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Two Centuries of American Macroeconomic Growth From Exploitation of Resource Abundance to Knowledge-Driven Development

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ABSTRACT

This monograph is concerned with the nature of the process of macroeconomic growth that has characterized the U. S. experience, and manifested itself in the changing pace and sources of the continuing rise real output per capita over the course of the past two hundred years. A key observation that emerges from the long-term quantitative economic record is that the proximate sources of increases in real GDP per head in the century between 1889 and 1999 were quite different from those which obtained during the first hundred years of American national experience. Baldly put, the economy's ascent to a position of twentieth-century global industrial leadership entailed a transition from growth based upon the interdependent development and extensive exploitation of its natural resources and the substitution of tangible capital for labor, towards the maintenance of a productivity leadership through rising rates of intangible investment in the formation and exploitation of technological and organizational knowledge.

ACKNOWLEDGEMENTS AND EXPLANATORY NOTE

A first draft of this essay was completed in August 1999, concurrently with the appearance of the authors' paper entitled "American Macroeconomic Growth in the Era of Knowledge-Based Progress: The Long-Run Perspective," *SIEPR Discussion Paper 99-03*, Stanford Institute for Economic Policy Research, Stanford University. The latter, a somewhat shortened form of the original, advertised itself as a chapter contributed to Volume 3 of *The Cambridge Economic History of the United States*, S. L. Engerman and R. E. Gallman, then still forthcoming from Cambridge University Press.

In the event, however, the text that emerged from the publisher as Chapter 1 in *CEHUS* , Vol.3 [Cambridge and New York, C.U.P., 2000 (pp. 1-92)], was a radical abridgement of the original essay: omitted were the detailed statistical tables underlying the summary tables in Part One of the text, virtually all of the quantitative material and analysis supporting the narrative interpretion presented in Part Two, the Endnotes to the text (which in the original equalled in lenght of the material comprising Part One), and serveral Technical Appendices pertaining to productivity measurement issues that bear immediately upon the interpretative arguments developed in this work.

The authors therefore have felt a two-fold call: to make a more polished version of the complete work available for wider consultation by distributing it in electronic form, and to carry the story forward into the 1990s. In doing so, we also wish to acknowledge our gratitude for the helpful comments that Robert Gallman offered on the preliminary drafts, and to take this opportunity – not afforded by the published version – to join with many others in mourning the loss that his premature death has meant for the field of American economic history. We are happy to reiterate here our thanks to our friends and colleagues Charles Feinstein and Gavin Wright for undertaking to read and comment on the whole of the August 1999 manuscript; and to Ralph Landau, who generously lent his encouragement and support to the Matrix of American Economic Growth Project at SIEPR, under the auspices of which the present manuscript was completed.

[*Postscript by P.A.D., March 2001*: Very soon after the revision of the August 1999 draft had been completed, Moses Abramovitz died, on 1 December 2001 within a month of reaching his 89th birthday. The sequelae to that sad event postponned my work on the incorporation of material on the boom of the 1990s, which he and I had been discussing during the preceding months. Thus, the release of the present version in the SIEPR Discussion Paper Series was delayed still further, and, alas, I must bear total responsibility for the form in which section 4 of Part Two appears. Unlike the rest of the manuscript, the text there could not benefit from Abramovitz's close, critical vetting.]

TWO CENTURIES OF AMERICAN MACROECONOMIC GROWTH
From the Exploitation of Resource Abundance to Knowledge-Driven Development

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Prologue: Focus, Method and Structure of the Work

The focus of this extended essay is the nature of the macroeconomic growth process that has characterized the United States experience, and manifested itself in the changing pace and sources of the rise of real output per capita in U.S. economy during the past two hundred years. Although our main interest here lies with the dynamics of the twentieth-century economy, we believe that its major characteristics and the nature of the underlying forces at work are most clearly seen in comparisons between the century just past and the one that came before.

A key observation that emerges from the long-term quantitative economic record is that the proximate sources of increases in real gross domestic product per capita in the century between 1889 and 1989 were quite different from those which obtained during the first one hundred years of the American national experience. Baldly put, the national economy moved from an extensive to an increasingly intensive mode of growth, and its development at the intensive margin has become more and more dependent upon the acquisition and exploitation of technological and organizational knowledge.

Our first objective, therefore, must be to assemble and describe the components of the U.S. macroeconomic record in some quantitative detail, in a manner that exposes the nature and dimensions of the contrast between the nineteenth and twentieth centuries. We approach this task within the well-established framework of "growth accounting". This enables us to show the secular acceleration that occurred in the growth rate of total factor productivity, which is the weighted average of the productivities of capital and labor, and the growth in the importance of total factor productivity as a source of labor productivity and per capita output increases. Further, by taking account of changes in the quality of the productive inputs, we arrive at "refined" measures of total factor productivity growth which highlight two contrasts between the eras preceding and following the transitional decades, 1879-1909.

The first of these is the enlargement of that element in the long-term growth rate of labor productivity that remains unexplained by the factor inputs we can measure and thus is associated, but not identical, with advances in technological knowledge – including in the latter the knowledge permitting realization of economies of large scale production. The second major contrast between the nineteenth and twentieth centuries is the diminished relative importance of conventional tangible capital accumulation in the twentieth century and the rising role of intangible capital formation through investments in education and training, on the one hand, and the organized investment in research and development (R&D) on the other.

After the turn into the twentieth century, the substitution of fixed capital for labor was governed by conflicting forces. It was strengthened for many decades by slower growth of labor supply and a concomitant tendency for wages to rise more substantially than they would otherwise have done. These developments stemmed in part from demographic changes, including the immigration restrictions following World War I, in part from the downward trend in hours of work and in part from the lengthening years of education. At the same time there were also important new opportunities to reduce costs by developing methods of intensifying the utilization of fixed facilities.

This was a strategy that was first implemented in the late nineteenth and early twentieth centuries by consolidation of railroads, by the technological innovations designed to increase train-speeds and power utilization, and by the growth of continuous process industries, notably petroleum extraction, transport, and refining, and its extension to petrochemicals. Its roots also can be found, as Alfred Chandler (1977, 1990: Ch.1) has pointed out, in the high throughput manufacturing regimes that appeared after 1870 when production and direct-selling by manufacturers were extended to serve increasingly wide markets.

The challenges of operating greatly enlarged technological and commercial systems on a continental scale contributed to the rising demand for a more formally educated breed of managers, as well as workers with higher levels of literacy and numeracy. They also called forth new control technologies, which played a role in initiating the pioneering U.S. advances in communications and information technologies, beginning with the telegraph system's close relationship to railroad operations in the mid-nineteenth century, and leading on to the development of the telephone system, and the computer systems of the present century.

Thus, however distinct and different was the new technological spirit of the twentieth century, we may see that the way in which a succession of general-purpose technologies came to be elaborated and implemented in the U.S. during the present century – how electricity, telecommunications, the gasoline-powered internal combustion engine, and, most recently, the digital computer have reflected the interplay of global developments that were expressed, first and most fully, in American circumstances, and so took forms that owed much to the particular legacy of America's nineteenth-century development.

Our second purpose, therefore, is to advance an interpretation of the forces underlying the ascent of the U.S. economy to its internationally dominant position in the twentieth century, and to account for the transformations that have occurred in the relationships among the proximate sources of America's macroeconomic growth. The principal elements of our interpretation to be presented by Part Two can be identified under two headings. First are those forces that can best be regarded as generic, global tendencies, linked to internationally shared advances in science and technology broadly construed. The emergence of new and greater potentiality for knowledge-based economic development during the twentieth century, and the working out of its implications for production methods and the endogenous growth of productive resources in the context of the U.S., is thus to be understood not as a unique, national phenomenon. Rather, these form part of a much broader set of tendencies, far more global in their ultimate manifestations, which took an early and particularistic form in the American setting.

Part Two mobilizes quantitative and qualitative evidence, and theoretical considerations to support the view that historical experience of technological and organizational change has been that of persisting significant differentials among the rates of "factor input-saving" due to such innovations. The existence of such differences affecting the relative usage of the factors of production represents a departure from the condition that economic theory conventionally refers to as one of "neutrality" in technological change, a usage that we shall follow here.[1] But, even more significantly for our interpretation, the predominant pattern of non-neutrality, or "biasedness" in the direction of technical and organizational progress itself underwent a transformation between the nineteenth and the twentieth century.

We read the available evidence as indicating that the overall bias of innovation during the nineteenth century was strongest in the direction of labor-saving changes; that the latter were not only relatively more pronounced than the tendency towards natural resource-saving, but were markedly stronger than the impacts on use relative to usage of tangible reproducible capital-inputs. Indeed, we contend that technological progress in the nineteenth century was characterized by an absolute *capital-using* bias.[2] By contrast, from the experience of the U.S. macroeconomy it appears that the twentieth century has been characterized by a bias towards innovation of an *intangible* capital-using kind, and the emergence of tangible capital-saving technical change alongside ordinary labor-saving innovation – albeit with a bias in favor of the latter that represents a continuation of what had been experienced in the preceding century.

Among the second broad category of forces are some that may be held to constitute more specifically American national characteristics, conditions which at the opening of the present century properly could be viewed, and were cited by contemporaries as responsible for the differences they perceived between the ways that production and distribution were organized and conducted in the U.S., compared with the economic practices prevalent in the Old World. Some of these had their roots in the trajectories of resource exploitation and technological adaptations that were established previously, during the extensive developmental phase of the preceding era. Others certainly reflected features of the socio-economic structure, political institutions and cultural ethos that were peculiar to or most prominently displayed by the young society that had taken shape in this region of recent European settlement. The ways in which the technologically driven demand-side forces in the factor markets elicited the supply-side responses necessary for the formation of new, and non-conventional, stocks of intangible capital, and the specific demographic and institutional developments that also contributed to shifting factor supply conditions, are shown in Part Two to account for the salient features distinguishing the U.S. growth path in the twentieth century from the preceding course of macroeconomic development. Nevertheless, in the continuing accumulation of capital at a pace which has exceeded the rate of growth of output, the long-run dynamics of the contemporary economy displays an important element of continuity with its past experience.

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[1] See Endnote 1 of Part Two for further discussion of concepts of "neutrality" and "non-neutrality" or "bias" in connection with the impacts of technological change.

[2] Because the associated concepts are central to the interpretation advanced in this chapter, it is important at the outset that the terms "factor-saving" and "factor-using" should be understood to be defined relatively, i.e., in relation to output. Endnote 1 of Part Two may be consulted for further discussion and formal definitions.

Part Three turns from the U.S. growth performance in the present century to that of the preceding epoch, and examines the American path of development in relation to the contemporaneous experiences of the other industrial nations. The twentieth century's opening half had witnessed the U.S. ascent to a position of international economic leadership in regard to the average level of real income enjoyed by members of the population. This, as will be seen, was based upon the early establishment and further widening of the country's productivity lead vis-à-vis the other industrialized and industrializing nations. Consequently, the years immediately following World War II found the U.S. at the pinnacle of comparative affluence and preponderance in the international economy, a position that soon began to be eroded by the recovery of other, war-torn economies, and the emergence of strong tendencies among the industrial economies not only to converge in their levels of productivity but to "catch up" with the U.S., and in some instances to forge ahead. These international perspectives on the American growth experience are developed more fully in Part Three, where we offer a broad account of the key forces that have worked to alter the economy's relative position on the global stage. A number of the important elements that had contributed to the creation of “American exceptionalism” in both the material and technological domains subsequently lost their former significance – having been either transformed at home, or come into existence more ubiquitously among the world’s industrially advanced societies in the course of the present century. Such developments, especially those that came to fruition in the post-World War II era, will be seen to help account for the modifications that have occurred in the U.S. position of industrial leadership.

Part One

A Statistical Profile of American Growth Since 1800

1. Problems of Measurement

Output per head of a nation's population, said A.C. Pigou in a classic study, is the "objective, measurable counterpart of [its] economic welfare." Output per head is only part of the content of economic welfare, but it is with this in mind that we make the growth of per capita output the focus of this chapter. Our purpose here is two-fold: first, to draw a statistical picture of American growth and of the proximate elements or sources from which it derived; and, secondly, to search for the conditions or forces that controlled the strength of these elements and their changes. We identify the proximate sources of growth in the manner of John Stuart Mill:

> *We may say, then, ... that the requisites of production are Labour, Capital and Land. The increase of production, therefore, depends on the properties of these elements. It is the result of the increase either of the elements themselves, or of their productiveness." (Principles of Political Economy, Ashley Edition, p. 156)*

We shall in the end search for the forces that lie behind the increase of the "elements" and their "productiveness". But our search is a limited one. It goes as far as our own understanding and the length of this chapter allow. We draw attention at this early point, therefore, to the deepest causes of growth that lie in America's attitudes and aspirations, in the institutions that govern the operation of the American economic system and in the incentives that support work, capital accumulation, enterprise and the advance of practical knowledge; but we cannot attempt a systematic exploration of these fundamental conditions. Our first task is simply descriptive.[3]

The growth with which we can deal with some degree of assurance is the growth as it appears in the available statistics. The growth rates of aggregate and per capita output that appear in the statistics are the growth that can be measured; with few exceptions that means the output that flows through commercial markets. Such measures are neither comprehensive nor unbiased. The goods and services that are produced in the home or on farms but that never reach the market must be included, if they can be, on the basis of rough estimates or else neglected entirely. Significant parts of total output – land clearing and drainage, timber felling and sawing, barn raising, food preparation and canning, the care of children, the sick and the aged, the repair of equipment and furniture, the provision of knowledge and entertainment, have moved from the household to the market and sometimes back again and so biased measures of growth either upward or downward. There are analogous troubles with our measures of the sources of output growth. In particular, the contributions

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[3] Several chapters in Volume III of the Cambridge History deal with the same subjects. See in particular the chapter by Robert E. Gallman, “Economic Growth and Structural Change in the Long Nineteenth Century” and by Robert A. Margo, “The Labor Force in the Nineteenth Century”.

of the various sources, which appear in the tables as if they acted on growth independently of one another, are, in fact, to some unknown but significant degree, the result of the joint action of two or more sources. Perhaps most important of all, the great advances in the quality and variety of goods and services register quite inadequately in our measures of output. Whether bacterial pneumonia is treated with poultices or penicillin makes no difference to our measures of output so long as their unit cost in the base years of the GDP indexes is the same. And so with communication by pony express, by telegraph, telephone or E-mail. A quality adjusted measure of output would on this account rise faster than the existing measures. But existing measures also neglect the disseminates and costs of growth, for example the congestion, pollution, noise, and crime of cities – to be balanced, of course, against their cultural wealth, intellectual vigor, and stimulation. No one can say exactly how a truly comprehensive measure of growth would look and there is no utterly objective way to provide one. These real difficulties must be set aside, but not lost to mind. We return to them later. Meanwhile we study the growth of output per capita because it is the only measure of the aggregate of goods and services available to people on the average over long periods of time.

The growth we study in this chapter refers to the long-term or sustained increase in national product. This means the growth that persists, not only across the inevitable year-to-year ups and downs of business activity, but also across the more extended fluctuations that reverse themselves only over a period of years. In the American economy of the nineteenth and early twentieth centuries, these fluctuations took two forms. One was the familiar "business cycle," which until the 1960s typically had a duration in this country of about five years. When, however, the effects of such business cycles are attenuated by calculating growth rates between the average levels or peak years of successive cycles, a second wave of longer duration emerges. In American experience, these "long swings" succeeded one another at intervals of fifteen to twenty-five years from early in the nineteenth century until about 1930 and, with some differences in mechanism, thereafter as well. To measure the trends of sustained growth properly, therefore, we must calculate growth rates between similar phases of long swings and choose years to represent those phases that are comparable in their business-cycle position. The years or groups of years that bound the periods so identified appear in Table IA and in the corresponding “A” tables that follow them in the Statistical Appendix.

A glance at Table 1: IA suggests a remaining element of irregularity. It was especially important during the long-swing intervals of 1855 to 1871 and 1929 to 1948. The first spans the Civil War and its disturbed aftermath. The second spans the Great Depression of the thirties and the intense but war-directed activity of World War II. Both were marked by large and anomalous slowdowns in output growth. The Depression of the thirties, which discouraged investment, and the war, which imposed restrictions on civilian investment, caused a serious reduction in private capital accumulation and retarded normal productivity growth. The effect of the Civil War was even more pronounced. The extraordinary upsurges of output, capital accumulation and productivity growth in the periods that followed these wars and depressions were, in part, rebounds based on exploiting backlogs of postponed investment and technological innovation and, in the case of the Civil War, gradually overcoming the post-war disruption of the economy of the South. Combining the records of the disturbed periods with the rebounds that followed offers a better view of the underlying long-term trends of economic advance. Table 1: I and similar tables in the text below are designed to do that.

Finally, the figures throughout are afflicted by errors of estimation, but we judge that these are more serious before the Civil War than after. To get a more accurate picture of long-term growth, it seems better, therefore, to view the pre-Civil War development as a whole. The result is the long period 1800-55, which appears in both Tables I and I-A and in later tables. We call the figures in Table 1: I and in analogous later tables "Measures Across Long Periods." They appear in the text.[4] The corresponding "A" tables provide figures for subperiods. We call them "Measures Across Long-Swing Intervals". Together with descriptions of sources, they appear below in the Statistical Appendix.

The scope of output on which the chapter focuses attention is the "private domestic economy." This is somewhat smaller than the national product as a whole in that the former excludes "government product," which is the payments made by governments directly to the factors of production. Essentially that means the compensation of government employees, since the national accounts treat government interest payments, not as factor compensation, but as transfers. In order to produce a total product made by factors working within the country, the private domestic economy also excludes net factor incomes from abroad, that is, the excess of incomes earned by the labor and capital of U.S. nationals employed abroad over the incomes earned by foreign nationals and foreign capital situated in the U.S. Neither item was of significant size in the nineteenth century. And while government product has become of much greater importance since, the long-term rates of growth of aggregate national product and private domestic product have remained quite similar.

Private domestic product, nevertheless, is a better basis for productivity measurement than is the aggregate national product. That is because the real, inflation-corrected, product of government is obtained by deflating current dollar wage payments by an index of nominal wages per worker. Real government product, therefore, emerges essentially as a measure of the growth of government employment. The productivity change, presumably the increase in productivity, of government workers, disappears, which introduces a downward bias into measures of the productivity of national rather than private scope.

Frame I in each table deals with the nineteenth century, Frame II with the twentieth. The sources and, to some degree, the methods of estimate of the output figures are somewhat different in the two frames. The tables, therefore, show figures for overlapping periods around the turn of the century on both bases. The Frame I figures for the turn of the century are better for comparisons with earlier years; the Frame II figures for the same period are better for comparisons with later years.

[4] See Endnote 1 of Part One for further discussion of the long-period dates.

Table 1: I The Output Growth Rates of the National Economy and the U.S. Private Domestic Economy, 1800-1989

(Average compound rates over "Long Periods," in Percent per Annum)

	GNP	GPDP	Population	Per capita rates		Intensive growth fraction	
				GNP/P	GPDP/P	GNP	GPDP
Periods						(percentages)	
			Frame I: The Nineteenth Century				
1800-55	3.99	3.93	3.03	0.93	0.87	23	22
1855-90	4.00	3.92	2.41	1.55	1.47	39	38
1890-27	3.56	3.50	1.73	1.80	1.74	51	50
			Frame II: The Twentieth Century				
1890-27	3.76	3.70	1.73	2.00	1.94	53	52
1929-66	3.18	3.05	1.30	1.86	1.73	58	57
1966-89	2.69	2.86	1.00	1.67	1.84	62	64

Note: Here and in Tables II-IV, the dates 1855, 1890 and 1927 are the midpoints of five-year average ending with the peak year of a "long swing". Thus the period 1855-90 is more properly 1853-57 to 1888-92. Other terminal years are single years chosen to represent the peaks of long swings.

Sources: Following Table 1: IA in Statistical Appendix.

The output figures in Table 1: I and in most later tables represent gross product before allowance for depreciation. Net product after depreciation would, indeed, be a better measure of output relevant to economic welfare. The long-term growth rates of net and gross output, however, are not significantly different, and gross output is a better basis for the measurement of productivity.

2. Output, Population and Output per Capita

Table 1: I and Tables 1: II to IV that follow encapsulate the main features of nearly two centuries of American development as it appears in the pace of measured output growth and its proximate sources. These numbers can be only the beginning of a search for the forces governing growth, but

they are a useful beginning, a framework that suggests the quantitative outlines of the American experience.

When we look at the record across the long periods of Table 1: I, it appears that the 1800s were a century of 4 percent growth of aggregate product. And this was true whether we look at growth in the national economy (GNP) or in the private domestic economy (GPDP). Beginning around the turn of the century, however, the pace began to fall off. From the 4 percent growth of the last century, it has gradually declined until in the most recent quarter-century it was under 3 percent a year. Both the 4 percent rate of the 1800s and the gradual slowdown in the 1900s, however, were the outcome of divergent movements in the components of aggregate output growth, that is, population growth and per capita output growth.

Population growth in the first half of the last century was very rapid. With few reversals it has slowed down ever since. The transient baby boom years of the 1950s and early 1960s were a notable exception. Per capita output growth, however, speeded up. It did so in two steps, a large one between the first and second halves of the last century, a smaller but still substantial one between the second half of the nineteenth century and the first quarter of the twentieth. The rate of about 1.8 or 1.9 percent a year that was achieved in private domestic product per capita between 1890 and 1927 was then roughly maintained, when viewed over suitably long periods, for the rest of the century. It was, indeed, a remarkably rapid pace. Sustained so long, it was enough to make the measured level of private output per head nearly six times as high in 1990 as it had been a century earlier.

With population growth declining, the big step-up of per capita growth during the last century was enough to sustain the pace of growth of the aggregate in the 1800s. With population growth declining still faster in the 1900s, the smaller step-up in per capita growth across the turn of the century, *a fortiori* its stability since that time, was not. So aggregate output growth measured over long periods, has declined steadily since the beginning of the present century.

This is the big picture. Within the long periods of Table 1: I, however, economic growth suffered fluctuations that deserve notice. The more important of these emerge in the measures across long-swing intervals (Table 1: I-A in the Statistical Appendix). For example, the private per capita growth rate in the cross-Civil War interval (1855-71) fell to a pace approaching zero, while in the seventies and eighties, during the rebound from the War, the growth rate was higher than in any similar interval before or since. There then followed a slowdown, the seriousness of which is perhaps muted by the timing of long-swing intervals in the Table. The impact of the Great Depression and World War II, taken together, however, emerges clearly; and so does the rebound that followed. Although the text here and later concentrates on the measures across long periods, readers can refer to the Statistical Appendix for a picture of growth across shorter intervals.

