD, *The Residual Factor in Economic Growth* (Paris, 1965), pp. 13–55.
Denison, Edward F., *Why Growth Rates Differ* (Washington, DC, 1967).
Denison, Edward F., *Trends in American Economic Growth* (Washington, DC, 1985).
Economic Report of the President (Washington, DC, annual).
Eisner, Robert, *The Total Incomes System of Accounts* (Chicago, 1989).
Field, Alexander J., "Modern Business Enterprise as a Capital-Saving Innovation," this JOURNAL, 47 (June 1987), pp. 473–85.
Field, Alexander J., "The Magnetic Telegraph, Price and Quantity Data, and the New Management of Capital," this JOURNAL, 52 (June 1992), pp. 401–13.
Freeman, Richard B., *The Overeducated American* (New York, 1976).
Gallman, Robert E., and Thomas Weiss, "The Service Industries in the Nineteenth Century," in Victor R. Fuchs, ed., *Production and Productivity in the Service Industries* (New York, 1969), pp. 287–352.
Jorgenson, Dale W., F. M. Gollop, and B. M. Fraumeni, *Productivity and U.S. Economic Growth* (Cambridge, MA, 1987).
Kaplan, David L., and M. Claire Casey, *Occupational Trends in the U.S., 1900–1950* (Bureau of the Census Working Paper No. 3, Washington, DC, 1958).
Katz, Lawrence F., and Kevin M. Murphy, "Changes in Relative Wages, 1963–1987: Supply and Demand Factors," *Quarterly Journal of Economics*, 107 (Feb. 1992), pp. 35–78.
Kendrick, John W., *Productivity Trends in the United States* (Princeton, 1961).
Kendrick, John W., *Postwar Productivity Trends in the United States, 1948–1969* (New York, 1973).
Kuznets, Simon S., *National Product Since 1869* (New York, 1946).
Lebergott, Stanley, *Manpower in Economic Growth: The American Record Since 1800* (New York, 1964).
Levy, Frank, and Richard J. Murnane, "U.S. Earnings Levels and Earnings Inequality:

A Review of Recent Trends and Proposed Explanations," *Journal of Economic Literature*, 30 (Sept. 1992), pp. 1333–81.
Nelson, Richard R., "Aggregate Production Functions and Medium Range Growth Projections," *American Economic Review*, 54 (Sept. 1964), pp. 575–606.
Parker, William N., "Productivity Growth in American Grain Farming: An Analysis of Its Nineteenth Century Sources," in R. W. Fogel and Stanley Engerman, eds., *The Reinterpretation of American Economic History* (New York, 1972), pp. 175–86.
Rosenberg, Nathan, "Learning by Using," in Nathan Rosenberg, ed., *Inside the Black Box: Technology and Economics* (Cambridge and New York, 1982), pp. 120–40.
Schultz, Theodore W., "Capital Formation by Education," *Journal of Political Economy*, 68 (Dec. 1960), pp. 571–83.
Schultz, Theodore W., "Education and Economic Growth," in Nelson B. Henry, ed., *Social Forces Influencing American Education* (Chicago, 1961), pp. 46–88.
Solow, Robert, "Technical Change and the Aggregate Production Function," *Review of Economic Statistics*, 47 (Aug. 1957), pp. 312–20.
Solow, Robert M., "Investment and Technical Progress," in Kenneth J. Arrow, Samuel Karlin, and Patrick Suppes, eds., *Mathematical Methods in the Social Sciences, 1959* (Stanford, 1960), pp. 89–104.
Solow, Robert M., "Technical Progress, Capital Formation, and Economic Growth," *American Economic Review Proceedings*, 52 (May 1962), pp. 76–86.
Trescott, Paul B., "The U.S. Government and National Income, 1790–1860," in William N. Parker, ed., *Trends in the American Economy in the Nineteenth Century* (Princeton, 1960), pp. 337–61.
U.S. Bureau of the Census, *Census of the Population, 1950*, "Education" (Washington, DC, 1953).
U.S. Bureau of Labor Statistics, "Trends in Multifactor Productivity, 1948–81, Bulletin No. 2178 (Washington, DC, Sept. 1983).
U.S. Department of Commerce, *Survey of Current Business* (Washington, DC, monthly).
Welch, Finis, "The Effect of Cohort Size on Earnings: The Baby-Boom Babies' Financial Bust," *Journal of Political Economy*, 87 (Oct. 1979), pp. 865–99.

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