If we look beyond the simple arithmetic of Table 1: I, it is clear that output per capita and population growth interact. The outcome has turned on a balance of offsetting influences. On the one side, powerful influences connected with the rise of per capita product and productivity and, more especially with the technological progress behind it, made for a decline in mortality. The migration to the cities, however, where death rates were relatively high, at first tended to raise mortality. Beginning around 1870, a movement to improve sanitation, together with a gradual betterment of nutrition, served to curb disease and morbidity generally. Still more important, the advance of knowledge that supports productivity growth included the germ theory of disease. It persuaded people to accept the expensive projects needed to bring clean water to the growing cities and to remove their wastes. Building on the anti-bacterial work of Robert Koch and Louis Pasteur in the 1870s and 1880s, growing knowledge also led to the great reductions of small pox, diphtheria, scarlet fever and measles made possible by vaccination and the inoculation of anti-toxins. Later in the present century came the dramatic improvements in the cure of infections with antibiotics. Increasing knowledge also brought valuable ways of detecting and treating cancers and avoiding and curing cardiac disease.[5]

High and rising levels of income and, mainly in the nineteenth century, cheap land attracted immigrants. And a large flow of immigrants did, indeed, account for a considerable, part of the total increase of population from early in the last century until World War I. From the 1840s until World War I, approximately a quarter of the growth rate of total population was attributable directly to immigration. The children of immigrants added still more. Between the early twenties and about 1970, the flow of immigrants, restricted by federal legislation, was much less important. It made up only some 11 percent of the rate of population growth. In the last 25 years, however, migration, legal and illegal, has again risen in importance.

It is the birth rate, however, that has been most weighty in governing changes in the growth of population. It is true that rising levels of income, taken by themselves, make it easier for young people to marry early and to raise large families. Other circumstances accompanying income growth itself have, nevertheless, worked in the opposite direction and produced the long-term trend toward lower birth rates and a decline in the rate of population growth. In the nineteenth century, the intensification of settlement gradually raised the price of land and made it difficult to establish numerous children on nearby farms. Industrialization attracted people to the cities where the costs of space were higher and where children were less well able to contribute to family income. It also weakened the economic bonds between generations that family farms and other family businesses create. So it reduced the economic security that children offered to parents and in that way undercut the attractions of a large family. It enlarged the opportunities of women for paid work outside the home and so raised the costs of devoting effort and attention to family. Remunerative and attractive employment in this century came to depend increasingly on higher levels and longer years of education, which again raised the costs of bringing children to adulthood. The technical progress on which, as we shall see, per capita output growth largely rests, included progress in the means of contraception. And the spread of education helped to diffuse knowledge of contraceptive techniques

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[5] See Richard Easterlin, “Twentieth-Century American Population Growth,” in Stanley Engerman and Robert Gallman (Eds), The Cambridge Economic History of the United States, vol. III. Also Easterlin, “Industrial Revolution and Mortality Revolution: Two of a Kind”? Evolutionary Economics, 5(1995), 393-408, and Michael R. Haines, in Stanley Engerman and Robert Gallman (Eds), The Cambridge Economic History of the United States, vol. II..

and made people more ready to use them. In sum – the decline in population growth and thus in aggregate output growth stemmed in large part from the rising level of per capita output, or, better, from the forces that support it and the conditions of life that go with it.[6]

There are also reverse influences that run from population growth to the rise of per capita output. An increase in population, if it presses on scarce resources, tends to reduce output per capita. In the conditions of land and resource abundance characteristic of the United States, however, the chief effect of population growth has been to raise the level of aggregate output by its effect, subject to a lag, on the growth of the labor supply. By its effect on the size of the domestic market it opened the way to a larger exploitation of the economies of large-scale production and so to higher output per capita as well. In these circumstances, the declining rate of population growth in the present century would have acted to limit the potential contribution of the economies of scale to the growth of productivity and per capita income. This century's declining population growth rates may, therefore, have been a constraint on aggregate output growth, not only because they tended to reduce the growth rate of the labor force but also because they held back the growth of labor productivity. But labor productivity rose for other reasons, and these must still be explored. We turn first, however, to review the course of labor input.

3. The Changing Contribution of Labor Input per Capita

Per capita output growth may be viewed as the sum of the growth rates of the annual number of hours of work per year per head of the population and of output per hour.

During the nineteenth century, per capita labor input rose at a rate somewhat under one-half percent a year (Table 1: II). This seemingly modest pace, however, amounted to more than 50 percent of the still low growth rate of per capita output in the first half of the last century. But even in the second half, when per capita output growth had risen toward rates more familiar now, about a quarter of the advance was still derived from the growth of labor input per head.

In the present century, by contrast, things were quite different. The input of labor hours began to decline on a per capita basis and did so at an accelerating pace. Given the high and steady rate of per capita output growth, this implies that long-term labor productivity growth was accelerating, at least through the first three quarters of the century (1890-1966). And then there was a reversal. During the quarter-century since 1966, the growth of per capita labor input jumped again to the higher rates characteristic of the nineteenth century, while labor productivity growth fell back to a slow pace not seen since the turn of the century, perhaps earlier. The two developments were, to some degree, connected, as our later discussion of the Slowdown shows (Part Two, Section 5).

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[6] Easterlin, "Twentieth-Century American Population Growth," and his "The American Population" in Lance Davis et al. American Economic Growth, New York: Harper and Row, 1972, Ch.5.

The growth of labor hours per capita can itself be decomposed, and this is done in Tables III and IIIA. Here the growth of labor hours per head is viewed as the sum of the growth rates of the labor force per head of the population, of full-time equivalent persons at work ("persons engaged") per member of the labor force, and of hours of work per person engaged. The sum of the latter two rates is the growth rate of hours per member of the labor force.

The strong growth of per capita labor input during the nineteenth century was due in part to the first of these components, that is to the faster growth of the labor force than of population. This is traceable partly to the effect of immigration, which brought in more people of working age than it did children, women and old dependants, and partly to the manner in which population growth declined. Because birth rates fell faster than death rates, the proportion of dependent children and youth declined relative to adult groups, and the population of working age rose compared with the general population.

The growth of labor input, especially in the first half of the nineteenth century, was bolstered as well by increases in the ratios of employment to labor force and of hours per person employed. Both developments were connected with the shift of population and employment from farming and rural life to the towns and cities and to employment in the growing non-farm sectors. Urban life gave women a better chance for paid (and, therefore, recorded) employment outside the home. And full time annual hours of work on the farms, because of its seasonal nature, were only some 75 percent as long as annual hours in the non-farm sector.[7]

As one moves into the twentieth century, the balance of forces changed, producing first a slow, then a very rapid decline in labor input per head which continued into the 1960s. Both long-term and transitory factors were at work. In the first third of the century, from about 1890 through 1929, the same balance of demographic developments, the relative growth of the population of working age, reflecting the decline of birth rates and, therefore, of dependent children, and until World War I, the continued flow of immigrants in large numbers produced a continuing rise in the importance of the working-age population and in the ratio of labor force to population. This was more than offset, however, by a more rapid drop in non-farm hours of work. The hours decline took place especially rapidly during World War I when workers took advantage of tight labor markets to gain shorter hours without a drop in pay. By 1919, this drop in average non-farm hours, together with a smaller rise in average annual farm hours, had made annual hours per worker in the two sectors about equal. The farm-non-farm shift no longer worked to support the growth of labor input.

Apart from these long-term developments, an important feature of the years since 1929 was a large and protracted fluctuation in labor input per capita. The decline which had begun in the early part of the century accelerated between 1929 and 1966 and proceeded at a multiple of its earlier

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[7] John W. Kendrick, Productivity Trends in the United States, Princeton, N.J.: Princeton University Press for the National Bureau of Economic Research, 1961, Table A-IX, and Paul A. David, “Real Income and Economic Welfare Growth in the Early Republic,” forthcoming, available from the author.

pace.[8] And then it turned around; for the last quarter-century, it has been rising almost as fast as it fell during the preceding four decades. Without the decline of labor input per capita in the middle decades of the century, the rate of advance of per capita output during the post-war growth boom would have been still more rapid; without the rise in the seventies and eighties the severe slowdown of labor productivity growth would have produced a marked decline in output per capita as well.

The sources of the large fluctuation in the growth of labor input per capita in the present century are complex. Some of the considerations are suggested by the informal table that follows. Here we view the growth of labor-force per capita (the labor-force ratio) as the sum of the growth rates of the working-age ratio – that is the ratio between the working-age and the total population – and the gross participation rate, that is, the ratio between the number of persons in the labor force and the working-age population. We call it the *gross* rate because it reflects changes both in the participation rates of specific groups, distinguished by age, sex and other characteristics, and in the importance of the groups.

[8] The size of the more severe retardation is uncertain. Comparing 1929-66 with our own estimate for 1890-1927 (shown in Frame I) puts the retardation at 0.5 percent a year. Using Kendrick's estimate for 1890-1927 (Frame II) makes the difference even greater.

Table 1: II Contributions of Labor Input and Labor Productivity Growth Rates to the Growth Rate of Output per Capita: U.S. Private Domestic Economy, 1800-1989

(Average compound rates over "Long Periods," in Percent per Annum)

Periods	Output per capita	Manhours per capita	Output per Manhour
	Frame I The Nineteenth Century		
1800-1855	0.87	0.48	0.39
1855-1890	1.47	0.41	1.06
1890-1927	1.74	-0.26	2.01
	Frame II The Twentieth Century		
1890-1927	1.94	-0.07	2.00
1929-1966	1.73	-0.78	2.52
1966-1989	1.84	0.60	1.23

Sources: See Statistical Appendix, Table 1: IIA.

Table 1: III Decomposition of the Growth Rate of Manhours per Capita
U.S. Private Domestic Economy, 1800-1989

(Average compound rates over "Long Periods," in Percent per Annum)

Periods	Manhours per capita	Labor Force per capita	Persons Engaged per Member of the Labor Force	Manhours per Person Engaged
		I. The Nineteenth Century		
1800-1855	0.48	0.19	0.14	0.15
1855-1890	0.41	0.33	0.07	0.02
1890-1927	-0.26	0.16	-0.17	-0.26
		II. The Twentieth Century		
1890-1927	-0.07	0.16	0.01	-0.24
1929-1966	-0.78	-0.09	-0.24	-0.44
1966-1989	0.60	1.12	-0.11	-0.37

Sources: Following Table 1: IIIA in Statistical Appendix.

Table 1: III-Addendum
Components of Change in the Growth Labor Force Participation Rate, 1929-89
(average compound growth rates in percent per annum)

Periods	Labor force per capita	Working-age population ratio	Gross participation rate
1929-1948	0.19	0.17	0.02
1948-1966	-0.38	-0.57	0.19
1966-1989	1.12	0.48	0.64

Sources: Underlying data from:
Population: Economic Report of the President, Jan. 1993, Table B-29 (Resident population 1929-48; total population including armed forces overseas after 1948.)
Working-age population: Ibid. Table B-29 (Population, ages 16-64).
Labor force: Ibid, Table B-30 (Civilian labor force aged 16+.)

Note: Growth Rate of Gross Participation rate ={1+[Col.(1)]/100}/{1+[Col.(3)]/100}-1]x100.

In the first period above, from 1929 to 1948, the growth of the working-age ratio was modest. This was a direct consequence of the birth rate reversal, from the low and declining rates that prevailed during the late twenties and the decade of the Great Depression, to the higher fertility levels that accompanied the tightening of labor markets during the forties. The depressed birth rate cut the fraction of children in the population and so pushed up the working-age ratio, whereas after 1945 the beginnings of the Baby Boom reversed the process.

The two decades following World War II saw no reversals of comparable magnitude in the fertility of Americans: the birth rate and the general fertility rate climbed rapidly to a peak at the end of the 1950s, and held at high levels for some years thereafter. Consequently, the proportion of the population made up of young dependants rose rapidly and the working-age ratio dropped sharply over the period 1948-66, as may be seen from the Addendum to Table 1: III. While this was partially offset by a modest rise in the participation rate, the net effect was that labor force per capita fell rapidly during that interval.

Toward the close of the sixties, however, birth rates started their recent dramatic decline and thus ushered in the latest period when the working age ratio rose almost as rapidly as it had dropped in the two decades after World War II. The turnaround, which raised the growth rate of the working-age ratio by a full percentage point (from –0.57 to +0.48 percent a year) accounted for 70 percent of the marked increase in the growth of labor force per capita.

The large fluctuation in birth rates and the accompanying decline and then increase in the growth rates of the working-age and labor-force ratio have been well explained by Richard

Easterlin.[9] On his hypothesis, fluctuations in birth rates are caused by changes in the economic circumstances and prospects of young adults in their most fertile years, taken in conjunction with the expectations they had earlier formed in their parents' households. Given the twenty-year or so lag between birth and entry into labor force and marriage, a kind of cycle is generated. Thus the cohort who came of age during the Great Depression, and who carried with them expectations formed in the prosperous twenties, married late and had few children. By contrast, the young adults of the fifties and early sixties were a much smaller cohort, reflecting the low birth rates of the thirties and early forties. This small supply of young workers, meeting the buoyant labor market of the post-war years, found good jobs and enjoyed early promotion and rising wages. And given the modest expectations they had formed in the depressed thirties, they married early and generated the Baby Boom. They then spawned the large cohort of young people whose expectations were consistent with the happy state of their parents' households. And these then entered the labor force in the seventies and eighties where they met the recent Slowdown of productivity growth, the accompanying stagnation of real wages and slower promotion. A rapid decline of birth rates followed.

A competing hypothesis lays greater stress on the long-term trend towards lower birth rates to explain the low rates of recent decades. It sees the Baby Boom as an aberration and the more recent decline in the birth rate as primarily a response to the forces controlling the long-term trend. There is, in fact, much to be said about the sources of the long-term trends that have helped bring birth rates to their present low levels. The economic and social conditions of the century have, indeed, made children more expensive to raise and perhaps reduced the benefits that parents may derive from them. Children can no longer contribute to the ordinary family's work and income as they did on the farms of a century ago. They occupy more costly house room in the city. They require long years of increasingly expensive medical care and education. They compete for the time, effort and income of their mothers when the world of paid employment has been opened to women. As adults they live separated from their parents by independent employment and often by long distances; they cannot offer the support and care for the elderly that they once did. And the parental support they used to provide is now far less important when the elderly can depend on Social Security and private pensions, on Medicare and on retirement communities. Young adults, therefore, are less likely to see the benefits and virtues of large families.

Still, there are birth rate effects that stem from disjunctures between labor demand and supply. When they occur, they have effects that echo a generation later. Moreover, they may echo once again, perhaps with diminished force, until a new disjuncture of independent origin occurs and starts the process once more. The Easterlin echo effects have been an important component of the growth of labor input in the present century and earlier, and we may see them again.

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[9] See Easterlin's "Twentieth-Century American Population Growth," and Richard Easterlin (1968), Population, Labor Force and Long Swings in Economic Growth, New York: National Bureau of Economic Research (distributed by Columbia University Press, N.Y. and London).

4. Labor Productivity Growth and its Sources

Between the first half of the nineteenth century and the second half (counting the years from about 1855 to about 1890 as the "second half"), the pace of labor productivity growth more than doubled. Then between the second half of the last century and the first third of the present century (1890-1927), it doubled again. (Table 1: IV). And between the first and second thirds of the present century, it increased still again, by 26 percent. Counting, therefore, from the slow rate of the first part of the nineteenth century to the far more rapid pace of the middle decades of the twentieth, there were more than a hundred years of accelerating long-term labor-productivity growth. True, this record of unbroken acceleration emerges when growth is measured over the long periods identified in Table 1: IV. Within these long periods, across the “long swing intervals” they span, there was a succession of slowdowns and accelerations (Table 1: IVA). And if we broke the record into still shorter intervals, the fluctuations of the labor productivity growth rate would be still more marked. Wars, depressions, post-war rebounds and booms, the vagaries of the pace of technological progress have all counted. Still, the record of long-term acceleration is clear enough.[10]

Against this accelerating trend of labor productivity growth rates, the quarter-century from 1966 to the present time is something of an anomaly. The occurrence of a slowdown is not in itself strange. As said, there have been many precedents. It is the severity of the current retardation and its duration which give this latest episode its special character. Compared with the preceding long period between 1929 and 1966, the rate of advance fell 51 percent. Compared with the booming growth of the post-war years (1948-66), the rate declined no less than 60 percent. Not since the second half of the nineteenth century, if we depend on the long-period measures, has the pace of labor productivity growth been so slow.

It is sometimes argued that the slowdown in the years since the latter sixties is not in itself evidence of long-term retardation. In this view, the slowdown may be only a transitory matter, comparable with the declines in productivity growth that accompanied serious depressions in the past.[11] The slowdown that began after 1966, however, had by the close of the eighties gone on for almost a quarter-century, which is longer than the full long swings of the past, their contractions plus their expansions. Signs of a faster long-term growth rate in the years since 1989 are still uncertain. The decline of the labor productivity growth rate between the previous long swing (1948-66) and the period of slowdown thus far (1966-89) is 1.9 percentage points. Earlier in the present century, the most drastic slowdown was that between the prosperous twenties and the depressed thirties; the decline in the growth rate then was much less – 0.75 points. Yet the recent period was not one of severe depression. The average civilian unemployment rate from 1966 to 1989 was 6.1 percent; from 1929 through 1939, it was nearly 17 percent. The future may well see a return to the labor productivity growth rates of the earlier twentieth century. But even if that does happen, the slow

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[10] See Endnote 1 of Part One.

[11] This is the contention of William J. Baumol, Sue Ann Batey Blackman and Edward N. Wolff, Productivity and American Leadership: The Long View, Cambridge, MA and London: The MIT Press, 1989, Ch. 4.

growth from 1966 to 1989 and perhaps longer will still remain as an episode of severe retardation that persisted for a significantly long period.

What were the elements from which the long acceleration of productivity growth arose and then the recent slowdown followed? The most elementary decomposition of labor productivity growth is one that divides it into two sources. One is the increase in productivity attributable to the enlargement of the stock of tangible capital that is available to aid each worker per hour of work (Table 1: IV, line 2). We sometimes call this the contribution of the growth of "capital intensity". The other element is the remainder of the increase of labor productivity. We call it the growth of "crude total factor productivity" (or "crude TFP"). It appears in line (3) of Table 1: IV. We term it "crude" because it is a remainder or residual which is itself an amalgam of various elements. These are discussed and, to some extent, measured in the lines of the Table that follow.

Table 1: IV The Source of Labor Productivity Growth, Private Domestic Economy, 1800-1989, Sources in Percentage Points Measures Across Long Periods

	I Nineteenth Century			II Twentieth Century		
	1800-1855	**1855-1890**	**1890-1927**	**1890-1927**	**1929-1966**	**1966-1989**
1. Output per manhour	0.39	1.06	2.01	2.00	2.52	1.23
Sources						
2. Capital stock per manhour	0.19	0.69	0.62	0.51	0.43	0.57
3. Crude total factor prod.	0.20	0.37	1.39	1.49	2.09	0.66
4. Labor quality	-	-	0.15	0.15	0.40(0.30)	0.31(0.16)
5. Capital quality	-	-	-	-	0.24	0.31
6. Refined total factor prod.	0.20	0.37	1.24	1.34	1.45(1.55)	0.04(0.19)
Addenda						
7. Gross factor share weights						
a. Labor	0.65	0.55	0.54	0.58	0.64	0.65
b. Capital	0.35	0.45	0.46	0.42	0.36	0.35
8. Vintage effect	-			-	0.04(0.05)	0.00(0.01)
9. Age-neutral refined total factor prod.	-			-	1.41(1.50)	0.04(0.18)

Sources: See text discussion and Notes and Sources following Table 1: IIIA in Statistical Appendix.

The formula for carrying out such a decomposition, commonly called a "growth account", was presented years ago by Robert Solow.[12] As applied to a decomposition of aggregate output, it reads:

$$Y^* = \epsilon_K K^* + \epsilon_L L^* + A^* \qquad (1)$$

In the formula, Y stands for output, L for labor hours and K for tangible capital stock (including land). The asterisk (*) denotes the per annum rate of increase over a trend interval; so Y* stands for the growth rate of output over a period of years, and similarly for L* and K*. The coefficient ϵ_K is the elasticity of output with respect to capital and represents the weight to be attached to the growth

[12] See Endnote 2 of Part One.

of capital in contributing to the growth of output. It is measured by the fraction of the value of total output that constitutes the compensation of the owners of capital stock for the use of their property: $\theta_K = \epsilon_K$. The "property income share" is the sum of before tax interest, rents, dividends and the retained profits of corporations plus an allowance for the compensation of capital in non-corporate business. In the gross terms in which we make our output calculations, it also contains an allowance for the depreciation (or retirement) of reproducible capital goods.

Since *at any given time,* and subject to certain assumptions, the (before-tax) earnings of capital and labor exhaust the total product, the weight to be attached to the growth of labor is, analogously $\epsilon_L = \theta_L = (1-\theta_K)$.[13] Over time, however, the growth of capital and labor inputs weighted as above does not necessarily exhaust the increase in total product, especially not when technological progress is raising the productive efficiency of the combined bundle of inputs. So the residue of the proportional growth of output, A*, that is, the part not accounted for by the sum of the weighted factor inputs, measures the contribution of the proportionate growth in crude total factor productivity (TFP) – along with that of any inputs left out of the accounting altogether, and also the net effect of errors in the data.

Under the same assumptions an alternative formula can be derived by simply rearranging the terms in Equation (1):[14]

$$A^* = \theta_K (Y^*-K^*) + (1-\theta_K)(Y^*-L^*) . \qquad (2)$$

This equation tells us that A*, that is, crude TFP, is the weighted sum of the growth of output per unit of capital and of output per unit of labor. And that is why it is called <u>total</u> factor productivity growth. Technological progress, the advance of economically useful knowledge actually incorporated into production, is presumably an important component of total factor productivity. But there are other contributors to this remainder.

An expression for the growth rate of real output per unit of labor input can also be obtained directly from Equation (1):

$$(Y^* - L^*) = A^* + \theta_K (K^*-L^*) . \qquad (3)$$

Since (K* - L*) represents the growth rate of capital stock per labor unit, Equation (3) gives us a formula for partitioning the proportionate growth of labor productivity into two components, the contributions of the capital intensity growth and those made by the growth of crude TFP. This relationship is applied in making the growth accounting calculations underlying Tables IV and IVA.

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[13] See Endnote 3, and the publications by Robert Solow and others cited in Section III of the Bibliography.

[14] Under the assumption that aggregate production relations are characterized by constant returns to scale we obtain this by making use of the restriction that the elasticity coefficients sum to unity, and hence: $Y = (\epsilon_K + \epsilon_L)Y$.

The decomposition of labor productivity growth, that appears in the second and third lines of Table 1: IV, crude as it is, reveals a striking difference between the growth records of the nineteenth and twentieth centuries. The present century, for most of its course, not only enjoyed a much faster rate of labor productivity growth than did the nineteenth century, but drew its advance from largely different sources. So far as these measurements can tell us, the labor productivity growth of the nineteenth century, and particularly its second half, found its source primarily in an enlargement of the tangible capital stock at the disposal of workers, and it owed its acceleration between the earlier and later parts of the century chiefly to a speed-up of such capital accumulation. In the present century, on the other hand, the major sources of both labor productivity growth and its period-to-period changes were the elements of advance that together account for crude total factor productivity growth.[15] The following figures, derived from Table 1: IV, bring out these conclusions plainly.

Table 1: IV-Addendum
The Relative Importance of Crude TFP Growth Among the Sources of Labor Productivity Growth in the U.S. Private Domestic Economy, 1800-1989

	Percentage of labor productivity growth rate due to			Percentage of interperiod change in labor productivity growth rate due to change in:	
Frame:Period	**Capital intensity growth rate**	**Crude TFP growth rate**		**Capital intensity growth rate**	**Crude TFP growth rate**
I:1800-1855	49	51			
I:1855-1890	65	35	**1800/1855 to 1855/1890**	75	25
I:1890-1927	31	69			
			1855/1890 to 1890/1927	-7	107
II:1890-1927	25	75			
II:1929-1966	17	83	**1890/1927 to 1929/1966**	-15	115
II:1966-1989	46	54	**1929/1966 to 1966/1989**	-11	111

Notes and Sources: Computed from Lines 1,2,3 of Table 1: IV; inter-period changes within Frame I, and Frame II.

The contrast between the two centuries is real, but, to a degree, overdrawn. Crude TFP which became the predominant part of twentieth-century growth is less an answer to our search for the sources of growth than a question that presses for answer. The growth account at the level of lines (2) and (3) in Table 1: IV is, to begin with, incomplete. It leaves out of account the contributions

[15] See Endnote 4.

made by changes in the composition of labor input and capital input which alter the effectiveness of hours of labor or units of tangible capital.

Labor hours are not homogeneous. They differ from one another because of differences in three major characteristics of the workers who provide them: their experience, which is a function of their age, their sex and their level of education. If we may judge marginal productivity by earnings, the productivity of workers rises with length of schooling and, for most workers, with their age. By the same test, an average woman is less effective than the average man of the same age and level of education. By classifying worker hours according to the levels of education of the workers who provide them and weighting the hours of each class by their relative average earnings, one obtains a measure of labor input that takes account of differences in education. If levels of education have been rising, such a weighted measure of labor input will rise faster than the unweighted index of labor hours, And the difference between the growth rates of the weighted and unweighted indexes is a measure of the growth of labor input attributable to the rising level of education. By analogous methods, one obtains measures of the growth of labor input due to changes in the age and sex composition of labor hours employed in production. We call the sum of the three growth rates attributable to age, sex, and education the input growth of Labor Quality. Weighted by labor's share of total income, labor quality growth then enters the account as a source of labor productivity growth.[16]

The composition of tangible capital per manhour presents similar problems. The annual gross returns to units of capital stock, for example, vary among assets of different classes. Structures with a long service life carry a smaller gross rate of return than does shorter-lived equipment; the depreciation rate on structures is naturally lower. Non-depreciable assets such as land and inventories have still lower gross returns. Differential tax treatment causes the gross rate of return before tax to differ according to the legal form of the organizations employing the capital: corporate business, unincorporated business, households and so on. Differences in risk produce differences in gross returns across industrial sectors. Dale Jorgenson and his collaborators have made indexes of capital stock weighted by average gross return to capital in cells differentiated jointly by all three characteristics: asset class, legal form of organization and industry.[17] Again the difference between the growth of the resulting index of weighted capital stock and that of unweighted capital stock is a measure of input growth attributable to changes in the composition or quality of the capital stock. As such, it enters into the growth account subject to capital's share of total income. It should be understood that when we speak of the growth of Capital Quality, we do not refer to the important changes in the characteristics of capital goods which raise their productivity but are the result of technological progress. That effect, for which there are no direct measures, remains embedded in the TFP residual.

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[16] See Endnote 5.

[17] Dale E. Jorgenson, "Measuring Economic Performance in the Private Sector," in Milton Moss (Ed..), The Univ. Press 1973, 233-351. See also Jorgenson, Gollop and Fraumeni in the Bibliography below.

Of the several sources of change in capital's composition, that by asset class was by far the most important at least since 1948. According to Jorgenson's estimates, the shift of capital among asset classes, principally the relative growth of short-lived, high gross rate-of-return equipment compared with structures, accounted for over 80 percent of the total growth of capital quality from all sources between 1948 and 1966.[18]

The contributions of Labor and Capital Quality growth were still small in the early part of the present century. Although high school enrollments speeded up, their effect on the educational level of the workforce itself remained limited until the twenties. As for Capital Quality we argue below that its contribution in the nineteenth century was very small and confined to the years from 1870 to 1900, and the same appears to be true in the early twentieth century since the rapid growth of the relatively short-lived Equipment fraction of the capital stock does not begin until the 1940s.

After the 1920s, however, growth in the quality of factor inputs made notable contributions. The schooling level of the labor force rose more rapidly and somewhat later there was a rapid increase in the relative importance of Equipment. Taken together, the two developments accounted for 25 percent of Labor Productivity growth in the long period from 1929 to 1966. (Table 1: IV).

In the most recent quarter-century – in the period of Slowdown – there were further changes. The contribution of the two quality sources taken together remained quite unchanged, but, of course, they were responsible for a larger fraction of the much-reduced growth of Labor Productivity. This outcome was the result of offsetting developments in the components of quality growth. The rise in the level of Education of the labor force went on apace. Changes in age and sex composition, however, both worked to reduce the measured productivity of workers. The coming-of-age of the Baby Boomers brought large additions of young, inexperienced workers into employment. The entry of women into the paid labor force speeded up. Taking Age, Sex, and Education together, the growth of Labor Quality became slower. On the other hand, the impact of the Slowdown on investment fell more heavily on Structures than on Equipment, so the pace of improvement in Capital Quality became faster.

The figures for quality change in Table 1: IV refer entirely to the twentieth century. Yet we believe that contributions to growth because of change in the composition of capital input must have been quite small during most of the last century, probably smaller than seems to have been the case even in the early years of the present century. There may, however, have been a modest rise in capital quality between 1870 and 1900.

We argue as follows, starting with Labor Quality. In the present century, its principal element has been the rise of the educational level of the workforce. In the nineteenth century, however, this was growing far more slowly and making a much smaller contribution to growth. At mid-century, in 1850, the fraction of young people, aged 5-19, enrolled in schools at some time during the year stood at just under 50 percent, and for these, the average number of school days per year was still

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[18] See Endnote 6.

small. The fraction enrolled was probably not a great deal lower in 1800, and hardly rose between 1850 and 1870. There was, indeed, a significant increase between 1850 and 1870 in the number of days spent in school by a student, and this would have raised the effective schooling of those workers who as children had attended schools in those years – essentially those who entered the workforce after 1870. There was also a rise in enrollments during the seventies; by 1880 the fraction enrolled reached 58 percent.[19]

These developments after 1850 could, indeed, have yielded some contribution to productivity growth between 1870 and 1890, but it would have been small. Since an increase of days in attendance took place only after 1850 and that of enrollments only after 1870, they could have affected only the younger workers of the post-1850 years and then mainly after 1870. The bulk of the labor force whose school-age years had been passed before mid-century would have been unaffected. Moreover, the rise in schooling remained confined to the elementary level. As late as 1890, only 1.6 percent of all students in public day schools were enrolled in secondary schools.[20] This means that the effect of higher enrollments on labor quality is proportionate only to the earnings differential between those workers with some elementary schooling and those who had not attended school and hardly at all to the higher differential between such unschooled workers and those with a secondary school education.

Whether there was also some significant change in the age and sex composition of the workforce taken together is hard to say. The average age of workers was rising slowly under the influence of falling birth rates; but immigration, which brought in a disproportionate share of young adults, was an offsetting force. The median age of the whole population, however, was rising very slowly. To what degree the effect of the rise in age, whatever it was, may have been offset by an increase in the proportion of women in paid work is also not clear. Movement off the farm and the rise of non-farm employment surely enlarged women's opportunities for work outside the home, and the expense of urban life would have pressed women to take such work. The rate of rise of persons engaged per member of the labor force is consistent with such a development (Table 1: III). Having regard to these various considerations, we believe that the contributions of labor quality change to productivity growth in the second half of the nineteenth century would have been smaller than even the quite low contributions suggested by our estimates for the early years of the present century (Tables 1: IV and 1: IVA).

Turning to Capital Quality, it appears that there may have been a small contribution from this source in the years between 1870 and 1900. In the first half of the century, the total capital stock consisted almost entirely of long-lived assets, cleared and improved land, houses and other structures. Equipment made up only a small and stable fraction of all assets – between 5 and 7 percent of the total. By 1870, however, the Equipment Fraction had become 11 percent of the total,

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[19] See Endnote 7.

[20] Historical Statistics, Series H-420 and 424.

and then grew rapidly to 28 percent in 1900. All these are the estimates provided by Robert Gallman.[21]

The rate of rise in the Equipment fraction (in constant prices) from 1870 to 1900 was 2.8 percent per year. This was more rapid than the comparable rate of rise between 1929 and 1948 (1.85 percent)[22] when our figures for the contribution of Capital Quality begin. This slower growth applies, however, to an Equipment fraction some 39 percent larger than it was in 1900. The impact of the relative growth of short-lived capital, therefore, would have been little different in the two periods. And on this basis we judge that the contribution from the growth of Capital Quality to the growth of labor productivity was of the order of only one-tenth of one percent a year from 1870 to 1900. Having in mind these considerations regarding both Labor Quality and Capital Quality, we think it reasonable to regard the nineteenth century estimates of crude TFP as at least roughly comparable with the more refined figures for the twentieth century.

What do these estimates of refined TFP growth represent? We regard them mainly as measures of technological progress actually incorporated into production together with the gains from economies of scale – insofar as the two can actually be usefully separated. We discuss this matter in an Endnote.[23] As a residual, however, the figures also include the effects on growth of whatever other factors we may have failed to identify and measure and which have operated through channels other than those we have measured.[24] As a residual, moreover, refined TFP is the inheritor of all the errors that may reside in the data or lack of data and in the estimating procedures by which they are put together.

We observe, finally, that the technological progress that moves refined TFP is the technological progress (and the economies of scale) that is "actually incorporated into production." Even in a progressive economy such as the U.S., however, the pace of actual incorporation may differ from the underlying rate of advance in practical knowledge. The main reason for such a difference in the U.S. stems from the fact that a portion, probably a major portion, of advances in knowledge must be embodied in tangible equipment and structures and often placed in new locations. Similar changes are needed to exploit the potential gains from economies of scale. True, not all advances of knowledge require such embodiment; some take the form of changes in managerial policies and procedures that require little or no new capital. Better control of inventories may be an example. But new, redesigned, or relocated equipment is needed to realize a large, presumably the major, share of advancing knowledge.

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[21] See his chapter in Vol. II of this history, Table 13.

[22] The figure for 1919-48 is from Raymond Goldsmith, A Study of Savings in the United States, Vol. III, Princeton, Princeton University Press, 1956, Table V-3.

[23] See Endnote 8.

[24] See Endnote 9.

Suppose we take it that the gross capital investment of each year – at least in twentieth-century America – embodies the most advanced technology available to the investing firms of the year. If so, the average level of technology actually in use during a year depends on whether the capital stock that has accumulated is made up more or less largely of recent or older, partly obsolete "vintages" of capital and so of embodied technology. In short, it depends on the average age of the capital stock. It follows that the growth rate of technology actually incorporated into production depends on three factors: (1) the fraction of new technology that requires embodiment; (2) the growth rate of "age-neutral" embodied technology (that is, the rate at which embodied technology would be incorporated into production if the average age of capital stock remained constant); and (3) a "vintage effect", which is the change in the rate of embodiment because of the change per year in the average age of the capital stock over a period of time. For any given rate of age-neutral embodied progress, measured progress will be faster if the age of capital is declining, but slower if age is rising. As between two periods, the growth rate of measured progress would be retarded if average age rises faster or declines more slowly in the second period than in the first.

We offer some rough estimates of the vintage effect in an Addendum to Tables 1: IV, and 1: IVA. The formula we employ,[25] the assumptions we make, and the data we use are described in the Appendix Note on the vintage effect. For reasons explained in that Note, we think the figures in the Tables may underestimate the actual effects of fluctuations in the rate of change in the age of capital stock. Nonetheless, the main lesson we draw from the figures is that the vintage effect may be of considerable size in comparisons between TFP in particular successive "long-swing intervals." When a combination of Great Depression and Great War produced a dramatic decline in the growth of the private capital stock, its average age rose markedly and refined TFP, expressing the actual rate of incorporation of technological progress, was driven below the presumptive underlying rate of advance of knowledge. With the return of peace and prosperity, the growth rate of the capital stock rebounded, the average age of capital fell and the rate of incorporated progress exceeded the rate of underlying progress. Before allowing for the vintage effect the rate of refined TFP growth from 1948 to 1966 stands higher than that from 1929 to 1948. Allowing for the vintage effect, the reverse seems to have been true. (Table 1: IVA). But the two intervals offset one another, and the long-period measure of the vintage effect f rom 1929 to 1966 is essentially zero. (Table 1: IV). That is one reason we prefer the long-period measures of Table 1: IV to those of Table 1: IVA. And, as said earlier, for the same reason, we prefer the figures of the long period from 1855 to 1890 rather than those for its component shorter periods, the long-swing interval across the Civil War and the interval of rebound from 1871 to 1890.

5. What Measured Growth Fails to Measure

Readers were warned early in this chapter that the output growth that is measured in the GDP is an imperfect approximation to the growth we really seek to measure and understand. Besides many

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[25] Our formula was first derived and presented by Richard Nelson, "Aggregate Production Functions and Medium-Range Growth Projections, American Economic Review, LIV, No. 5 (Sept. 1964), 575-606.

minor problems, the GDP, as it has been measured until now, largely misses the additions to consumer satisfactions made by new types of goods and services as they enter the market, gradually spread and come to account for larger shares of consumer expenditures. Nor does the GDP successfully take account of improvements in the quality of pre-existing goods and services. These failures stem from the fact that the price deflators, which transform the value of aggregate output in current prices into measures of real output in constant prices, are themselves measures of the change in the cost over a period of a bundle of goods and services of constant composition and quality.[26]

The composition in each period of the priced bundles does, indeed, correspond to the proportions in which consumer expenditures were divided among the various objects of expenditure in either the initial or terminal year of each measurement period. In American data, these have been periods of ten years or even longer in the earlier data; they are five-year periods now. Yet, even within these periods, the composition of expenditures on the types and qualities included in the standard bundle changes. More important, the quality of goods within bundles generally rises and new types of goods appear on the market. The improvement in quality has been caught quite inadequately for most of our two centuries and the true significance of new goods for consumer satisfaction not at all.

Between periods, the composition of the bundles measured is changed. But the growth rates of one period are then linked to those of a preceding period in a way that does not recognize the higher capacity of the new or improved products that are represented in the second bundle to meet the basic needs that consumers seek to satisfy – except insofar as the new goods have higher base-year prices per unit than those of the products they replace. Thus, as said, if a unit of penicillin has the same base-period price as a mustard plaster, the two count equally. Yet the penicillin can save the life of a patient with bacterial pneumonia, while the poultice is at best harmless. For the same base-period price per hour of service, electric light bulbs provide more light than the gas mantles, kerosene lamps and wax candles they replaced. They eliminated the need to trim wicks, clean globes and maintain the supply of kerosene – and they reduced the fire hazard. The length of the useful day was extended. Electric-powered washers, dryers and refrigerators reduced the drudgery and fatigue of housework; they freed women for a more varied and interesting life. Together with automobiles and extended hours for marketing, the new household appliances helped women enter paid employment. To that extent, the growth of measured output is raised. Little of the value of these new products or a myriad other examples of new goods and services is caught by the standard measures of output.

Suppose their true value could be captured, how would the growth rates of output over the two centuries be changed? We can be confident that output growth rates would look higher in both centuries. But would the twentieth-century rates be raised more than those for the nineteenth, or vice versa? In the absence of true and comprehensive measures, we cannot say with assurance, but we

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[26] This simple statement exaggerates the difficulty somewhat. For some goods, but not for all, price indexes have tried to account for quality change insofar as the change consists of an identifiable physical component whose base-year cost can be established or estimated.

can make a tentative judgment. We think that the twentieth century saw the appearance and spread of more new and improved products and services of benefit to consumers than did the nineteenth.

A representative consumer of 1800, if transported forward to, say, 1870 would have found the composition of consumer expenditures familiar in many ways. About 74 percent of consumer expenditures still went for food, clothing and shelter.[27] The percentage was still as high as 65 in 1890. By 1989, it was only 37. Much of the decline, of course, represents only the inelasticity of demand for basic necessities as income rises. But the point is that it is within the rising margin for expenditure on products beyond the provision for these basic necessities that the great changes in the character of goods and services and in the quality of products has taken place, and these are largely the developments of the twentieth century.[28]

Major twentieth-century developments in transportation, communications, information and entertainment and, most important of all, in the provision of health care and the length of life itself transformed the character and quality of life for people. A few summary figures are enough to suggest the importance of the changes brought by new goods and services in the twentieth century.

Table 1: V
Private Transportation and Communications Equipment in U.S. Households, 1899-1990

	1899	**1920**	**1950**	**1990**
Passenger cars per household	-	0.33	0.93	1.54
Telephones per 1000 people	13.3	123.4	258.1[1]	
Households with telephones (%)	-	35.0	58.2[1]	93.3
Households with radios (%)	-	0.2[2]	92.8	73.3
Households with TV (%)	-	-	8.9	96..37
Households with computers (%)	-	-	-	15.7

Notes: [1]1948; [2]1922
Sources: Historical Statistics and Statistical Abstract, 1994.

[27] See Simon Kuznets (1946), [National Product Since 1869, New York: National Bureau of Economic Research], Tables II-11 and II-16.

[28] See Endnote 11 to Part One.

With the benefit of vaccines and antibiotics, the incidence of the more serious infectious diseases (other than AIDS) has declined over the last century to almost insignificant levels. With these developments and with the advances in the treatment of malignancies and of diseases of the liver and heart, death rates have declined rapidly and the length of life has been greatly extended. The expectation of life had begun lengthening in the second half of the last century as the better provision for pure water and for sewage systems and waste disposal reduced urban death rates. But the rate of increase of life expectancy at birth doubled during the first half of the present century and then continued to rise. At the turn of the century a new-born infant could expect to live till 48. By 1991, this figure had risen to 73, a gain of a quarter-century. At later ages, the gains in length of life came later. At 40 expected life was about the same in 1930 as in 1900, but since 1930, expected life at 40 has increased 22 percent and at 70 by 51 percent.[29]

One way to integrate the improved expectations of survival with the picture of rising average material well-being is to consider what they imply for the expected lifetime increase in average (real gross) income that might be experienced by the members of the cohorts of white males born at successive dates between 1800 and 1991. For those born at the opening of the nineteenth century the expected lifetime improvement was 54.8 percent, whereas the representative member of the cohort born in 1855 could have anticipated a 101 percent increase in average real GNP per capita within his lifetime. By 1900-2 the mean lifetime rise in average real income for new-born males had increased further, to 126 percent, and, for those forming the cohort born just as the world was sliding into the Great Depression, that is, in 1929-31, the average gain experienced over an expected lifetime was as great as 188 percent.[30]

There were, of course, other new products with transforming significance: such as the household appliances already mentioned that helped free women from household drudgery, and the air conditioners that made the South more attractive both for work and for life at home. And the service from all these new products, the telephones, the automobiles, the motion pictures, radios and

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[29] See Endnote 12 to Part One.

[30] For these calculations we use the average annual per capita real output growth rates from Tables 1: I and 1: IA for the periods starting in 1800-55 (for 1800 to 1847), the weighted average of 1855-90 and 1890-1905 (for 1855 to 1900, the weighted average of 1890-1927 and 1929-48 (for 1900/02 to1949) and 1929-89 (for 1929/31 to 1989). The survival prospects for the members of the (white) male birth cohort starting life in 1991 have improved remarkably, as has been noticed, but their prospects for per capita real income growth – over the expected 73 years that the mortality table for that year would allow them – remain especially cloudy. If the 1966-89 growth rate of real GNP per manhour is projected into the future, implicitly assuming that manhours per capita remained constant, they might anticipate experiencing an average lifetime gain of only 144 percent, or substantially less than that enjoyed by the 1930-1 birth cohort. On the other hand, implicitly assuming that the lowered rate of labor productivity growth over the 1966-89 period is transitory and there will be some rebound, the (higher) growth rate of GNP per capita during the 1966-89 period could be projected forward, indicating a gain of 237 percent between 1991 and the year 2064. When we take the geometric average of these pessimistic and optimistic estimates, the "golden mean" figure turns out to be an expected lifetime average real income gain of 184 percent, which is, more or less, a satisfying continuation of the experience of the 1929-31 birth cohort. Of course, more of that projected proportionate measure of material improvement would be "enjoyed" by the 1991 cohort when they are at older ages. And, indeed, a larger part of it is likely to take the form of health care services.

TV's, the vaccines and antibiotics improved immensely as time passed and as the original innovations came to be supported by roads, service stations and repair services, by TV broadcasting stations and networks and, in the case of medical care, by the scientific training of physicians and by better chemistry and biology and by better instruments for diagnosis and treatment. In all these areas, the new products and services, their quality improvements and supporting facilities, formed complementary complexes that supported the spread of the initial innovations and increased their value to consumers.

It seems to us that these important twentieth-century developments in consumer goods, which are unmatched, in our view, by equally important nineteenth century advances, create a strong presumption that a measure of per capita output growth that took into account the true values of new and improved goods and services would show a more pronounced rise in the pace of growth between the centuries than the standard figures now show. And this difference would, of course, register *pari passu* in the estimates of labor productivity growth.

The effect of more comprehensive measures on the inter-century difference in the growth rate of the output of capital goods is more difficult to gauge. The important product developments of the nineteenth century were, indeed, in the sphere of capital not consumer, goods. This meant such products as the cotton gin, steam engines for factories and mines and the belts and shafting that transmitted the power to the new textile and apparel machinery and to wood and metal-working machinery and machine tools. It meant steam ships and railroad structures and equipment and the electric telegraph. And all these new capital goods improved in quality over the course of the century. Taken into account, the measured growth rate of capital goods output in the nineteenth century would certainly appear as substantially more rapid than it now is. But would this change be greater than an analogous reform of the capital goods output figures in the twentieth century?

That is hard to say, for there were, of course, also important new and improved capital goods that were introduced during the last hundred years. Gasoline-powered trucks took over much of the older railroad-freight business; diesel-electric engines replaced steam. Airplanes replaced railroad passenger trains. Gasoline-powered tractors replaced horse-power on the farms. Telephone communication became universal in the business world. Factories were illuminated and air-conditioned, and so were offices and stores. Factory machinery was electrified. Physicians, dentists and hospitals were equipped with X-ray equipment, then with the CAT scan and then with equipment for magnetic resonance imaging. The pain of routine dentistry was greatly reduced by the modern dental drill. Finally, in the last two decades, the computer has become the most important category of new business investment. It would be hard to say whether a more comprehensive and adequate national accounting system would raise the nineteenth-century growth rate of the real output of capital goods more than it would do in the twentieth.

If we treat this ambiguous result as meaning that the significance of new capital goods was about equally great in the two centuries, then the presumption about the comparative growth rates of output in the two centuries remains. With a full accounting for the significance of new and improved products, the twentieth-century growth rate of output would exceed that in the nineteenth century – by an even greater margin than our present measures suggest. But even if one thought that new products meant more for the growth of capital formation in the nineteenth century than it did in the twentieth the presumption would not be seriously weakened. Gross private investment in the last third of the 1800s, when capital formation was especially strong, absorbed only some 20 to 25 percent of GDP. And the percentage became even smaller in the course of the 1900s.

This judgment about the effect of reformed measures on the growth rates of output in the two centuries carries over to comparisons of labor productivity and TFP. Better measures, if they could be made, would, therefore, support a judgment that the contribution of the advance of knowledge to the growth rate of output was, indeed, greater in the last 100 years than in the century before. The difference would then have been even more pronounced than the standard data now available suggest.[31]

These speculations about the significance of new and improved goods and services – uncertain as they may be – are intended to help us make a better judgment about differences between growth rates of output over long periods of time. Our discussion was confined to differences between two successive centuries. They say nothing about differences between successive shorter periods such as those in our tables. More important, even a reformed system of output measurement, if it could be contrived, would not yield a measure of the growth of economic welfare, although it would help us make such judgments. Measures of output and judgments about welfare are separated by many problems and puzzles. Some take us far beyond what any system of output measurement could grasp. Our own speculations about per capita output growth look at past experience from our own perception of the values of people now living. How else could a present-day observer view the past? But a representative person living in 1800 or 1850 might place a different value on today's output of goods and on the way of life involved in its making and spending.

There is much more that is germane to a full picture of the long-run course of economic changes affecting the welfare of Americans. Aggregate output tells us nothing about the division of income among income classes or among other divisions of our society. It does not deal with the character of work, its toilsomeness, dangers, stimulation or torpor. It does not count the costs of growth, such as insecurity in jobs and income or the costs of higher average income and population such as congestion and pollution. Output and its associated income are important considerations in an assessment of economic welfare. They are not the whole story.

6. A Provisional Summary

Five major developments define the profile of growth across the two centuries of modern economic growth insofar as this can be drawn from the available statistics.[32]

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[31] See Endnote 13.

[32] The quantitative picture of U.S. macroeconomic growth in the nineteenth century presented here differs in some particulars from that in Robert Gallman's chapter in Volume 2 of the *Cambridge Economic History of the*

(1) Sustained growth with modern characteristics began in America during the first half of the nineteenth century. It started slowly with an average rate of per capita output growth well below one percent a year over the first half of the century. There was substantial acceleration between the first and second halves, and again at the turn of the century. Since then, for a full century (1890-1989), per capita output growth has risen steadily at a rate hovering around 1.8 percent a year when measured by private output across "long periods." As a result per capita output now stands at a measured level six times as high as a century ago [Table 1: I].

(2) The sources of per capita growth have changed dramatically. A first change was in the relative importance of labor input per head versus output per unit of labor input. In the first half of the nineteenth century, they were of equal importance. In the second half, the labor productivity share rose to two-thirds. And then for three-quarters of a century (1890-1966), the growth of labor input per capita turned negative, and labor productivity growth has utterly dominated the growth of output per capita [Table 1: II]. But the period of Slowdown since 1966 has seen what is probably a transient reversion to the pattern of the nineteenth century. The coming-of-age of the Baby Boom cohorts combined with an accelerated entry of women into paid work to make labor input again an important source of output growth [Table 1: III].

(3) Other major developments consist of the changes in relative importance that occurred among the sources of labor productivity growth [Table 1: IV]. In the nineteenth century taken as a whole, and more particularly in the second half, the growth of tangible capital per manhour was the most important proximate source of labor productivity growth. It was largely responsible for the great speed-up of growth between the first and second halves of the nineteenth century. In the twentieth century, however, the growth rate of tangible capital per manhour was slower, and its decline in relative importance was large [Table 1: IV-Addendum].

(4) In some part, its decline was offset by the growing twentieth-century contributions of Labor and Capital Quality, essentially by the rising educational level of the workforce and by the growing importance of short-lived, high gross return capital equipment relative to that of land and long-lived structures [Table 1: IV]. The rise of education may be seen as a symptom of a still broader rise of knowledge-carrying intangible assets, a development that we have still to take fully into account. But the relative rise of rapidly depreciating capital equipment within fixed reproducible business assets, is another expression (and a tangible one) of the economy's emergence from an earlier epoch of extensive growth to its present dependence on technological progress.

(5) Our measures of TFP growth include such gains as derived from both technological and organizational innovations proper, improvements in allocative efficiency of business enterprises and markets, and economies of scale. Extensive growth, involving rapid population growth and land

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United States. Endnote 10 of Part One provides a reconciliation of the two views, showing that the differences arise largely from differences in the choice of periods, our use of gross private domestic product measure of output rather than net domestic product, and of manhours rather than worker-years for the measure of labor services.

settlement, together with its concomitant provision of a great transportation network of local, regional and national roads, canals, river ways and railroads was the material basis for great gains from economies of scale, as well as the erosion of local monopolies and their attendant inefficiencies. These may have been a very large element in the TFP growth of the nineteenth century. In the twentieth century, however, this gave way to more rapid technological progress based on the advance of practical knowledge with an ever more important scientific base. That progress went on for three-quarters of the present century at a rapid pace. As measured by refined TFP (including further gains from the economies of scale) the pace was more than 3.5 times faster than in the earlier century's second half [Table 1: IV].

(6) Rising total factor productivity thus became the principal source of the present century's rapid growth in both labor productivity and real output per capita, but this is only one facet of the more complicated and interrelated temporal evolution taking place in the configuration of growth sources. The shifting pattern of relative importance among the latter is concisely displayed by the two panels of Table 1:VI. The left-hand frame shows the relative contributions of capital-intensity and input quality (factor composition) improvements to the labor productivity growth rate, based upon the estimates in Table 1: IV. The right-hand frame shows the percentage contributions made by these sources to the rate of growth of real output per capita, and reflects the fact that the rates of growth of labor productivity and labor input per capita are complements in the growth rate of real output per capita manhours. The great rise in the importance of (refined) TFP growth between the centuries emerges clearly from this table, and especially dramatically in per capita than of labor productivity.

Table 1:VI
The Relative Importance of the Sources of Growth: U.S. Private Domestic Economy

	Percentage Contribution to the Growth Rate of Labor Productivity			Percentage Contribution to the Growth Rate of Output per Capita			
	Capital per manhour	Factor composition	TFP (refined)	Manhours per capita	Capital intensity	Factor composition	TFP (refined)
I Nineteenth Century							
1800-1855	49	-	51	55	22	-	23
1855-1890	65	-	35	28	49	-	23
1890-1927	31	7	62	-15	36	8	71
II Twentieth Century							
1890-1927	26	7	67	-4	27	7	70
1929-1966	17	25	58	-45	25	36	84
1966-1989	46	52	3	33	35	40	12

Sources: Computed from growth rates in Tables 1: II and 1: IV.

We end this section with a question, or, more precisely, a bundle of related questions. Up to a point, the broad profile of inter-century differences we have drawn in sources of growth seems easy to accept. One can well believe that the growth of labor input per head became weaker and began to decline in the present century when immigration was restricted and, when, as incomes rose, workers chose to take part of their potential gains in shorter hours and greater leisure. One can well understand that land settlement and development came to an end around the turn of the century and that after the very great nineteenth-century investments in transport and in the provision of the basic infrastructures of town and city life had been made, the importance of the growth of tangible capital should decline. Indeed, the evidence supporting the view that such a change occurred is even stronger than these considerations suggest, as subsequent sections will show. Yet not everything in this historical picture is so transparent. Questions arise mainly from our findings about the pace of TFP growth itself, the inter-century contrast and the relations between technological progress and the contribution from capital accumulation.

On the face of our numbers, TFP growth including both technological progress proper and economies of scale seems very low in the nineteenth century and especially in the second half, when it rose at an average rate of only 0.37 percent a year, although per capita output growth was twice as fast as in the first half, and when the growth account suggests that three-quarters of that increase was attributable to the accelerated growth of tangible capital per manhour. The TFP figure on its face seems small absolutely and small relative to its pace in the twentieth century (beginning 1890) when the speed of TFP growth from 1890 to 1966 appeared to be at least 3.5 times faster. We may well believe the suggestion that technological progress was faster in the twentieth century than in the nineteenth. But was TFP really so much slower in the nineteenth, when the great investments in transportation and the introduction of steam railroads and the telegraph created local, regional and national markets and, presumably, large economies of scale, when steel replaced wood and fragile iron, when harvesting was mechanized, steam power came to factories, the machine tool industry developed and the repetitive assembly of interchangeable parts became common?

Turning to the twentieth century, one asks whether a growth account that allows only for the growth of tangible capital does not turn a blind eye to the rise of a new source of growth in the form of intangible capital. It is not quite a blind eye since our account makes allowance for the growth of labor quality by formal schooling. That, however, is hardly sufficient. There are other components of intangible capital, accumulated by on-the-job training, organized R&D and the costly organization of the administrative infrastructure of large-scale business.

Having in mind our observations of measured capital accumulation and TFP, we point to a general problem. The growth accounts on which we have based our description gain their clarity only at a cost. They assume that the various sources of growth rise or fall and achieve their effects independently of one another. In the world of the standard growth accounts, capital, whether tangible or intangible, accumulates regardless of the pace of technological progress. The growth accounts assume that technological progress is "neutral," raising the returns and demands for labor and capital in equal proportion. They pay no attention to changes in the character of technological progress that influence the kinds of capital required: land, structures, equipment; tangible capital or intangible. And there are reverse effects that run from capital accumulation to technological progress. We shall not understand the forces that have made the pace and proximate sources of twentieth-century growth different from the nineteenth until we face these problems. That is the job of Part Two of this chapter.

Part Two

The U.S. Economy's Shifting Growth-Path

A significant interpretative challenge is posed by the changing magnitudes and the shifting constellation of relationships among the summary growth rate estimates for long periods examined in Part One. As those aggregative measures pertain to the proximate sources of rising real income per capita, we are faced with the task of finding a way to make sense of the rather dramatic transformations that have taken place over the past 200 years in what might be termed the "morphology of American economic progress." What we can provide here will necessarily be less than a full "explanation" of the salient features of that dynamic process, and much less than a definitive account. We propose, instead, an historical interpretation whose principal elements can be classified under two main headings, which might be referred to in an approximate way as subsuming "global dynamic drivers" and "evolving national and regional contexts."

Under the first heading we include forces having largely to do with the development and dissemination of scientific, technological and organizational knowledge of an essentially transnational (Northern Atlantic region) character, but which, of course, came to be expressed in particularistic forms in the North American setting. In the second category are influences that reflected more uniquely American attributes of the economic environment. Among the latter were cultural legacies, social and political styles, institutional habits and routinized commercial and technical practices surviving from the past; learned conditions that were formed by the peculiar experiences of an immigration society newly colonizing a vast and sparsely settled region that was richly endowed in its natural resource *potential;* and still others, which reflected particular American national responses to political and social circumstances that unfolded on the world stage during the twentieth century. We see the historical drama of the U.S. economy's development, and the changing characteristics of its growth-path, as having been shaped by the interplay between those two sets of forces.

To provide a narrative overview of our interpretative account, we may begin by taking notice of those powerful forces of temporal development that can best be viewed as generic, "global" tendencies: they are internationally shared advances in science and technology, considering the latter of those changes broadly to embrace knowledge pertaining to the organization and management of economic activities as well as to the industrial arts. The emergence of the logic of knowledge-based economic development in the U.S. during the present century, and many of the institutional adaptations that have supported and reinforced that process, is thus not to be understood as a unique, national phenomenon. This was instead the manifestation of a broader and more global process, which took particular forms in the U.S. setting.

1. A Narrative Overview

The era ushered in by the Industrial Revolution of the late eighteenth century in Britain saw a definite and increasingly pronounced movement in the direction of what we today think of as conventional "capital-deepening" economic development – the accumulation of stocks of fixed tangible reproducible assets that rose in relationship to the concurrent flow of real output. Part of this tendency involved the growing relative importance of fixed capital vis-à-vis working capital inventories, reflecting the development of tighter technological complementarities between new, inanimately powered production facilities and natural resource inputs, including capital-energy input complementarities; there were relative labor-saving advances, stemming from the creation and extension of the possibilities of substituting machinery and non-human power sources for human effort and skill, but which turned out also to be less conserving in their usage of the raw materials that were being mechanically processed. Although the exploitation of these new technological possibilities became palpable first in the British economy of the late eighteenth century, they began to manifest themselves with increasing force in the U.S. even within the first half of the nineteenth century.

The American Economy's Development Path in the Nineteenth Century

In the U.S., the period stretching from the 1830s through the 1880s saw manufacturing in general follow the path of transformation of production systems that had already been blazed in the textile sector. But the transition from the artisanal shop to the factory in this period was neither equally swift nor uniform in what was entailed across the range of industries, as the work of Jeremy Atack and Kenneth Sokoloff has pointed out.[33] Even as late as 1870, a substantial portion (albeit the minor part) of value added in a number of consumer goods industries (such as boots and shoes, clothing, furniture, meat-packing and tobacco) came from establishments employing fewer than seven workers, and using no inanimate power sources; and there were still some branches of production in which artisanal shops remained the norm. The growth in the scale of production units, and their accompanying transition to greater use of water-powered and steam-driven machinery, entailed changes in the technology of manufacturing processes, and in the organization of work, materials procurement and marketing. But the success of the new factory regime was especially dependent upon the reduction of transportation costs and increasing access to reliable, "all-weather" transportation facilities.

These developments were accompanied by increasing "roundaboutness" of production, and the substitution of tangible capital for artisanal labor in a widening range of industries that came to cater to and encourage the formation of mass markets for their output. The transformations thus

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[33] Jeremy Atack (1987), "Economies of Scale and Efficiency Gains in the Rise of the Factory in America, 1820-1900," in Peter Kilby (ed.), Quantity and Quiddity: Essays in U.S. Economic History, Middletown, CT: Wesleyan University Press, and Kenneth L. Sokoloff (1984), "Productivity Growth in Manufacturing during Early Industrialization: Evidence from the American Northeast, 1820-1860," in Stanley L. Engerman and Robert E. Gallman (eds.), Long-Term Factors in American Economic Growth, Chicago and London: University of Chicago Press.

entailed increases in the ratio of tangible capital to output at the macroeconomic level, and expansions in the scale of productive plant – with corresponding resource savings and increasing capital and raw materials intensity of production – at the microeconomic level. The new possibilities for profitably substituting capital for labor emerged through processes of experienced-based learning, and trajectories of deliberate inventive exploration. The latter paths of innovation had been historically selected by the conditions of relative labor scarcity, and relative natural resource abundance under which early manufacturing activities were established in the U.S. These were characteristically “biased” in a direction that was increasingly "labor-saving" and "capital-using". The overall impact of this bias in nineteenth-century industrial innovation, therefore, was towards raising the ratios of tangible reproducible capital to labor, and to real output. Indeed, those ratios in the economy rose more than would have been called for merely by the inducement that changing relative factor prices provided to substitute capital for labor, within the constraints of an unchanging set of technological possibilities.[34]

While these tendencies toward "biased" technological change were broadly evident elsewhere in the nineteenth-century industrializing world, we see them as having come to be realized most fully and most prominently in the setting of the U.S. The reasons for this, and its implications for the comparative international performance of the American economy both before and after the 1890-1913 era (during which U.S. industries ascended to a position of world leadership), are matters that will occupy us, particularly in Part Three. There we will bring our interpretation to bear upon the question of international convergence and catchup in levels of productivity and per capita real income that occurred in the second half of the twentieth century.

A second key aspect of the mid-nineteenth-century transformation which scarcely can be held to have been a uniquely American development was the extension of an increasingly dense railroad network, and the ensuing reductions in transport charges and transit times that underlay the shift from waterborne carriage and overland freight and passenger haulage by wagon and stage-coach. These were improvements to which not only greater coverage of the continent with trackage, but increasing train speeds and capacities, and the elimination of gauge-breaks and the growth of “through-freight” service were contributing, especially after the Civil War.[35] Their impacts in the restructuring and regional economic integration of the economy, and their further ramifications in the re-organization of industrial and commercial enterprises, were both far-reaching and profound.

Internal transport improvements contributed to breaking down the “protective tariff-walls” of distance, frozen lakes and rivers, and muddy roads that previously had sheltered inefficiently small

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[34] This theme is more fully elaborated in section 2 of this Part, but the reader may wish at this point to consult Endnote 1 to Part Two for clarification of the concepts of "labor-saving" and "capital-using" bias, and the corresponding notions of "neutrality" of technological progress to which these terms implicitly make reference.

[35] See Albert Fishlow (1966), “Productivity and Technological Growth in the Railroad Sector, 1840-1910,” in Output Employment and Productivity in the United States After 1800, Vol. 30. New York: National Bureau of Economic Research, 1966.

local manufacturers and wholesalers. Expanded market access, by the same token, continued to increase the economic viability of ever-larger, fixed-capital intensive industrial establishments and thereby contributed to the aggregate capital-intensity of the manufacturing sector. Thus, over the period from 1870 to 1900, according to Robert Gallman's (1986) estimates, the aggregate ratio of reproducible capital to value added (in constant prices) rose by 81 percent in the manufacturing and mining sectors, whereas it had risen by 57 per cent over the previous thirty-year interval.[36]

This picture just sketched of industrial transformation as the new and significant tendency of the post-bellum decades (1870-1900), however, must be tempered by a recognition of that sector's comparative situation vis-à-vis the rest of the U.S. economy. The level of the aggregate mining and manufacturing capital-net output ratio (in current prices) remained below the corresponding ratio of the comprehensively defined agricultural business sector, even though it was moving upwards towards it during these decades. Although, by the same measure for the industrial sector, the roundaboutness of the industrial commodity-producing sectors well exceeded that characteristic of commerce and other private business, the manufacturing and mining capital-output ratio was only approximately one-fourth of that prevailing in the transportation and public utilities sectors. Thus the growth of the demand for transportation, and the latter's connection with the public utilities infrastructure requirements of an increasingly urbanized population, were the powerful proximate driving forces in the economy-wide rise of the capital-output ratio.

Continuity and Change in the Trajectory of Technological Innovations

New and contrasting tendencies in the progress of technologically relevant knowledge became evident from the closing decades of the nineteenth century onwards. A further step in the progression of industrial development, following on from the supplanting of the artisan shop by steam-powered factories, saw the beginnings of assembly line methods of mass production. This was a movement that may be said to have sprung from the fusion of two manufacturing principles. The first of these derived from the continuous flow transfer techniques (for the *disassembly* of animal carcasses) that were being implemented and elaborated in Chicago's large meat-packing plants during the late 1870s and 1880s; the second involved the methods of production by interchangeable parts that during the same period had been brought to full practical realization in the manufacture of the Singer Co.'s sewing machines, and McCormick harvesting machinery.

Yet, more than two more decades passed before the culmination of developments along this characteristically American trajectory of technological evolution, in 1913, when the Model T automobiles began rolling off the assembly line of Henry Ford's Highland Park Factory on the northern edge of Detroit. Great advances of production engineering had been made by the Ford Motor Co. during 1908-13, involving the integration of machine shop, mechanized foundry and sub-assembly operations, the automated conveyor slide, and the accompanying implementation of

[36] See Robert Gallman, "The United States Capital Stock in the Nineteenth Century," in Engerman and Gallman (eds.), 1986: Table 4.8.

Frederick Taylor's ideas in the standardization of work routines and establishment of "work standards" at Highland Park.

But those developments went beyond merely revolutionizing the business of building motor cars, which hitherto had been essentially an artisanal shop product. As David Hounshell (1984: p. 261) rightly has observed: "The Ford Motor Company educated the American technical community in the ways of mass production."[37] A deliberate policy of openness was embraced during the design and construction of the Highland Park plant, and this, along with the subsequent publicity that Ford himself gave to the idea of "mass production," contributed to the rapid diffusion of these new techniques throughout American manufacturing. They were quickly imitated by other automobile producers, even those producing far smaller runs of cars. Within a decade, conveyor systems were being applied to the assembly of many other new and complex durable goods, including vacuum sweepers and radios, among the range of electrically powered household appliances that were gaining popularity in the 1920s. In 1926, Henry Ford himself described the generic principles of mass production as "the focusing upon a manufacturing project of the principles of power, accuracy, economy, system, continuity, and speed."

Accompanying the dawn of the "Fordist" stage in the evolution of manufacturing, the opening decades of the twentieth century saw the fruition of earlier departures in the inorganic and organic chemicals industries, and in electrical manufacturing and supply industries. These heralded the rising importance of science-based industry and organized industrial innovation. Ultimately, the late nineteenth-century developments in those two particular fields – associated with the work of Haber, Solvay and Dupont, and that of Edison, Ferranti and Siemens – greatly expanded the sphere of new industrial applications of organic chemistry, telecommunications, avionics and the commercial exploitation of biological knowledge in agriculture, animal husbandry and medicine.

An increasing ability to control, and hence to predict the experimental process, and the movement of essentially trial-and-error learning activities from semi-controlled industrial environments into the laboratory, speeded the organized search for technologically exploitable knowledge. The reduction of the expected costs and uncertainties surrounding the inventive process, in turn, worked to increase the rate of return on R&D investment, and hence increased the readiness of firms to commit resources to new process and product research on a regular basis. Integration of R&D as a competitive strategy within the orbit of business management planning was thereby encouraged, as was the extension of the R&D approach to the area of production engineering – particularly in those industries (such as heavy chemicals) where the production of new products entailed radical redesign of manufacturing processes.

Two further consequences may be seen to have been entailed by the foregoing developments. First was an increasing demand for scientists and engineers and supporting personnel, who could carry on the necessary knowledge-generating and knowledge-applications activities. That created

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[37] David Hounshell, From the American System to Mass Production, 1800-1932, Baltimore: The Johns Hopkins University Press, 1984, p. 261.

new incentives for individuals to seek (and invest in) the necessary university training. The prospective demand from industrial employers also stimulated efforts on the part of colleges and universities to adapt existing curricula, or establish entirely new areas of instruction that would be better attuned to those needs. This was a movement that around the turn of the century was already beginning to carry the land grant colleges beyond an initial commitment to responding to the vocational needs of farmers, and into the realms of mechanical and mining engineering. Secondly, and somewhat analogously, the development of organized research in corporate laboratories brought both growing company financing of R&D expenditures, and political interest in the expansion of public and private charitable patronage of research to create a basic knowledge infrastructure that would further raise the private rate of return on applications-oriented R&D. Most of the developments just cited, however, remained nascent, or very limited in quantitative importance at the dawn of the twentieth century. They were harbingers of the coming morphology of growth that would assume full-blown form in the U.S. after World War II.

It is important for our story, however, to re-emphasize that the U.S. economy did not pioneer single-handedly in the fundamental advances of scientific and engineering knowledge that formed the basis for the rise of its newest forms of industrial activity. International (especially trans-Atlantic) participation in the process of invention, and the rapid diffusion of new contributions to the technologies emerging in the fields of machine tools, chemicals, electricity, and automotive engineering, already was quite striking in the period 1870-1913. Yet, in being quick to move towards exploiting the commercialization opportunities that had been created by the advances of the underlying knowledge base, the industrial sector of the American economy already had achieved a particularly advantageous long-run position in this regard when the nineteenth century drew to its close – the recurringly depressed macroeconomic conditions and financial instabilities of the 1890-1907 era notwithstanding. The start that had been made towards the creation of a whole group of new industries came on top of the solid foundations laid in the post-Civil War decades: a heavy industrial, mining and minerals processing sector, which was served by an extensive network of railroads that gave all-weather access to a national market of continental dimensions.

The Exploitation of Natural Resource Abundance

Many features of the industrial structure that at this time was undergoing consolidation and reorganization reflected specifically American conditions that in the preceding century had shaped the path of the country's economic development. These were first, the great abundance, variety and cheapness of natural resources and primary materials; second, the emergence in the course of that century of the largest-scale domestic market in the industrializing world. Both conditions favored a fuller exploration and exploitation of that century's dominant trajectory of technological progress than was possible in European circumstances. The technological path was materials-intensive and tangible capital-using but scale-dependent, and American conditions were especially congruent with it. Large market scale encouraged the invention and use of expensive machinery whose costs could be spread over large sales to a wide market. Abundant and cheap materials facilitated the invention of relatively crude and simple forms of tools and power-driven machinery. These made extensive and seemingly extravagant use of natural resources. Yet, because the latter were complementary with greater use of sophisticated machinery and animate power sources, this profligacy was more apparent than real; it reduced overall production costs by allowing firms to dispense with relatively expensive workers, and especially with higher skilled craft labor. At the outset of its industrial development America possessed abundant virgin forests and brushlands, and, in the Age of Wood that preceded the Age of Iron, this profusion of forest resources generated strong incentives to improve methods of production that facilitated their exploitation, to use them extravagantly in the manufacture of finished products (such as sawn lumber and musket-stocks), and to lower the costs of goods complementary to wood (such as iron nails, to take an humble example). In describing America's rise to woodworking leadership during the period 1800-1850, Nathan Rosenberg aptly writes:

> "[I]t would be difficult to exaggerate the extent of early American dependence upon this natural resource: it was the major source of fuel, it was the primary building material, it was a critical source of chemical inputs (potash and pearlash), and it was an industrial raw material par excellence."[38]

Beyond that stage, the industrial technology that had emerged by the decades at the close of the nineteenth century and the beginning of the twentieth century was based firmly on the exploitation of the continent’s endowment of minerals: on coal for steam power, on coal and iron ore for steel, and on copper and other non-ferrous metal for still other purposes. American enterprise, reprising its early nineteenth-century performance in rising to "industrial woodworking leadership" by combining technological borrowing from abroad with the induced contributions of indigenous inventors, now embarked upon the exploration of another technological trajectory: the new path was premised upon, and in turn fostered the rapid and in some respects environmentally destructive exploitation of the country's vast mineral deposits, just as in the preceding era wastefully impatient use had been made of the nation’s virgin forest resources.

During the second half of the nineteenth century and continuing into the early twentieth century, the dominant path of technological progress and labor productivity advance continued to be naturally resource-intensive, but made increasingly heavy use of mineral resource inputs, as well as being more markedly tangible-capital-using. This particular path of innovation was, moreover, scale-dependent in its elaboration of mass-production techniques and high-throughput operating strategies for business organizations. Although the characteristic features of this technological trajectory individually can be traced back to industrial initiatives in both Britain and the U.S. earlier in the nineteenth century, the ensemble found fullest development in the environment provided by the North American continent.

As has been indicated, one source of the country’s advantage in following this particular trajectory of biased innovation stemmed from the congruence between its pattern of input complementarities, and the North American continent’s abundant and cheap supplies of primary materials. The new methods of production substituted tangible capital equipment for labor, while making more intensive use of raw materials and energy. Their profitability was therefore enhanced where the relative prices of the latter inputs were lower in the mid-nineteenth century phases of this

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38 Nathan Rosenberg, Perspectives on Technology, Cambridge: Cambridge University Press, 1976: Ch. 2.

evolution, the costs of coal as a source of steam power, of coal and iron ore for steel-making, and of copper and still other non-ferrous metals, bulked larger in the total costs of finished goods than subsequently has come to be the case. Those economic circumstances, from the middle of the nineteenth century onward, had acted as a stimulus for programs of public and private investment aimed at discovering, developing and intensifying the commercial exploitation of these mineral resources. Ultimately, as the results of state and federal programs of geological exploration bore fruit, those earlier historical conditions became the foundations for America's growing comparative advantage as an exporter of natural resource-intensive manufactures during the period 1880-1929.[39]

Of course, there were also powerful commercial incentives for private investment in minerals exploration and development. These derived largely from the perceived growth of demand, as American manufacturing shifted away from heavy concentration on the processing of agricultural and forestry products, and towards the production of minerals-based capital and consumer goods. There was, therefore, a fruitful interaction between the development of primary materials supply, the advance of American technology, and the growth of manufacturing, construction and transportation activities serving the large domestic market.[40]

Thus, the twentieth century's opening quarter saw the continued influence of some of the same features of the U.S. resource endowment. Thereafter, for a variety of reasons that we discuss in Part Three, natural resource abundance in general, and mineral resource abundance specifically, became of smaller importance over the broad spectrum of American economic activity. In special ways, however, it remained a potent influence. A notable instance is the continuing discoveries and advances in the exploitation of the country's known petroleum resources, which were extended westward to the southern California basin during the opening quarter of the century.[41] These developments yielded far more than the nation's growing exports of crude oil and high value distillates, such as gasoline and kerosene, and even more than the resource base for the future industrialization of the part of the country that bordered on the Pacific Ocean.[42] Elsewhere at home, petroleum products became part of the underpinning for the rise of car, truck and tractor production and the expansion of the automotive services sector during the 1929-66 era until it was responsible for roughly a tenth of gross domestic product originating in the U.S. economy. Still more directly,

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39 See Gavin Wright, "The Origin of American Industrial Success 1879-1940," American Economic Review, 80(4), 1990: pp. 651-68. See, esp., Chart 5 and Table 6.

40 See Endnote 2 to Part Two.

41 See H.F. Williamson and A.R. Daum, The American Petroleum Industry, Evanston, Illinois: Northwestern University Press, 1959; H.F. Williamson et al., The American Petroleum Industry: The Age of Energy, 1899-1959, Evanston, Illinois: Northwestern University Press, 1963; Paul A. David and Gavin Wright (1997), "Increasing Returns and the Genesis of American Resource Abundance," Industrial and Corporate Change, 6(2), pp. 203-45.

42 On California's industrial development esp., see Paul W. Rhode, Growth in a High Wage Economy: California's Development, 1900-1960, (Unpublished Ph.D. Dissertation), Stanford University, 1900.

the abundance of domestic petroleum supplies yielded by exploitation of the oil fields of West Texas, Oklahoma and southern California contributed to the creation of a wide group of new petrochemical-based manufacturing industries in which America took a technological lead.[43]

Another important set of region-specific influences was linked to the development of an economically large national economy that was integrated by transport and communications systems of continental reach, and which, in comparison with other contemporaneous societies, would soon become remarkably homogeneous in its political and social structures. From an early point in its history, the U.S. was among the pioneers in the elaboration and replication of large, spatially distributed technological systems, including systems of business organization and public service provision. Like airline systems, the multi-divisional and multi-plant corporations, and the public school and university systems, the electricity supply and telephone systems first developed locally and regionally to achieve conventional economies of scale. They were then replicated across localities and regions to form dense and extended networks (with corresponding network externalities) that differentiated the American economy from all but a few others by the mid-twentieth century.

Rising Intangible Investments and the Transformation of Human Resources

Formation of these large production organizations and systems of distribution that were complex and intricate created new demands for manpower, with needs for novel skills emerging as old ones were rendered obsolete or redundant. The absorption of European immigrants into the American workforce in the post-Civil War decades was facilitated by the substitution of mass production technologies that reduced artisanal skill and training requirements for production workers, while raising demands for non-production workers in clerical and managerial positions. Yet, over the course of the twentieth century the overall demand-side impact has been quite unambiguously that of supporting a rise in the minimum level of educational attainment in the population, while expanding the proportion of the workforce that had undergone prolonged periods of formal education.

The twentieth century has witnessed two distinct waves of human capital formation. The first of these was centered in the first quarter of the century and involved the extension of High School education to a large segment of the population, whereas the "college education" movement, which formed the second wave, gathered momentum after the mid-point of the century. In the closing decade of the nineteenth century, only rather less than half of the population in the age range from 5 to 24 years was enrolled in some regular educational institution. From that low base c.1890, the pace of progress began to quicken: this was reflected two decades later by the accelerating rise of the average number of school years completed by all males in the age group 25 and older: it rose by 6.4 percent in the decade 1910-20, by 7.6 percent in the following decade, and so on, until the

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[43] On U.S. petrochemical manufactures more generally, see Ashish Arora, Ralph Landau and Nathan Rosenberg, (Eds.), Chemicals and Long-Term Economic Growth: Insights from the Chemical Industry, New York: John Wiley and Sons, Inc., 1998, esp. Chs. 3, 5, 7.

decadal rate of advance topped 10 percent during the 1940s.[44] The average number of years of schooling among American males was thereby raised from 7.56 to 11.46 between the birth cohort of 1886-90 and that of 1926-30, and the average annual rate of increase shifted upwards by a bit more than 1 percentage point.

Claudia Goldin's (1998) research brings out the striking fact that approximately 70 percent of this increase was accounted for by increases in *secondary* schooling alone.[45] The male high school graduation rate, for example, stood at 10-15 percent for the cohort born in the 1890s, but rose to nearly 50 percent for those born after World War I. High school thus became part of the system of mass education in America during this era, whereas previously it was typically either the final stage of the training of school-teachers, or a requirement for the tiny minority of the population who sought a Bachelor's degree (or the professional equivalent thereof). Whereas almost one-half (49 percent) of the high school graduates of the mid-1880s went on to receive a Bachelor's degree from an American institution of higher education, the widespread extension of high school education in the following decades brought that fraction down to 30 percent by 1906, and to 22 percent by 1926.[46]

Although the stock of graduates from U.S. institutions of higher education was rising very rapidly early in the century, it was still negligibly small, and its formation was neither a significant claimant upon national resources nor a noticeable influence upon the quality of the workforce. To the extent that investments in education beyond the common school level could be rated as important on either count during the first quarter of the twentieth century, they were entailed in the public high school movement. The latter took root first in the Midwest during the 1880s, spread quickly to other regions in the North before 1914, and by the 1930s had largely been completed – with the widespread achievement of generally high attendance rates, a significantly lengthened average school year, and substantial graduation rates – everywhere in the country save for the still largely agricultural South.

The early phases of this movement, however, cannot properly be understood as merely an automatic, market-induced adjustment of the nation's labor supply, in response to occupational demand shifts driven by technological and organizational innovations in industry. It seems only

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44 The figures for 1910-40 are based on Edward F. Denison, The Sources of Economic Growth in the United States and the Alternatives Before Us, New York: Committee for Economic Development, 1962, Table 4, col. 2. These estimates were made using the cohort method, subject to an upward adjustment of 0.2 percentage points per annum to allow for a suspected reporting error. For educational attainment estimates based upon U.S. Population Census data for the period 1940-60, see Moses Abramovitz and Paul A. David, "Technological change and the rise of intangible investments: the US economy's growth-path in the twentieth century," in Employment and Growth in the Knowledge-Based Economy: OECD Documents, Paris: OECD, 1996: esp., Table 2 .

45 See Claudia Goldin, "America's Graduation from High School," Journal of Economic History, 58(2), June 1998: pp. 345-74.

46 See Footnote 12 above.

reasonable to suppose that an important impetus for this movement derived from the increasingly widespread public awareness of the developing statistical association between high school attendance and subsequent access to "better quality jobs," even jobs in blue collar occupations. By working backward from the comprehensive schooling data presented in the 1940 census, Claudia Goldin and Lawrence Katz have been able to show that the percolation of high school graduates throughout the manufacturing sector initially was extremely uneven; that those industries which had been built upon the newly emergent science-based technologies – such as aircraft, electrical machinery, and petroleum refining – employed large numbers of high school graduates in both blue- and white-collar jobs, and it appears that this pattern goes back at least as far as the 1910s.[47] Detailed job descriptions and qualifications, developed by the Bureau of Labor Statistics between 1918 and 1921, reflected the increasing role of schooling-based skills, such as "knowledge of weights and measures," "record-keeping and computations," "knowledge of how to set machines and test results," "special ability to interpret drawings," and so forth. Yet, these were quite atypical among the mass of manufacturing pursuits, and in the older, staple industries such as meat-packing and cotton manufactures, virtually no jobs are listed as having any required level of schooling at all; even a "loom fixer," the most important and skilled worker in the weaving room, was not expected to have more than a common school education. Furthermore, even in the newer industries drawing on newer technologies, the job descriptions of this era suggest that very limited levels of cognitive mastery actually were expected. Actual command of scientific knowledge as a job requirement was limited to a tiny fraction of the overall work force, and these positions typically required post-secondary training if not professional degrees.

The new and more rapidly growing industries, nonetheless, had ample reasons for adapting their hiring criteria and job descriptions to match the curriculum of high school education. Another recent reading of the evidence from the pre-1929 era, by David and Wright (1999), suggests that in setting hiring standards certain personality traits, such as patience, reliability, and general amenability to instruction, were given equal if not greater prominence than were the more strictly academic cognitive qualifications. In the technologically more sophisticated industries, and especially in branches of manufacturing where continuous production processes raised both productivity and the damage that incompetence or carelessness could cause, employers increasingly sought workers who could accustom themselves to changing work routines, and would be dependable in executing mechanically assisted tasks. High school attendance and high school completion appear to have constituted signals of these attributes, and of the motivation to respond to experience-based wages and job promotion incentives that were designed to stabilize and upgrade the quality of the workforce in the leading manufacturing firms during this era. Thus, it was in their interest both to advocate and to exploit the public's subsidization of the secondary education system

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[47] Claudia Goldin and Lawrence F. Katz, "The Origins of Technology-skill Complementarity," Quarterly Journal of Economics, 113, (August) 1998: pp. 693-732. For further discussion, see Paul A. David and Gavin Wright, "Early Twentieth Century Productivity Growth Dynamics: An Inquiry into the Economic History of 'Our Ignorance'." Stanford Institute for Economic Policy Research Discussion Paper No. 98-3, (April) 1999, esp. pp. 25-7 and Table 5.

as a screening mechanism, through which "signals" of those desirable qualities could more readily be acquired by workers who also would be willing to enter blue-collar occupations.[48]

But, there were other social, political considerations that came into play in America's precocious initiation of mass secondary education. Middle-class support for public education beyond the grade school level, especially in preparation for the "genteel," non-manual pursuits, was increasingly vocal during the decades immediately surrounding 1900, and this impetus was reinforced by political concerns to promote "Americanization" among first-generation citizens. Such motives were quite compatible with perceptions on the part of employers that increasing cultural homogeneity of young members of the workforce would serve to increase the interchangeability and adaptability of the labor force, thereby facilitating the replication of standardized work routines and labor management practices within and across regional labor markets – at least as far as concerned the white workforce. These influential currents of opinion, which issued in the provision of tax-funding for state and local programs of mass secondary education, may be seen as part of the response evoked by the heavy influx of "new" immigrants from southern and eastern Europe in the period. Consequently, beginning most notably in the Midwest (and, more generally in those regions of the North where there were relatively fewer youths from low-income foreign-born households, who needed the earnings from their labor in factories and shops), the 1890s saw an increasing fraction of young Americans attending and completing High School.

Thus was set in motion the dramatic and sustained growth of the nation's stock of intangible human capital, led by the increasing educational attainments of its workforce. Reinforced by industrial and derived occupational shifts that increased the demand for longer schooling, it laid the foundations for the subsequent transition to mass college and university attendance that marked the post-World War II era, and which has continued the upward course of the U.S. population's average educational attainment. Of course, the pace at which the schooling level of the workforce as a whole could rise during 1886-1926 was slower than the speed at which high school completion was diffusing through the population. As the more schooled males were the last to enter the workforce, the full effect of the increase in years of schooling had to wait for the retirement of successive cohorts of older workers since so few of them had as much as a year of high school attendance.

Indeed, according to Goldin, of the cohort of males born in 1886-1890 who survived to report their educational attainment to the 1930 census takers (when they were 40-44 years old), 72.5 percent had fewer than eight years of formal schooling, and only 17 percent had 12 or more years.[49] Among

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48 In explaining cross-state variation in the spread of high school education, Goldin (1998) reports that the relative importance of manufacturing in a state was in fact a negative influence. Furthermore, in his study of evolving employment relations in Philadelphia, Walter Licht (Getting Work: Philadelphia, 1840-1950, Cambridge MA: Harvard University Press) reports that increases in the compulsory school-leaving age were never welcomed by either employers or by the bulk of the students; these policy changes were part of the broad policy trend to exclude teenagers from the labor force, and for the most part not a response to rising educational demands by employers.

49 See Goldin, "America's Graduation from High School," (1998): Table 1.

the entire U.S. male population aged 25-34 years old at the time of the 1930 census, 24.4 percent reported having had four years of high school education and beyond, whereas the corresponding figure among the 25-34 year olds in 1910 had been only 15.7 percent. The average speed at which high school completion had spread through the male population of prime working ages was thus about 2.2 per cent per annum during the 1910-30 interval. The comparable rate rose on average to 7.5 percentage points per annum over the interval between 1930 and 1960, by which date well more than a majority of them (53 percent) had at least completed high school, and a significant minority had completed four years of college.[50] Something must also be given to the effects of closing immigration to the U.S. after 1918, in creating conditions that facilitated the speed of the shift towards higher average educational attainments, and so provided the skills and worker qualities that were complementary with the new technologies and the more complex systems that were being developed.

"College education" had been a rarity among the American populace until the latter decades of the nineteenth century. The seventeenth and eighteenth century origins of institutions such as Harvard College, Columbia College and Yale notwithstanding, it was not until the 1860s that Americans first began hearing about the “business colleges” and “state teachers’ colleges” that eventually would bring higher education within the grasp of the common citizen. By 1880, however, some 811 higher education institutions (HEI’s) were already in existence, having a combined faculty of roughly 11,500 and awarding something in the order of 13,000 bachelors degrees annually, though it was not until 1888 that the total number of academic doctorates awarded annually in the whole country moved past the 100 mark.[51] While it took more than a half-century for the number of HEI’s to double from the level that had been reached in 1880, the average number of faculties per institution had undergone a 3.5-fold expansion during those 50 years, and the annual number of Bachelor’s degree recipients per institution had increased 5-fold. Still, only 2 percent of America’s 23-year olds received a Bachelor’s (or equivalent professional degree) in 1910, and in 1930 the corresponding figure remained below 6 percent.

The major period of advance in the college and university education of the labor force, therefore, has been a feature of the post-1929 era, and it only began to make a large impact on the quality of the workforce during the late 1960s and 1970s when the large birth cohorts of the post-World War II “Baby Boom” were moving through the universities. Between 1930 and 1948 the number of college graduates expressed as a proportion of all those who had graduated from high

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50 The figures cited in the text refer, respectively, to the numbers of Bachelor’s degree recipients in 1888, 1910 and 1930, expressed as a percentage of the total number of high school graduates four years previous to each date. See U.S. Department of Commerce, Historical Statistics of the U.S. (1975), v.I: Series H-759.

51 The diffusion of high school completion proceeded at a matching pace among the female population, but the initial and hence the terminal levels of the fraction of women ages 25-34 who reported having had four years of high school and beyond were even larger than in the case of the males (58.0 in 1960). See the estimates based on corrections of the original census figures by Susan O. Gustavus and Charles B. Nam, “Estimates of the ‘True’ Educational Distribution of the Adult Population of the United States from 1910 to 1960,” Demography, 5(1), 1968: pp. 410-21.

school four years before was raised from 22 percent to 27 percent, a level that was maintained through to the mid-1960s. Thereafter, the early years of the Vietnam War era witnessed a further sharp rise, so that by 1969 the 31 percent level had been reached. At that date the number of Bachelor's degree recipients represented more than one-fourth of the nation's 23 year-olds, twice the proportion that had been achieved in 1948. The "golden era"of post-World War II economic growth also saw the first substantial movement into postgraduate education since the 1920s, as the numbers receiving doctorates swelled from approximately 4,000 in 1948 to 28,000 in 1969.[52]

Tangible Capital-Saving Innovations and Quickening Total Factor Productivity Growth

The substitution of fixed capital for skilled artisanal labor that was characteristic of the preceding era now gave way to a new twentieth-century tendency that was augmented in strength by the prospects of declining fertility and slowed labor force growth (unrelieved by any possibility of revival of mass immigration). With the resumption of rising real wages following World War I,[53] capital-labor substitution continued to be encouraged, but there also were opportunities to reduce unit costs of production by developing ways of intensifying the utilization of fixed facilities. This was a strategy that was first implemented in the late nineteenth- and early twentieth-century consolidation of railroads, and the technological innovations designed to increase train-speeds and power utilization. Its roots can also be found, as Alfred Chandler has pointed out, in the high throughput manufacturing regimes that appeared after 1870, when production and direct-selling were extended to serve increasingly wide markets.[54]

Along with the new managerial focus and increasing expertise devoted to increasing the throughput rate of production and marketing enterprises, there came savings on the costs of inventories of goods in process and stocks of finished products, all of which worked in the direction of lowering the marginal capital-output ratio in the nation's manufacturing sector.[55] With the coming of enhanced transportation and communications facilities, it also was feasible to achieve high stock turnover rates, and narrowed margins in the distribution trades; the late nineteenth century thus saw the appearing of the pioneers of that strategy among the large-scale retail businesses – such as Marshall Fields, Macy's and Sears Roebuck. But, throughout the next half-century, in the distribution sector small, low-turnover and high-markup firms managed to co-exist with the high

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52 See Endnote 3 to Part Two.

53 On the altered industrial labor market conditions that emerged after 1917, and behavior of real wages, see David and Wright, "Early Twentieth Century Productivity Growth Dynamics," (1999), esp. 19-25.

54 See Alfred D. Chandler, Jr., <u>TheVisible Hand: The Managerial Revolution in American Business</u>. Cambridge, MA: Harvard University Press, 1977.

55 On inventory stocks and investment, see Moses Abramovitz, <u>Inventories and Business Cycles, with Special Reference to Manufacturers' Inventories</u>. New York: National Bureau of Economic Research, 1950. On increased throughput rates and savings on working capital, see Alexander J. Field, "Modern Business Enterprise as a Capital-Saving Innovation," <u>Journal of Economic History</u>, 47(2), June 1987: pp. 473-85.

volume enterprises to much greater degree than was feasible in manufacturing. Local market power, arising from locational convenience, certainly afforded small stores a measure of protection from the competition of supermarket chain-stores, and other high-turnover retailers. But the persistence of the share of the market throughout the interwar era and early post-World War II years, also owed something to the imposition of differential taxation of chain-stores by state legislatures early in the twentieth century, and the introduction of "price maintenance laws" (starting with the passage of the Robinson-Patman Act of 1936).[56]

The technological developments that expanded the scope for continuous process industries, such as the reorganization of batch production systems to move them towards an around-the-clock shift-working basis, and the managerial changes that were required to coordinate the flows of men and materials in these high-throughput operations represented innovations of the "tangible fixed-capital augmenting" kind. These contributed to the turn-around in the trend of the real tangible capital-output ratio, which in the first decade of the present century commenced a secular fall not only in the manufacturing sector, but in the private business economy at large.

A marked acceleration of total factor productivity (TFP) growth took place in the U.S. manufacturing sector following World War I. This surge saw the annual growth rate jump fully 5 percentage points between the second and third decades of the century, and it contributed substantially to the absolute and relative rise of the TFP residual that we observe (in Part One) when the "growth accounts" for the first quarter of the twentieth century and those for the latter half of the nineteenth are compared.[57] Annual measures of TFP in U.S. manufacturing are not available for this era, but it seems nonetheless clear that the discontinuity revealed by comparison of the decadal average rate of growth for 1919-29 with that for 1909-19 was not an artifact of cyclical fluctuations accentuated by wartime and postwar demand conditions. The recent statistical analysis by David and Wright[58] of the available annual figures for labor productivity (real gross product originating per full-time equivalent manhour in manufacturing) confirm an upward shift in the trend rate of growth from 1.5 percentage points per annum during 1899-1914, to 5.1 during the period 1919-29.

While this historical break in the productivity trend was not a phenomenon unique to the manufacturing sector, it was heavily concentrated there. John Kendrick's (1961) estimates of the

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56 For further discussion, see, e.g., Alexander J. Field, "The relative productivity of American distribution, 1869-1992," Research in Economic History, 16, 1996: pp. 1-37.

57 See Paul A. David, "The Dynamo and the Computer: An Historical Perspective on the Productivity Paradox," American Economic Review, 80(2), May: pp. 355-61; "Computer and Dynamo: the Modern Productivity Paradox in a Not-Too-Distant Mirror," in Technology and Productivity: The Challenge for Economic Policy, reminded economists and economic historians of the surge which followed an industrial "productivity pause" that extended throughout the period 1890-1918.

58 Paul A. David and Gavin Wright, "Early Twentieth Century Productivity Growth Dynamics: An Inquiry into the Economic History of 'Our Ignorance'," SIEPR Discussion Paper No. 98-3, Stanford Institute for Economic Policy Research, April 1999.

decadal increase in total factor productivity (TFP) during 1919-29 were approximately 22 percent for the whole of the private domestic economy, whereas the corresponding figure for manufacturing was 76 percent, and for mining 41 percent. The proportionate increase of TFP in transportation, communications and public utilities exceeded the average for the U.S. private domestic economy as a whole by lesser amounts, while the farm sector was in last position with a relatively low gain of 14 percent.

At the heart of the story, then, was manufacturing, where the acceleration was particularly pronounced and pervasive among the main industrial groups. The movements of the partial productivity indexes for these same industry groups over the course of the 1919-29 interval shows a striking positive correlation, which was a departure from the tendency in the preceding decades. For industrial labor productivity increases to be associated with decreasing capital productivity, rather than capital-deepening, reflected in a rise in real capital inputs per unit of real output, manufacturing industries both in aggregate and at the industry group level were undergoing "capital-shallowing" or rising capital productivity after 1919.

A long period of stasis in the real unit costs of industrial labor during 1890-1914 came to an end with the outbreak of World War I, and the ensuing rapid rise in the price of labor inputs vis-à-vis the prices of both capital inputs and gross output was sustained during the post-War decade. The change in relative factor prices thus was in a direction that would be expected to induce the substitution of capital for labor within the pre-existing set of production technologies. Therefore, it is particularly striking that after 1919 the rise of capital-intensity in U.S. manufacturing proceeded at a greatly *retarded* pace. Between the 1889 and 1909 census benchmark dates, the ratio of capital inputs per unit of labor input was rising at the average rate of 2.6 percentage points per year, and the pace quickened to 2.8 percent per annum over the decade 1909-19. But, as John Kendrick's (1961) figures show, despite the upsurge of real wage growth, during the 1920s the growth in capital-intensity slowed to (1.2 percentage points per annum) well below half its previous pace. This change, and the emergence of tangible "capital-shallowing" tendencies with which it was linked represented a new departure, which one of us (David 1990, 1991) has connected to the concurrent diffusion of a new factory regime in which the productive potentialities of the electric dynamo were, at last, fully exploited by the "unit drive" system in which independent motors were placed on each machine.[59]

It is also worth noticing that there was an easing of another previous source of upward pressure on the aggregate capital-output ratio. That pressure had come from the demand to create urban infrastructures – in the form of housing, streets, sewers and local transportation facilities – to serve the commercial distribution and industrial centers of new regions of the country that were being opened up for population-intensive forms of economic exploitation. James Duesenberry[60] long ago observed that the successive waves of internal migration, which had carried the "urban frontier"westward during the nineteenth century, had the effect of increasing the demand for fixed

59 This explanation recently has been elaborated upon by David and Wright (1999).

60 James Duesenberry, Business Cycles and Economic Growth, New York: McGraw-Hill, 1958.

capital in new locations, yet did not cause an offsetting, commensurately rapid run-down of the corresponding capital stock components in the older cities of the Eastern seaboard. Of course, the urban infrastructure of the latter region was coming to be more intensely utilized to accommodate the large influx of immigrants arriving from Europe in the period 1880-1914. But, until late in the century, the balance of those forces, working in combination with the related demands for expanded transport infrastructure in the West, was operating in a way that held the marginal capital-output ratio above the average capital-output ratio in the economy as a whole. With the closing of the frontier and the choking off of European immigration (by World War I, and the subsequent imposition of legislative restrictions in the U.S.), this former demographic mechanism no longer functioned to sustain a secularly high ratio between the level of the desired fixed tangible capital stock and the level of the real gross domestic product.

Management of large technological and commercial systems also called for new techniques for "communication and control."[61] These rendered more effective the push for ever-higher rates of utilization of fixed capital facilities, and faster stock-turn to lower the costs of inventory holds of goods in process. The same capital-saving motivation in the drive for improved "control" had played a role in initiating pioneering U.S. advances in information systems – from the telegraph system's close relationship to the railroad industry's operations and the activities of wholesale distributors starting in the mid-nineteenth century, to the twentieth-century development of a nation-wide telephone network, and of computer systems in the twentieth century. To cite another, and emblematic link of this kind, the modern digital computer grew out of Vannevar Bush's designs for "differential analyzers," an analogue computer that was sought for the purpose of performing the calculations necessary for real time management of electrical power supply systems.[62]

Engines of Growth – The Recurring Dynamics of General Purpose Technologies

Thus, however distinct and different was the new technological thrust that has characterized the twentieth century – encouraging through its demand effects the rise of investment in intangible productive assets in the form of more highly educated people and stocks of R&D-generated innovations, and reducing the demand for conventional tangible capital goods in relationship to real output – in these developments there also were some important continuities from an earlier epoch. Perhaps the most striking among these was the way in which a succession of "general-purpose

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61 This general theme is treated in James R. Beniger, The Control Revolution: Technological and Economic Origins of the Information Society, Cambridge, MA: Harvard University Press, 1986. On the role of "internal" communications technologies in the growing size of business organizations in the period 1850-1920, see JoAnne Yates, Control through Communication: The Rise of System in American Management, Baltimore: The Johns Hopkins University Press, 1989.

62 See Beniger (1986), esp., Ch. 9, on the historical roots of modern information and control technologies. The differential analyzer, built by Bush in 1930, was the first automatic computer general enough to solve a wide variety of mathematical problems; it preceded Wallace Eckert's more widely mentioned "mechanical programmer" (1933), which linked various IBM punch-card accounting machines to permit generalized and complex computation.

technologies" came to be elaborated and implemented in the U.S. during the present century. General purpose technologies open up new opportunities for innovation – in both inventive and entrepreneurial activities – rather than offering a complete, self-contained and immediately applicable solution to one or another specific problem.[63] In that sense, their nature enables further changes, inducing further investment of resources in the creation of clusters of complementary innovations; and their pervasive penetration into products and processes across a wide and varied range of industries permits their own further elaboration and enhancement to exert a greatly magnified impact on productive performance throughout the economy.

Thus, in the twentieth century, the extensive deployment and continuing development of the electric dynamo, mass production in fixed transfer-line factories, telecommunications via the electromagnetic spectrum, internal combustion engines fueled by petroleum distillates, and, most recently, the microelectronics-based digital computer – represented a recurrence of dynamic patterns of innovation and diffusion that were experienced earlier, in the age of the steam engine, factory system, railroad and telegraph.[64] The sources of the scientific and engineering knowledge underlying the creation of these "enabling technologies" have been international, rather than peculiarly American. But these innovations found practical expression and extensive commercial development first and most fully in the United States' highly flexible and adaptive social and economic environment.

Consequently, the specific forms that emerged from the initial implementation of these general purpose technologies during the twentieth century owed much to the particular legacy of the country's nineteenth-century development. Their subsequent diffusion within a widening international sphere, in turn, has transmitted to many societies in the economically developed world some portion of the legacy of that earlier era of "American exceptionalism." Abroad, as previously had been the case within the sphere of the U.S. domestic economy, the drive to exploit this accumulating body of knowledge and know-how has been a powerful force for "convergence"– reshaping the organization of production and distribution globally, and transforming the nature of work, consumption and leisure activities in the process of raising material standards of living.

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[63] On "general purpose engines," and the generalized concept of a "general purpose technology" (GPT), see Paul A. David, "General-purpose engines, investment and productivity growth: from the dynamo revolution to the computer revolution," Ch.7 in Technology and Investment: Crucial Issues for the 1990s (E. Deiaco, E. Hornell and G. Vickery, (Eds.), London: Pinter Publishers, 1991; Timothy F. Bresnahan and Manuel Trajtenberg, "General Purpose Technologies: Engines of Growth," Journal of Econometrics, 65, 1995: pp. 83-108; Elhanan Helpman, ed., General Purpose Technologies and Economic Growth, Cambridge, MA: MIT Press, 1998; Paul A. David and Gavin Wright, "General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution," (Paper for the International Symposium on Economic Challenges of the 21st Century in Historical Perspective, in Oxford, 2-4 July, 1999), University of Oxford Discussion Papers in Economic and Social History (June), 1999.

[64] For comparative discussion of these and other historical episodes, see Richard G. Lipsey, Cliff Bekar and Kenneth Carlaw, "What Requires Explanation?," Ch. 2 in Helpman, General Purpose Technologies (1998).

2. Interpreting the Macroeconomic Record

The U.S. macroeconomic record that we examined in Part One exhibits a number of striking features which distinguish the morphology of the long-term growth path during the twentieth century from the economy's growth characteristics in the preceding century. The contrasting dynamics of those two epochs is evident from the movements of key macroeconomic ratios, and a brief review of these at this point will serve to highlight the new nature of the growth process. It will be seen that the following five salient points of contrast in the macroeconomy's movements also have been perceptible at the lower levels of aggregation, which were touched upon in the foregoing narrative overview.[65]

(1) The trend of labor productivity (real gross output per manhour) has been upwards throughout the whole course of the national experience, but it underwent a quickening that became evident from the mid-nineteenth century onward, and a still faster long-term rate of growth (approximating 2 percent per annum) has been maintained throughout the present century.

(2) The trend in the ratio of real gross output to total factor input, or TFP (refined index), also was upwards over the course of the nineteenth century, but at a pace that remained very moderate in absolute terms until the century's closing decades, averaging only a fraction of the approximate 1 percent per annum trend growth rate of TFP (refined) that characterized the whole of the period between 1890 and 1989. Within that century-long span, however, the trend in the pace at which TFP was rising did not remain constant: starting in the 1920's, it accelerated to an average annual rate approaching 1.5 percentage points, which was sustained over the 1929-66 interval. The collapse of the TFP residual which then ensued appears both in its magnitude and its extended duration to be a turn-around quite without precedent in the nation's economic history.

(3) A rising ratio of tangible capital services per manhour labor input has accompanied the rise of labor productivity, but in the twentieth century the gap between the trend rates of growth of tangible capital services and manhours has not been as wide as it was previously. On the other hand, since the closing decades of the nineteenth century the rise of investment in education and training, and in organized R&D activities, has meant that the ratio of the services of *intangible* capital inputs to tangible labor inputs (i.e., manhours) has grown at a much faster pace, both absolutely and relatively than before.[66]

(4) The ratio between inputs of (gross) tangible capital services and real gross output rose markedly over the whole of the nineteenth century, although its approximate doubling was

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65 See the Endnote 4 to Part Two, on methodological issues concerning the relationship between macro-level analyses in economic history.

66 This last point will be brought out more explicitly, below, in the discussion of Tables 2: I and 2: II.

concentrated within the central period, stretching from c.1835 to c.1890.[67] By contrast, starting soon after the beginning of the twentieth century the trend in this ratio turned downwards, and remained markedly so until early in the post-World War II era; the tangible capital-output ratio continued to drift downwards at slowing pace during 1948-73 and has approached stability thereafter.[68] Although we presented no explicit estimates of the growth of the intangible capital stock over the course of the nineteenth century, reasons were given for surmising that it could not have been rising much faster than inputs of manhours and, consequently, must have been growing slowly by comparison with the tangible reproducible capital stock. From the late nineteenth century onwards, however, the ratio between the intangible and the tangible stock of capital has been rising rapidly, as will be seen more explicitly from new estimates that we shall introduce, below.

(5) The share of the gross private domestic product represented by the earnings of labor actually declined during the nineteenth century, whereas it has followed an upward trend in the present century. It was the rising share of output represented by the gross private returns (imputed) to tangible reproducible capital that was responsible for the nineteenth century contraction in the share of labor, because the share of output represented by rental income on the stock of non-reproducible tangible wealth (unimproved land) remained essentially constant. During the present century, the expansion of the labor income share has been largely concentrated in years between 1929 and 1973, and, as shall be seen, this reflected the growing portion of labor earnings that can be attributed to the relative accumulation of human (intangible) capital.

The patterns of change in these macroeconomic relationships that characterized each of the centuries within our purview, and the contrast between the two epochs, both call for explanation and interpretation. In the interpretive account developed in the three following sub-sections (2.1 -2.3), these quantitative trends are viewed primarily as reflections of, and direct and indirect endogenous responses to underlying developments affecting the rate and direction of technological innovation, broadly conceived. Our interpretation carries some quite direct implications about the altered behavior of U.S. savings that has been observed at the macroeconomic level during the twentieth century. This section therefore concludes by touching briefly upon that question (in sub-section 2.4).

2.1 The Critical Role of Technological Progress and the Changes in Its Direction

Although the changing pace and character of technological innovation figures centrally in our reading of the U.S. historical experience of growth, "the progress of invention"– as it was referred

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67 The significance of the dating of this interval, which combines the 1835-55 trend period with the "long period" 1855-90, is discussed briefly in section 2.3, below.

68 These trends may be inferred directly from a comparison of the growth rates for the stock of total tangible reproducible capital and real gross private domestic product shown in Table 2: I, or from the movements of the constant dollar tangible capital-output ratio for the U.S. domestic economy that can be calculated from the data in Table 2: II.

to by economic writers in the nineteenth century – should not be seen as a wholly independent, autonomous force driving the process of growth. On the contrary, many of the determinants of the generation and diffusion of innovations quite clearly were endogenous to the economic system. At the same time, the main features of the course of technological and organizational innovation that so powerfully shaped the economy's growth-path in each century, were neither formed exclusively by the concurrent American economic environments, nor were their effects confined to the U.S. domestic product and factor markets.

For the present purposes, then, technological evolution can best be conceptualized as a trans-national, global force whose underlying tendencies in regard to pace and direction manifested themselves particularly clearly in the American setting. This was in some part due to the nature of the precocious contributions that inventive activities taking place in the young Republic had made to the expanding international pool of industrially useful knowledge. But, perhaps more importantly, inasmuch Americans were notable borrowers of technologies (and underlying scientific principles) from Europe, it also reflected the comparatively greater plasticity of the economic environment in this region of Europe's New World settlements. The young and undeveloped state of the country left much scope for institutions, capital structures and cultural attitudes to become adapted in ways that were congruent with successful economic exploitation of the productive potentialities created by "the progress of invention."

There were many channels through which technological advances directly and indirectly shaped the path of U.S. economic development.[69] Of course, we see such developments as contributing in a straightforward way to improving the overall efficiency of the economy's use of the factors of production. But the effects of technology changes extend beyond that, and impinge upon the endogenous dynamic processes through which productive inputs are created. This applies not only to the impact of technological change upon the derived demands for stocks of conventional capital in the form of reproducible structures, equipment and livestock. The ways in which the size and commercial value of the known reserves of non-reproducible (depletable) natural resources are influenced by technologies of exploration, resource extraction, and processing, also are embraced within this view. So too are the shifts in the derived demands for specific intermediate inputs of natural resources, shifts that may emanate from technologically induced changes in the mix of goods and services produced by other sectors of the economy. In addition, of course, there were direct and indirect impacts upon the market for labor services of different kinds, stemming from the combined effects of technological change and the alteration of the nature and extent of available capital equipment.

[69] For specific discussion of three clusters of technological innovations – surrounding the internal combustion engine, electricity, and organic chemicals and chemical engineering – that have been especially important in the twentieth-century economy, see the Chapter by Nathan Rosenberg and David R. Mowery (in The Cambridge Economic History of the U.S., S.L. Engerman and R.E. Gallman, Eds., vol. 3). Rosenberg and Mowery's discussion points out that in 1900 the U.S. already was extensively involved in international flows of technological knowledge, on both the contributing and receiving sides of the ledger.

Another way of putting the foregoing propositions is to say that our reading of both the macroeconomic and the microeconomic evidence from the U. S. economy's experience over the past two centuries leads us to view technological change (broadly conceived) as having not been "neutral" in its effects upon growth. The specific meaning of "non-neutrality" in this context is that technical and organizational innovation had effects upon the derived demands for factors of production, and thereby affected the relative prices and the composition of the heterogeneous array of productive assets in the economy.[70] But, significantly for our interpretation, the size of the respective asset stocks also was affected in the process. By directly and indirectly impinging on structure of real rates of remuneration established in the markets for particular types of human labor and skill, and for the services of specific tangible and intangible capital, the course of technological and organizational innovation altered key conditions governing the growth rates of the various macroeconomic factors of production.

Two main motifs therefore will recur in the following discussion. The first theme lays stress on the non-neutrality of the impacts of innovations on the demand side of the markets for productive inputs, and the consequent necessity of recognizing technological change as contributing to complex *interactions* among all the proximate "sources of growth." It was valid for us to present the total factor productivity growth as a separate element, additively entering the growth accounts (in Part One) as a component of the growth rate of labor productivity and, hence the pace of increase in per capita real output. Yet, the non-neutral character of technological progress invalidates simplistic identification of the latter with the growth of even refined measures of total factor productivity. The second theme is an extension and elaboration upon the first: it concerns the differences between the twentieth and the nineteenth century in regard to the predominant patterns of bias in those "non-neutral" technological impacts. We argue that as a consequence of the altered nature of the "bias" of innovation, the twentieth century witnessed shifts among the relative demands for productive assets. The new tendencies led away from the accumulation of stocks of tangible reproducible capital and towards the formation of intangible productive assets by investments in education, training and the search for new scientific and technological knowledge.

We proceed next (in 2.2) to set out the grounds for our broad characterization of the thrust of nineteenth-century technological progress as having been *labor-saving but tangible reproducible capital-using* in its effects. Then we turn to examine the respects in which the twentieth century witnessed significant new departures from those tendencies (in 2.3). The salient macroeconomic trends are shown, by arguments analogous to those applicable to the nineteenth century experience, to be consistent with the broad characterization of technological change as having become *intangible capital-using but tangible reproducible capital-saving*, as well as remaining relatively labor-saving. By taking into consideration the relatively rapidly growing inputs of intangible capital that were omitted from the standard growth model underlying the growth accounts in Part One, we arrive at

70 See Endnote 1 to Part Two for formal definitions and discussion of the concepts of Hicks-neutrality and Harrod-neutrality. Our text references to "non-neutrality" apply the violation of both conditions, unless otherwise qualified.

an augmented set of growth accounts and a further "refinement" of the residually estimated, multifactor productivity growth rate during the twentieth century.

In broadening the scope of the growth accounts to include the formation and utilization of intangible capital, our analysis implies a somewhat unorthodox view of the long-term trends in the supply of savings. This is briefly exposed in sub-section 2.4, where it is argued that there is little evidence to suggest that the long-term growth of labor productivity and per capita real income in the U.S. has been increasingly tightly constrained by adverse shifts in the aggregate supply of savings. Instead, we take an expanded view of savings behavior as largely being responsive to the effects of innovation-driven changes on the demand side of the relevant asset markets, and so becoming progressively oriented towards new and unconventional forms of "savings." This has involved a dramatic growth of the relative importance in the national wealth portfolio not only of stocks of consumer durables, but of stocks of intangible knowledge-assets created by expenditures on organized R&D, and, of still greater quantitative significance, the formation of intangible human capital by public and private investments in education and training.

This expansion of the growth accounting framework – to include unconventional, intangible capital inputs – will be seen to exacerbate, rather than mitigate what undoubtedly is the major puzzling feature of the U.S. growth record during the closing quarter of the century: the striking collapse of the multifactor productivity growth rate. In doing so, the findings from the expanded growth accounts draw attention in a rather dramatic way to the question of whether, and by how much the "productivity slowdown" observed in the post-1966 period is an artifact of measurement problems, particularly those affecting the estimated growth rate of real GDP. We take up this issue along with other proposed explanations of the productivity slowdown in the concluding section (3) of Part Two.

2.2 The Changing Direction of Technological Progress and the Residual's Rise

An issue that needs to be addressed at the outset is whether it is justifiable to accord such central importance to the influence of technological progress in the nineteenth century, and therefore to not view U.S. growth during the twentieth century as being fundamentally distinguishable from that in the previous epoch on the ground that technological change has come to have a far greater impact. Of course, this is a matter of what one means by "the economic impact" of technological progress. But, could it not be argued, on the basis of the very low absolute estimates we presented for the pre-1890s TFP growth rate, and the subsequent pronounced "rise of the residual," that technological progress was really a rather insignificant factor in U.S. nineteenth-century growth, and emerged as a potent force only in the twentieth century with the advent of the science-based industries and organized research and development activities? Such a reading of the growth accounting results is one that we would reject most firmly.

We hold that position, however, not because the occurrence of so large an acceleration in the rate of productivity growth renders the underlying estimates themselves somehow suspect;[71] nor because there are good grounds for doubting that advances in fundamental scientific understanding of physical phenomena have come to play a much more central role in industrial (and agricultural) process and product innovation since the end of the nineteenth century. Rather, our view is that, in general neither the pace at which technological change proceeded, nor the importance of its "contribution to economic growth" can be gauged by simply considering the absolute growth rate of total factor productivity, or the size of the relative contribution being made by the latter to the growth of labor productivity and real output per capita. Although there are special circumstances in which such a direct interpretation of the growth accounts would be justifiable, those so-called "neutrality" conditions regarding the factor-saving effects of technological innovation did not obtain for the U.S. economy during most of the nineteenth century. Nor have they obtained during the twentieth century.

Yet, departures of "neutrality" themselves need not take an invariant form. It is precisely in the macroeconomic evidence for the altered nature of technology's *non-neutral* progress that we find an important key to understanding the rise of the TFP residual – and with it the other developments that distinguished the macroeconomic growth path taken in the twentieth century from the course along which the U.S. economy previously had been developing. The apparent difference between the two centuries in respect to the TFP growth rate thus reflects a substantive difference. It involved not merely an acceleration in the underlying pace of internationally shared technological advances, but a shift in "the direction of innovation" away from the very pronounced nineteenth-century bias towards *labor-saving and tangible capital-using* innovations.

One way to grasp intuitively what the existence of such a "bias" would imply for our interpretation of the TFP growth rate is, first, to recall the alternative, formally equivalent way in which the residually estimated measure of multifactor productivity can be obtained, as shown by equation (3) in Part One, Section 4: it is simply equal to the weighted average of the partial productivity growth rates of the various factor inputs, in this case full-time equivalent manhours of labor and the combined services of tangible capital (in constant dollars). Since we have seen that the ratio between inputs of tangible capital and output was rising, it is evident that this must have worked against the rise in labor productivity, dragging the weighted average of partial productivity growth rates downwards.

The second step is somewhat more exacting, as it involves showing that the opposing movements in the labor and (tangible) capital productivity trends were reflecting changes in the set of technological possibilities, rather than being simply a matter of the substitution of capital for labor in response to the rising relative price of the latter inputs. For this purpose it is best that brief but

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[71] Some allowance must of course be made for the possibility of measurement errors, but a quantitative evaluation leads to the conclusion that the gap in the long-term TFP growth rates of the magnitude indicated is too large to be dismissed as an artifact of measurement errors. See Endnote 10 to Part Two 2 on this issue.

nonetheless explicit reference is made here to the hypothetical aggregate production function underlying our growth accounting framework.

We may imagine a function describing the relationship between real output Y(t) at a given moment in time and inputs of labor and total tangible capital, in which each of those input service flows (measured in its "natural" units, e.g. manhours in the case of labor, and constant dollars in the case of the various elements of the tangible capital stock) enters multiplied by its own time-varying index of productive efficiency, $E_L(t)$ and $E_K(t)$, respectively. The functional relationship involving inputs thus measured in efficiency units will be assumed to remain invariant over time, although the relationship between output and the inputs measured in their natural units is presumed to change, as a result of the impact of technological and organizational innovations upon the respective input-specific efficiency index.

Now using the gross income shares of the factors in lieu of the respective input elasticity weights, one may identify the refined residual TFP growth rate as the weighted average of the growth rates of the individual indexes of labor efficiency and capital efficiency:[72]

(5). . . . . $Y^* - [\theta_L L^* - \theta_K K_T^*] \; = \; E^* \; = \; \theta_L E_L^* + \theta_K E_K^*$.

It then is plain that the direct impact of a *capital-using* technological bias would be to expand the demand for capital input services relative to the flow of real gross output, given the pre-existing real rate of return. That is tantamount to a negative rate of growth in the index of average capital efficiency, which would tend to offset the contribution being made to overall input efficiency growth (E^*) from concurrent *labor-saving* technical changes that were registered in the positive rate of growth of the index of average labor input efficiency, E_L^*.[73]

This is as much as to say that the refined TFP residual (E^*) can be directly informative about the pace of technological change (or, more strictly, about pace of efficiency improvements deriving

72 The simplified presentation in the text distinguishes only labor and tangible capital inputs, and derives from a more general production model that "nests" the growth accounting frameworks implemented in Parts One and Two for the nineteenth and twentieth centuries, respectively. The underlying general model is set out and discussed in the Technical and Statistical Appendix 1: Note on a General Form of Production Function with Factor-Augmenting Technological Change.

73 The other things being held constant for the purposes of this exposition are the relative shares of the factor inputs. Just as an average factor share weight is used for each interval when implementing the conventional growth accounting in Part One, the same set of within-period weights would be employed in the alternative calculation just described. If the factor shares were tending to change over the course of the interval in question, this could either reinforce or counteract the quantitative effects of the bias of technological change upon the resulting multifactor productivity growth rate. We return to discuss the significance of this point in the text below. Note that there is no reason for the rates of change in the partial productivity of labor and capital to correspond immediately with the respective input rates of efficiency growth, since the partial productivity ratios would also be affected by changes in the input proportions due to factor substitution.

therefrom) only in the special circumstance where the direction of innovation is “neutral” : namely, when $E_L^* = E_K^* = E^*$, so that the innovation does not affect the relative mix of factor inputs.[74] What we find, however, is that over the course of U.S. economic history in general technological change has *not* been neutral in this sense.

Specifically, the dominant macroeconomic bias of innovation in both the nineteenth and twentieth centuries was relatively "labor-saving", that is, $(E_L^* - E_K^*) > 0$ contributed to raising the desired ratio of tangible capital inputs per manhour. But, in the nineteenth century this bias was far more pronounced than that which has persisted throughout the present century. Indeed, the former epoch was distinguished from the latter by the existence of a strong “absolute tangible capital-using” bias ($E_K^* < 0$), which imparted a marked upward trend to the ratio between tangible-capital and real output.

Tangible Capital-Using, Scale-Intensive Technology and Increasing Economic Roundaboutness

The technological trajectory that emerged in nineteenth-century America and persisted into the early years of the twentieth century was both tangible capital-using and scale-dependent. Exploiting the technical advances of the time demanded heavier use of machinery per worker, especially power-driven machinery in ever more specialized forms. But it required operation on an ever-larger scale to render the use of such structures and equipment economical. Furthermore, it required steam-powered transport by rail and ship, itself a capital-intensive and scale-intensive activity, to assemble materials and to distribute the growing output to wider markets.

Contemporary observers understood what was happening during the closing quarter of the nineteenth century in terms that were closely related to this. They spoke of technological progress as achieving gains in the productivity of labor by increasing the “roundaboutness” of production; innovations could be incorporated into production, on this view, only by the agency of raising the economy’s stock of tangible capital goods in relation to the real flow of final goods and services. Or, putting the point slightly differently in the terminology of those times, “the progress of invention” was tending to raise the physical capital-output ratio that producers would choose at any given level of the real rate of interest.[75]

Technological progress and enlargement of markets appear to have operated with specially great force to encourage capital accumulation during the nineteenth century. The widening introduction of steam engines as a prime-mover in transportation, and for new power-driven machinery, the development of the iron and steel and other heavy, capital-intensive industries, the

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74 “Hicks neutral” innovations satisfy this condition, and leave the capital-labor input service ratio undisturbed (so long as relative factor prices are unchanged). But, as Endnote 1 to Part Two points out, the latter way of stating the condition strictly might more accurately be described as that of "Salter neutrality."

75 This “absolute capital-using bias” also violated the condition known as “Harrod-neutrality”. See Endnote 1 to Part Two for further discussion.

increasing refinement of new systems of production of standardized products based on the machine manufacture and assembly of interchangeable parts all served to raise the relative rates of return on new forms of tangible reproducible capital (given the same ratio of aggregate capital inputs to output) and so encouraged their substitution for other assets as well as for labor services. All required, at least as a permissive condition, however, the enlargement of markets. It would not have paid to use the larger quantities of specialized fixed plant and equipment unless their cost could be spread over a large volume of sales. And the expansion of the railroad itself and of the telegraph system it used served both to enlarge the national market and to permit and encourage the local concentrations of industry, trade and finance that were required by the new factory system and that held out a potential for advances in productivity.

All this is consistent with the teachings of a line of eminent economists who formed their ideas upon the close observation of the nineteenth-century developments that had been taking place under their own eyes. In their view, the processes of technological advance, enlargement of markets, more intricate specialization of labor and enterprise and the accumulation of capital appear as an intimately interconnected process. They argued that, while technological progress did not necessarily involve enlargement of scale or the heavy investment of capital, the path of progress in the nineteenth century tended strongly in that direction. They held that advance characteristically took the form of discovering new methods for increasing the "roundaboutness" of production (Eugen v. Bohm-Bawerk), which is to say, new ways to substitute capital goods – and capital goods for making capital goods – for labor directly applied to producing goods for consumers and producers. Similarly, it took the form of greater degrees of specialization of production, machinery and labor in an ever more intricate system of exchange and cooperation – all of which is another way of expressing the role of the enlargement of scale and specialization in realizing the potential of new knowledge and in encouraging the substitution of capital for labor. Frank W. Taussig, one of the founders of modern American economics wrote:

> In the past, those inventions and discoveries which have most served to put the powers of nature at human disposal have indeed often taken the form of greater and more elaborate preparatory effort. The railway, the steamship, the textile mill, the steel works, the gas works and electric plant – in all of these, invention has followed the same general direction. But that it will do so in the future, or has always done so in the past, can by no means be laid down as an unfailing rule.[76]

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[76] Frank W. Taussig, Wages and Capital, New York, 1897: p. 10. In this, Taussig was closely echoing the earlier views of Henry Sidgwick (The Principles of Political Economy, 2nd Edition, London, 1887: p.133):

> Though the progress of Invention – including the developments of the great system of cooperation through exchange – does not necessarily increase the need of capital, it has, on the whole, tended continuously and decidedly in this direction: the increase in the amount of consumable commodities obtainable by a given amount of civilized labor has been attended by a continual increase in the amount of real capital required to furnish these commodities to the consumer.

This is a view that – in both its characterization of the past bias of innovation towards capital-deepening, and its hesitation to extrapolate that tendency into the future – finds modern support, in the literature of the economic history of technology and from econometric studies of American industrial production during the nineteenth and early twentieth centuries.[77] While the quantitative macroeconomic evidence that is available is not conclusive in its support for this view, what there is lends further reinforcement of the presumption in its favor: the data is consistent with the classical, neoclassical and Austrian economists' shared vision of long-term development as essentially a process of "capital-deepening." Indeed, with appropriate allowances for the changes that have occurred in the composition of the nation's stock of productive assets (changes that we interpret as having been induced by the changing bias of innovation), we find in that shared vision an illuminatingly unified way to comprehend the U.S. experience of economic growth during the twentieth century, as well as the nineteenth.

2.3 The Testimony of the Macroeconomic Variables: Capital-Using Biases of Two Kinds

The growth rates for the factor input and real output measures that we have assembled in Table 2: I tell a tale of not one, but two successive movements toward greater "roundaboutness" in the U.S. economy's aggregate system of production system. This story is one of "unity in diversity," featuring a contrast between historical epochs that have witnessed distinctive, yet in one sense closely analogous changes in macroeconomic dynamics of the American macroeconomy.[78] Its quantitative outlines may be summarized in the following broad terms.

The first of the two movements towards a high aggregate capital-output level involved the accumulation of tangible reproducible assets. This was temporally concentrated during the middle decades of the nineteenth century, as may be seen from the upper panel (Panel A) of Table 2.I. Yet, its force already was largely spent by the *fin de siècle* era (1890-1905), after which the trend in the aggregate tangible capital-output ratio has been continuously downwards.

The emergence of a second capital-deepening drive has shaped the economy's growth experience during the twentieth century, but, as this involved the rapid rise of the *intangible* capital inputs in relation to real output, its quantitative dimensions are not fully visible within the conventional growth accounting framework based upon the official national income and product and concepts. In the lower panel (Panel B) of the table, therefore, we have "augmented" the conventional set of input and output growth rates by the inclusion of estimates for the rate of growth of the real stock of intangible productive assets, which we denote by the variable H* – since, as shall be seen,

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77 See Endnote 6 to Part Two.

78 The two parts of this story are brought together within the explicit framework of an augmented Solow growth model, in Paul A. David, "A Tale of Two Traverses: Continuity and Change in U.S. Macroeconomic History," Stanford University Social Science History Workshop paper (October 22 1998), revised March 1999.

(non-tangible) human capital forms the preponderant element within this part of the total U.S. domestic capital stock. For growth accounting consistency, it is necessary to consider the rate of change in a correspondingly "augmented" measure of real gross product, which we denote by the variable Y_A*. The latter reflects the movements of the more comprehensive output measure that includes, among other resource expenditures, the gross investments directed toward human capital formation through formal education and training, and outlays for intangible non-human assets such as are created through the performance of organized research and development activities.

We shall come subsequently to a closer examination of these matters, but for the present overview it is important to note that the movement towards a higher intangible capital-output ratio (H/Y_A) became particularly pronounced during the extended period from 1929 to 1989. The growth of the intangible part of the stock over the course of those six decades was fast enough to more than compensate for the retarded pace of accumulation of tangible productive assets. This brought about a reversal of the previous "capital-shallowing" trend that had characterized the economy – in regard to both tangible and total productive assets – during the 1890-1927 era. But, rather than being a continuous upward trend over the entire 60 years, virtually all of the implied post-1929 rise of the total (tangible plus intangible) capital-output ratio has come about since the end of the 1960s.[79]

On the Tangible Capital-Using Bias of Technological Progress in the Nineteenth Century

In regard to our contention that the first of these capital-deepening episodes owed a great deal to the absolute tangible capital-using bias of technological innovation over the decades running from the 1830s to the 1890s, the key macroeconomic observations concern the coincident upward movement of the reproducible capital-output ratio and the expanding share of the gross returns attributable to capital in the gross (private) domestic product.

The figures in the upper panel of Table 2: I reveal that a positive gap was being maintained between the growth rates of the entire reproducible capital stock and real output throughout the period stretching from the mid-1830s to the end of the 1880s. From the underlying estimates it is evident that the growth of the reproducible capital stock was sufficiently rapid, that it soon bulked large in the total real tangible stock and was proximately responsible for the latter's rise at a rate that surpassed the annual growth rate of real output by 0.5 percentage points on average during the period stretching from 1835 to 1890.[80] Over that interval the real reproducible capital-output ratio was almost doubled, and the total tangible capital-output ratio rose by almost one-third. Just as the contemporary economists opined, the development impelling this trend was a differentially more

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79 See Endnote 7 to Part Two.

80 These years of aggregate "capital-deepening" form the central period of what one of us (see David, 1977) has called the nineteenth-century American economy's "Grand Traverse." The term refers to the movement of the economy *between different (steady-state) growth paths*, each characterized by a constancy of the capital output ratio and the real rate of return on capital (or, equivalently, constancy in the capital share).

rapid accumulation of fixed capital in the form of structures and equipment.[81] This had been plainly revealed by Robert Gallman's exacting and detailed estimates of the changing distribution of the fixed reproducible stock *inclusive of improvements made to farm land* during the period 1840-90.[82] Whereas at the beginning of the century (1799-1805) the stock of improvements made to farm land constituted more than 62 percent of the nation's fixed domestic stock of reproducible capital, that share had been reduced to 47 percent by 1840, and over the next half-century it dwindled to a mere 14.5 percent. Moreover, Gallman's comprehensive estimates tell us that although in 1840 fixed reproducible capital goods had represented only 35 percent of the aggregate domestic capital stock (valued in 1860 prices), that share had risen to 66 percent in 1890 and had fully doubled by 1900.

Yet, during the very same extended era, as one may see from the entries in Table 2: III (Frame I), the share of gross income going to owners of reproducible capital underwent a sustained enlargement, rising from an average of 19 percent during the 1800-35 interval to almost 34 percent during the 1890-1905 period. The total property share thus rose by essentially the same (proportional) extent, from about 32 to 46 percent according to the estimates shown in Frame I for the *fin de siècle* period, and by only a little less if one consults the alternative total property share estimate shown for 1890-1905 in Frame II of the table.

The concurrence of these two trends, one in the real capital-output ratio(s) and the other the property share(s) carries a strong implication supporting our interpretation of the dynamics of nineteenth-century capital-deepening growth as having been driven by technologically induced shifts in the desired capital-output ratio, and consequently in the desired real investment rate. Had the growth of the aggregate capital-output ratio been pushed upward simply by an increase in thrift, this would have had to work entirely through the induced substitution of capital for labor in production; the higher rate of savings (gross) in relationship to the growth rate of the labor supply would have led to a downward pressure on the real rental price of capital vis-à-vis the wage rate, and thereby induced the substitution of tangible capital for labor. The behavior of the share data, however, implies that the real rate of return was not being forced sharply downwards.

How far the relative return to capital would have been depressed in proportion to the consequent rise of the tangible capital-labor ratio is what is measured by the elasticity of substitution, which we may view as a parametric feature of aggregate production relations in the economy during this epoch. Successive econometric investigations of aggregate production function models of U.S. private (and private business) domestic economy in the present century, as well as a parallel inquiry

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[81] Compare the constant 1860 price estimates of the composition of the U.S. domestic capital stock presented in Table 13 (Panel D) of Robert E. Gallman's chapter ("Economic Growth and Structural Change in the Long Nineteenth Century') in The Cambridge Economic History of the U.S., S. L. Engerman and R. E. Gallman, Eds., vol. 2. From those figures the ratio of structures and equipment to the total of the fixed reproducible components (which included improvements to farmland) can be seen to have been rising at 0.96 percent per annum during 1840-90; and it had been growing at virtually the same average pace (0.86 percent per annum) over the course of the preceding four decades.

[82] See Gallman, "Economic Growth and Structural Change," in CEHUS, v.2: Table 13.

for the nineteenth-century domestic economy, and numerous sectoral and industry studies, all concur in finding the elasticity of substitution to be less than unity.[83] Unitary elasticity would imply, of course, that the relative shares of the factors in gross output would be unchanged. But, if that elasticity was less than unity, and if technological progress had been (Hicks) neutral, tangible reproducible capital's share in gross income would have been *contracting, and labor's share would have been rising* – as the latter was the slower growing of that pair of inputs. Yet, just the opposite happened: in the first half of the nineteenth century the share of capital rose by 19 percent, and during the second half the proportional increase was again 19 percent, for an overall 41 percent expansion (see Table 2: III).

The immediate implication of this is that the effects of technological change must have been "non-neutral," and have worked to counteract the rise of the capital-labor ratio measured in "natural" units, i.e. the ratio of the constant dollar value of the flow of capital services per manhour. By raising the efficiency of labor faster than the efficiency of capital inputs, the pronounced capital-using bias of technological innovation operated so as to offset the depressing effect that the accumulation of capital goods tended to exert on the real rate of return.[84]

A further aspect of these macroeconomic relationships enables us to venture a step farther: the implied trend differential between the growth rates of the average efficiency of manhour inputs and average efficiency of the services of tangible capital during the nineteenth century turns out to have been so pronounced that one has to conclude that it was the impact of technological and other innovations in the nineteenth century which worked to push the desired aggregate capital output ratio upwards. Equivalently, we may say that in the absence of any other change in the capital-output ratio, the effect of technological progress was tending to raise the real rate of return on the existing stock. In the event, however, it served substantially to moderate its downward course over the century.[85]

83 See Endnote 6 to Part Two, on econometric estimates of the elasticity of substitution.

84 It is possible to obtain an estimate that puts the rate of capital-using technological change for the period 1835-90 at $E_K* = - 0.68$ per cent per year. The corresponding rate of growth of the manpower inputs' efficiency index is found to be 1.02 per cent per year. See Endnote 16 to Part Two for the method of estimation.

85 This interpretation of U.S. macroeconomic growth in the nineteenth century as a capital-deepening "traverse," and the implications drawn from that view, were initially presented in Moses Abramovitz and Paul. A. David, "Reinterpreting Economic Growth: Parables and Realities," American Economic Review, 63(2), May 1973: pp. 428-439; and more fully developed in Paul A. David, "Invention and Accumulation in America's Economic Growth: A Nineteenth Century Parable," Journal of Monetary Economics, 6 (Supplement), 1977: pp. 179-228 [published also as International Organization, National Policies and Economic Development, K. Brunner and A. H. Meltzer, Eds., Amsterdam and New York: North-Holland, 1977.

Table 2: I
Real Gross Output and Factor Input Growth Rates (percent per annum), 1800-1989
U.S. Private Domestic Economy

	Y^*	Y_A^*	L^*	K_T^*	K_{TQ}^*	H^*	Y^*-L^*	K_T^*-L	K_{TQ}^*-L	$H - L^*$
Panel A: *Frame I*										
1800-1835	3.84	---	3.57	3.84	---	---	0.27	0.27	---	---
1835-1890	4.02	---	3.32	4.51	---	---	0.70	1.19	---	---
1890-1905	3.80	3.81	2.41	3.64	(3.64)	4.40	1.37	1.20	(1.20)	1.94
Panel B: *Frame II*	Y^*	Y_A^*	L^*	K_T^*	K_{TQ}^*	H^*	$Y_A^*-L^*$	K_T^*-L	K_{TQ}^*-L	$H^* - L^*$
1890-1905	4.25	4.26	2.28	3.49	(3.49)	4.40	1.94	1.16	(1.16)	2.07
1905-1927	3.31	3.70	1.24	2.43	2.43	4.40	2.43	1.18	1.18	3.12
1929-1966	3.05	3.17	0.52	1.85	2.52	3.88	2.64	1.32	1.99	3.34
1966-1989	2.86	2.84	1.61	3.11	4.00	3.82	1.21	1.48	2.37	2.17

Notes and Sources for Table 2: I: Description of Growth Rate Variables and Data Sources

Panel A:

Y^*, L^*: See Statistical Appendix, Sources for Tables 1: IA, and 1: IIA (Frame I), for real gross product, and manhours, respectively.

Y_A^*: Augmented real gross product for the interval 1890-1905 is based on Y^* in that interval, adjusted by extrapolating the growth rate of (Y_A/Y) in the period 1890-1905, from estimates underlying the entries in Panel B in this table.

K_T^*: Total real tangible capital stock (estimated as a constant price Divisia index of the reproducible and non-reproducible tangible stock). See Statistical Appendix, Sources for Table 1: IVA (Frame I).

K_{TQ}^*: Total real tangible capital adjusted for (compositional) "quality change": $K_{TQ}^* = [K_T^* + q_K^*] = K_T^*$ in the 1890-1905 interval, by extrapolation of the argument in Part Two, section 2.3, based upon constant dollar stock estimates showing that the composition of the tangible reproducible stock remained virtually unchanged over the period 1910-29. See sources for Panel B of this Table.

H^*: Real stock of intangible capital: See Panel B of this Table for sources of the 1890-1905 estimate.

Panel B:

Y^*, L^*, K_T^*: See Statistical Appendix, Sources for Tables 1: IA, and 1: IIA (Frame II).
1890-1905 and 1905-1927, based on underlying estimates in Kendrick, 1961, Table A-XXII (for Y, and L), Table XV (for K_T); *1929-1966 and 1966-89*, from Statistical Appendix for Part One, Tables 1: IA and 1: IIA, based on underlying data from U.S. NIPA (1992, 1993), for Y^* and L^*; Table 1: IVA (Frame II), from BEA, Tables A6 and A9, for K_T^*.

Y_A* : *1890-1905 and 1905-1927*, from Y* adjusted by the growth rate of (Y_A/Y) computed for 1905-29 from augmented real domestic product estimates in Table 2: II, pt.A; *1929-1966 and 1966-1989* from Y* adjusted by the growth rate of (Y_A/Y) computed by interpolation from the Table 2: II, pt.A estimates for 1929, 1973 and 1990.

K_{TQ}*= [K_T* + q_K*]: *1929-1966 and 1966-1989* adjustments of K_T* for (compositional) quality change, using estimates underlying Table 1: IV and 1: IVA, as described in Statistical Appendix. The growth rate estimates for q_K* appear in the Technical Appendix Note 2. See Sources for Panel A of this Table on the basis of the estimate of q_K* = 0 in the period 1890-1927.

H*: *1905-1927, 1929-1966 and 1966-1989* computed from Total Intangible Stock estimates in Table 2: II, pt. A. See Statistical Appendix Sources for Table 2: II.

Table 2: II- Part A
Real Gross Domestic U.S. Capital Stocks and Product
(billions of 1987 dollars, and ratios)

Part A: Stocks and Flows

Selected Components of Real Stock	**1900-1910**	**1929**	**1948**	**1973**	**1990**
Conventional Tangible: Total	3583	6075	8120	17490	28525
Structures and Equipment	2305	4585	6181	13935	23144
Inventories	300	268	471	1000	1537
Natural Resources	978	1222	1468	2555	3843
Non-conventional Non-tangible: Total	1131	3251	5940	17349	32819
Education and Training	1001	2647	4879	13564	25359
Health, Safety, Mobility	120	567	892	2527	5133
R&D	0.1	37	169	1249	2327

Alternative Measures of Real Product

Conventional Real GDP	330	822	1300	3269	4878
Augmented Real GDP	410	1112	1715	4302	6395

Source: See Statistical Appendix for Part Two: Notes and Sources to Table 2: II-Part A.

Table 2: II - Part B
Real Gross Domestic U.S. Capital Stocks and Product, 1900-1990

Part B: Ratios Derived from Part A Entries

	1900-1910	1929	1948	1973	1990
Ratio of Non-tangible Stock to Conventional Tangible Stock	.316	.535	.731	.992	1.150
Ratio of Education and Training and R&D Stocks to:					
Conventional Real GDP	3.03	3.26	3.88	4.53	5.67
Fully Augmented Real GDP	2.44	2.41	2.94	3.44	4.33
Total Conventional and Non-Conventional Capital Stock	0.21	0.29	0.36	0.42	0.45
Ratio of R&D Stock to Fully Augmented Real GDP	.0002	.033	.098	.290	.364

Source: calculated from entries in Table 2: II-Part A.

Table 2: III
Gross Factor Shares: Input Weights for Conventional and Augmented Production Models: U.S. Private Domestic Economy, 1800-1989

	Weights for Conventional Tangible Inputs: Labor Man-hours	Reproducible Capital	Unimproved Land	Adjustment Ratios: Human Intangible Inputs	Non-Human Intangibles	Weights for Augmented Model: "Raw" Man-hours	Total Tangible Capital	Total Intangible Capital
	θ_L	θ_R	θ_K	α_L	α_{KT}	θ_L'	θ_{KT}'	θ_H
Frame I :								
1800-1835	.683	.125	.192	---	---	---	---	---
1835-1855	.623	.152	.225	---	---	---	---	---
1855-1871	.536	.162	.300	---	---	---	---	---
1871-1890	.553	.130	.317	---	---	---	---	---
1890-1905	.539	.124	.337	.092	.000	.448	.461	0.092
Frame II :	**Labor inputs:**		**Capital: $(\theta_R+\theta_K)$**			$(\theta_{KT}-\alpha_L)$	$(\theta_{KT}-\alpha_L)$	$(\alpha_L+\alpha_{KT})$
	θ_L		$= \theta_{KT}$	α_L	α_{KT}	$= \theta_L'$	$= \theta_{KT}'$	$= \theta_H$
1890-1905	.560		0.44	0.092	0.00	0.468	0.440	0.092
1905-1927	0.60		0.40	0.185	0.003	0.415	0.397	0.188
1929-1966	0.64		0.36	0.244	0.084	0.396	0.276	0.328
1966-1989	0.65		0.35	0.246	0.084	0.404	0.266	0.330

Sources:

Frame I. Standard Weights: See Statistical Appendix, Sources for Table 1: IV and 1: IVA (Frame I) discussion of imputed factor share estimates. For 1890-1905 adjustments for intangible inputs, see Sources of Frame II estimates in this Table. Weights for Augmented Inputs are the conventional shares minus α_L and $\alpha_{K,}$ respectively.

Frame II. Conventional gross factor shares are obtained for 1890-1905 and 1905-1927 by raising the net share estimates from Kendrick, 1961, Table A-X for 1899-1909, and the average of 1909-19 and 1919-29, by 0.09, to allow for capital consumption; for 1929-1966 and 1966-1929 see Statistical Appendix Sources for Table 1: IV and 1: IVA (Frame II), factor share estimates. Imputed estimates of α_L and $\alpha_{K,}$ the gross returns on stocks of intangible human capital, and on the stock of (non-human intangible) R&D capital, expressed as fractions of augmented GPDP, respectively, are obtained by the procedures described in Statistical Appendix Sources for Table 2: III. Note that $\theta_H = \alpha_L + \alpha_K$.

What this means, then, is that to the extent that the supply of savings was elastic to the real rate of return, as seems quite plausible, a portion of the rise that has been observed to have occurred in the proportion of the nation's aggregate income that was being channeled into net (and gross) savings in the form of tangible reproducible wealth, can be attributed to the upward pressure that biased innovation was bringing to bear on the demand side of the market for loanable funds. Some part of the rise in the fraction of income saved undoubtedly is traceable to independent supply-side shifts, stemming from altered household savings habits, institutional innovations that improved bank and non-bank financial intermediation, and other such developments.[86] But, to the extent that the aggregate supply of savings was responsive to changes in the functional distribution of income, which would be the case if the propensity to save out of the earnings of property exceeded that out of wages, the expanding share of income going to holders of tangible reproducible property as a consequence of the bias of technological change provided a mechanism through which the upward shifts in the demand for loanable funds tended to be met by an accommodatingly high elasticity on the supply side.[87]

The Relative Rise of Real Stocks of Intangible Capital

Turning now to the twentieth century, we must begin by looking beneath the growth rates of those large aggregate measures of tangible and intangible capital inputs, which are reported in the lower panel of Table 2: I. This can readily be done by consulting the estimates in Table 2: II-Part A pertaining to the U.S. Domestic Economy, where estimates of the component stocks valued in constant prices of 1987 are set out for benchmark dates between 1900 and 1990. From these it will be seen that the secular rise of each of the principal categories of intangible assets – Educational and Training, Health, Safety and Mobility (combined), and R&D – outpaced the accumulation of conventional tangible assets in the form of commodity inventories, structures and equipment.

The main facts of the national "portfolio transformation" that this has involved stand out plainly enough from comparisons of their respective absolute 1987 dollar magnitudes: beginning from a level that was less than one-third that of the tangible capital stock in the first decade of the century, the size of the real stock of intangible capital grew to match that of its tangible counterpart in 1973, and, by 1990 it already was 15 percent larger. Thus, the ratio between the non-conventional (intangible) stock and the conventional (tangible) components of total non-financial wealth (which appears in the topmost line of Part B of Table 2: II) increased by 3.5-fold over the 1900/1910-1990 interval as a whole, and was more than doubled between 1929 and 1990.

Two distinct sets of secular forces can be identified as having been responsible for bringing about this striking twentieth century switch in the composition of the nation's portfolio of domestic non-financial wealth. On the one hand were those forces that tended to *reduce* the desired demand for wealth in the form of tangible capital stocks at given levels of real income and the real rate of interest, and on the other were

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86 These developments are summarized by Gallman's chapter (CEHUS, vol. 2), which gives references to the relevant literature on nineteenth-century trends affecting the supply of savings.

87 See Endnote 9 for further elaboration of this point.

the set of forces that were tending to *raise* the desired ratio between real intangible wealth and real income. As the focus of the discussion in the following pages will rest upon the latter two, before going on it is important to take note of the emergence of a number of significant tangible-capital saving developments, especially during the first quarter of the twentieth century.

More intensive utilization of fixed capital facilities that were initially installed in large, lumpy blocks, was a prominent source of gains in tangible capital productivity, which became especially pronounced first in the railroad transportation industry and the new public utilities, particularly electricity supply and telephone networks during the 1890-1905 era.[88] But it should not be supposed that this was simply a matter of waiting until demand grew up to the levels of the capacity that had been originally installed. As the research of Albert Fishlow has shown, for the case of U.S. railroads in the post-bellum era, numerous technological advances were required to permit attaining higher ton-mileage rates with reliability, and fuller utilization of the fixed capacity of roadbed, stations, marshaling yards and the rolling stock itself.[89] These innovations ranged from the design of heavier and more powerful locomotives, to the introduction of air-brakes and automatic car coupling, as well as more reliable signaling systems to control train movements. Similar technological advances underlay the expanding generating capacity of electrical dynamos, and the integration of more extensive electricity distribution networks across with "load balancing" became possible, permitted reductions in the excess capacity that was entailed when generators were installed to meet daily and seasonal peaks in demand.[90]

In manufacturing industries the introduction of continuous process production and the increasing use of multiple shift-work in the years around 1915, and the diffusion of automated materials handling technologies to increase the rates of charging and discharging of batch production processes, similarly rested on technological innovations, including the growing use of electro-mechanical control systems in chemical plants, breweries, steel rolling mills, and the like.[91] Moreover, during the 1920s particularly, the introduction of the unit drive system of factory electrification in many industries completed the

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88 See, e.g., Melville J. Ulmer (1960), Capital in Transportation, Communications, and Public Utilities: Its Formation and Financing, Princeton University Press (for NBER), and John W. Kendrick (1961), Productivity Trends in the United States, Princeton University Press.

89 See Fishlow, "Productivity and Technological Change in the Railroad Sector, 1840-1910" (1966).

90 See, e.g., Thomas P. Hughes (1983), Networks of Power: Electrification in Western Society, Baltimore and London: Johns Hopkins University Press, and Paul A. David and J.A. Bunn (1988), "The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History," Information Economics and Policy, Vol. 3, pp. 165-202; Paul A. David (1991), "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror," in Technology and Productivity: The Challenge for Economic Policy, Organization for Economic Co-operation and Development, Paris, pp. 315-48; Sam H. Schurr, et al., Electricity in the American Economy: Agent of Technological Progress, New York: Greenwood Press, 1990.

91 See Harry Jerome (1934), Mechanization in Industry, New York: National Bureau of Economic Research; Claudia Goldin and Lawrence F. Katz (1998), "The Origins of Technology-Skill Complementarity," Quarterly Journal of Economics, 113, pp. 693-732.

replacement by wires of the former mechanical means of power transmission using shafts and belting, and this brought significant savings in fixed construction costs, as well as permitting reductions in lost output during "down time" for retro-fitting of particular departments in the plant, or for reconfiguring the layout of the factory floor to accommodate product changes.

Once initiated, this trajectory of development and diffusion of fixed tangible capital-saving innovations has persisted into the 1929-66 era. Wartime pressures on capacity in the 1940s led to new methods of intensive utilization which could be introduced in conjunction with plant renewals, but it was not until the 1960s that a further notable increase in the "work-week" of manufacturing capital took place, due to structural changes that increased the importance of the continuous production industries and the extent of shift-working. According to the estimates prepared by Murray Foss, the index of intensity of utilization of manufacturing capacity rose at the average annual rate of 0.38 percentage points per annum.[92] As manufacturing is a comparatively capital-intensive sector, capital-savings from these sources carried considerable weight in the aggregate, but the share of manufacturing in gross private domestic product shrank towards the 20-25 percent range in the post-World War II period, setting a limit on their ability to raise intangible capital's productivity economy-wide.

It is therefore significant that this era also saw a similar movement towards organizational and technological changes that permitted greater fixed capacity utilization in the service sector: banks and insurance using computers moved to time sharing of that equipment in the 1960s, while automatic teller machines reduced the demand for numerous small retail banking facilities that typically could attain only relatively low levels of transactions throughput. In retail distribution, stores catering to a rising number of women in the workforce began significant extension of their opening hours during the 1970s. The contribution of such developments towards raising the economy-wide level of tangible capital productivity is difficult to quantify with any precision. But, if the average yearly rate of rise in the long-term utilization rate of fixed capital overall matched that estimated for the manufacturing sector during the years 1929-73, that alone would have accounted for roughly two-thirds of the concurrent increase (by 0.61 percentage points) that occurred in the annual growth rate of fixed capital productivity.[93]

A second major contributor to the differentially faster pace of accumulation of the intangible portion of the aggregate domestic capital has been the growing difference between the average service lives of tangibles and intangibles, and the fact that the latter difference has also reflected the shifting internal make-up of those broad classes of assets. Consider first the non-conventional intangibles: from the estimates of the absolute 1987 dollar magnitudes in Table 2: II-Part A it is seen that education and training have remained the overwhelmingly dominant element within the intangible stock. Indeed, the rise of this particular form of human capital has been the development that must be assigned proximate responsibility for driving the secular shift towards intangible asset formation. Because the real capital stock figures we

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[92] Murray F. Foss (1997), Shiftwork, Capital Hours and Productivity Change, Boston, Dordrecht, and London: Kluwer Academic Publishers, 1997.

[93] This partial productivity measure is the ratio between augmented real gross domestic product and the real stock of fixed reproducible tangible capital. See Table 2: II-Part B, for the estimates underlying the calculation.

are considering are estimated gross of depreciation (and obsolescence), the assumed average service life of the intangible component reflects the dominance of the comparatively long-lived humans in whom educational, training (and health) investments have been embodied; even though its share of education and training in total intangible capital drifted downwards, from 88 percent to 77 percent between the first and the final decade of the century, this was not sufficient to shorten appreciably the extended average service life of the entire class of intangible assets.

By contrast, however, the average service life of newly installed tangibles has fallen appreciably, in part as a consequence of the rising relative importance of equipment relative to structures especially from 1929 onwards, but also due to the shortening of the average service life of equipment itself.[94] Taken in conjunction with the longevity of educational and training investments embodied in the labor force, this shift towards a higher average rate of depreciation on tangible reproducible assets has meant that even if a constant comprehensive rate of real gross savings had been allocated in an unchanged way between tangible and intangible capital formation, the intangible component of the total U.S. real gross capital stock would have been growing at a differentially rapid pace – at least since 1929.

But it is evident also that these preliminary considerations cannot be the main part of the story of the relative rise of the intangible stock, which, in any case, can be seen to have been underway since the beginning of the century.[95] Demography also has had a hand in this development. On turning the problem around so as to consider the historical evolution of an education-health care nexus from the prospective viewpoint of the late nineteenth century, it is evident that the advance of scientific knowledge in the fields of medicine, including public health, contributed substantially in the late nineteenth and early twentieth centuries to lengthening adult life expectancy. It did so first by reducing the incidence of diseases SUCH AS tuberculosis, which are economically very costly because they debilitate if not abbreviate the lives of young adults, and subsequently by prolonging the potential working lives of mature adults.[96]

These demographic developments may be seen to have had two entwined effects. On the one hand, by extending the prospective "service lives" of human capital investments, they worked to raise the anticipated rates of return on formal education and training. An illustrative set of calculations conveys some idea of the magnitude of the impact upon the demand for further education that this consideration alone may have entailed. Starting from a representative age-earnings profile of U.S. male workers aged 15 to 60 who had a grade school education, and the corresponding profile (with earnings starting at age 25)

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94 See Endnote 10 to Part Two for discussion of service lives of tangible assets and estimates of the changing composition of the real tangible stock.

95 See Endnote 11 to Part Two on the assumptions underlying the intangible capital stock growth rate estimates in Table 2: I for the pre-1929 era, and the extrapolation of the real stock figures in Table 2: II back to 1900-10.

96 On the shift in mortality schedules and the effects of public health especially, see Samuel H. Preston, Mortality Patterns in National Populations, New York: Academic Press, 1976 ; on infant and child mortality conditions in the U.S. around the turn of the century, see Samuel H. Preston and Michael R. Haines, Fatal Years: Child Mortality in Late Nineteenth-Century America, Princeton, NJ: Princeton University Press, 1991.

for those who completed four years of college, one may ask what would be the effect on a rational assessment of the economic return to opting for college completion of an improvement in adult life expectancy such as that which actually occurred between 1870 and 1960. Using the age-specific mortality schedules for the U.S. white male population at those two dates, the corresponding expected values of the (1960) alternative education-associated earnings profiles can be obtained, and the present value of those may then be evaluated and compared by positing alternative time-discount rates. What a counterfactual exercise of this kind reveals is that the impact of the historical improvement in male survival probabilities in the U.S. was sufficient to raise the expected present value of a college education by 25% if the discount rate were as low as 5 percentage points per annum, and by 60% if the discount rate was as high as 15 percentage points per annum.[97]

At the same time one should notice the implications of the tendency for the age distribution of the U.S. workforce to shift upwards over the period 1890-1940 – both as a consequence of the early twentieth-century continuation of the fall in fertility rates until the late 1940s, and the subsequent reductions in adult mortality levels. This meant that the accelerated pace in the advance of knowledge and its translation into new techniques of production and work routines increased the problem of obsolescence in the human capital stock. Taken by itself, that would have contributed to depressing the *average* index of the human capital stock's efficiency, whilst raising the marginal rate of return to gross investment in intangible capital formation through the education and training of young workers. As shall be seen, the movements of the observable macroeconomic variable in the twentieth century are consistent with the existence of such a secular bias towards *intangible capital-using* efficiency changes.

Intangible Capital-Deepening and the Growth Accounts for the U.S. in the Twentieth Century

The first point to be considered is that the rise in the intangible capital-output ratio was accompanied by a rise in the share of total intangible capital in the augmented gross product, as may be seen by comparison of the positive growth rates of the (real) ratio H/Y_A indicated for the U.S. Private Domestic Economy by Table 2: I (Panel B), with the trend in the share θ_H that appears in the lower panel of Table 2: III. Over the whole of the 1905-89 interval the rate of increase of the former ratio averaged 0.74 percentage points per annum, but the pace quickened perceptibly from the late 1960s onwards and during 1966-89 was running at 0.95 percentage points per annum. Thus, by 1989 the intangible capital-output ratio stood at 190 percent of its 1890 level, a proportionate rise that was approximately the same as that recorded over the nineteenth century by the *tangible* (reproducible) capital-output ratio.[98] There is a further parallel to be noted between the experience of the two centuries in the behavior of the corresponding gross factor shares, for the share of augmented gross product that we have imputed to total intangible capital inputs rose along with the intangible capital-output ratio.

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97 The results reported are based upon Paul Taubman, "The Effect of Mortality on the Choice of the Level of Education," Unpublished seminar notes, Stanford University Department of Economics, January 11, 1971. They make use of the earnings functions for the two educational attainment categories from G. Hanoch, "An Economic Analysis of Earnings and Schooling," in B.F. Kiker, Investment in Human Capital, (1971).

98 These average annual growth rates are computed as $(H^*-Y_A^*)/(1+Y_A^*)$ from the entries in Table 2: I.

From Table 2: III (Frame II) it is evident that the rising imputed returns on intangible *human capital* were the quantitatively important development during the period 1890-1927, reflecting the labor force impact of the High School education movement. When those returns are subtracted from the total labor earnings, the resulting estimate of the share of "raw labor inputs" in gross (augmented) output shows no rise during the twentieth century; indeed, the essential constancy of the share at the 40 percent level after 1890-1905 can be viewed as the eventual bound reached by the secular contraction that had begun early in the nineteenth century. Privately and publicly financed expenditures for research and development began to rise rapidly from initially negligible levels in relationship to national output during the 1920s, and the sustained rise in this ratio over the next three decades produced the almost ten-fold rise in the ratio of the real R&D capital stock to gross (augmented) product between 1929 and 1973, according to the estimates presented in Table 2: II–Part B. That movement underlay the rapid expansion of the share of gross product imputed to the non-human component of intangible capital inputs, an increase of approximately 8 percentage points between the immediate post-World War I and post-World War II years. Subtraction of this component from the imputed gross earnings of all capital results in a sharper contraction of the gross share of tangible assets (in augmented output) between the first quarter and the following part of the present century. Thus, the share of all tangible inputs (human and non-human) is seen to have decreased from approximately 90 percent at the turn of the century (1890-1905) to the 67 percent level that has been maintained over the 1929-89 period.

The input growth rates and estimated factor shares are brought together in Table 2: IV-Part A to provide a more comprehensive growth accounting for the U.S. Private Domestic Economy in the three long periods since 1890. We make use of the adjustments for the changing composition of tangible assets, previously introduced as a "capital quality improvement" in Table 1: IV, but make no corresponding adjustment of the labor inputs, inasmuch as the estimates of the growth of the stock of intangibles directly and indirectly reflect compositional shifts in the expenditures and foregone earnings flowing into investments in human capital. Because the contributions of the growth of intangible inputs per manhour exceed the previously estimated contributions of improved "labor quality", the resulting multifactor productivity residuals are smaller in each of the periods than the corresponding entries in Table 1: IV-Part A. The reduction is quite minor for the pre-1929 period and moderate in the 1966-89 interval, but quite pronounced for the 1929-66 period. Consequently, the new, "super-refined" TFP estimate (E_A*) is found to have declined from the 1.3 percentage point per annum high point it attained during the first quarter of the century (it stood at 1.375 percentage points per annum in the sub-period 1905-27, slightly above its average for 1890-1927).

If we accept the estimate of 1.00 percentage points per annum for the "refined" TFP growth rate in the long period 1871-90 (from Table 1: IVA) as roughly comparable with these figures, the picture that emerges is one of acceleration to a peak in multifactor productivity growth reached during 1905-27, followed by a return to the same (1 percentage point per annum) rate during 1929-66, followed by further and sharp decline. The final row in Table 2: IV-Part A shows the post-1966 "slowdown" in our comprehensive multifactor productivity growth rate amounting to a drop of 1.13 percentage points, a decline somewhat smaller than that indicated by the standard growth accounts presented in Part One, but very substantial nonetheless.

Table 2: IV-Part A
The Sources of Labor Productivity Growth:
Augmented Accounting Framework for U.S. Private Domestic Economy

(Growth rates in percentage points per annum)

Long Periods	Growth Rate of Augmented Real Output per Manhour:	Contribution of Tangible (Quality-Adjusted) Capital per Manhour:	Contribution of Intangible Capital per Manhour:	Contribution of Total Capital Inputs per Manhour:	Contribution of Refined Multifactor Productivity:
	$[Y_A^* - L^*]$	**$\theta'_{KT}[K_{TQ}^* - L^*]$**	**$\theta_H[H^* - L^*]$**		**E_A^***
1890- 1927	2.21	0.484	0.424	0.908	1.302
1890-1905	1.94	0.510	0.190	1.230	
1905-1927	2.43	0.498	0.587	1.055	
					0.995
1929-1966	2.64	0.549	1.096	1.645	
1966-1989	1.21	0.630	0.716	1.346	-0.136
"*The Slowdown*":					
from 1929-1966 to 1966-1989	- 1.43	+ 0.081	-0.380	-0.299	-1.131

<u>Notes and Sources:</u> For cols. (1), (2) and (3) the growth rates and input weights from Table 2: I (Panel B), combining entries for 1890-1905 and 1905-27 rates, geometrically averaged with appropriate relative weights for lengths of sub-periods. Col. (4) is the sum of cols. (2) and (3). For col.(5): E_A^* is obtained as a residual from col.(1) minus col.(4).

Table 2.IV - Part B
The Relative Contributions to Labor Productivity Growth and the MFP "Slowdown": Augmented Accounting Framework for U.S. Private Domestic Economy

	Growth Rate of Augmented Real Output per Manhour:	**Relative Contributions in Percentages of Column 1:**			
		Tangible (Quality-Adjusted) Capital per Manhour:	Intangible Capital per Manhour:	Total Capital Inputs per Manhour:	Refined Multifactor Productivity:
1890- 1927	.0221=100	21.9	19.2	41.1	58.9
1929-1966	.0264=100	20.8	41.5	62.3	37.7
1966-1989	.0121=100	52.0	59.2	111.2	-11.2
"*The Slowdown*": from 1929-1966 to 1966-1989	-.0143=100	-5.7	26.6	20.9	79.1

Sources: Calculated from entries in Table 2: IV-Part A.

In Table 2: IV-Part B the relative contributions of tangible and intangible capital-intensity growth, and of multifactor productivity change are calculated. The steadily mounting relative importance of intangible capital per manhour, and, consequently, of total capital inputs per manhour forms a decided contrast with the picture presented by the standard accounting in Part One. From this perspective the decreased importance of multifactor productivity growth in the most recent period appears less of an anomaly, and more a continuation of previous developments. The resurgent relative role of tangible capital-intensity growth after 1966, which parallels the increased absolute size of the contribution to labor productivity growth, is seen now as an accompaniment to the relative growth of the contribution of rising intangible capital-intensity. We will return to consider (in Section 3, below) what light the standard and expanded growth accounting exercises throw upon the post-1966 "slowdown" in productivity growth. For the moment, however, it simply may be noted that by considering the role of intangible inputs we have made some headway in that direction. Whereas the standard growth accounts in Part One indicated that more than the entire reduction of the labor productivity growth rate had to be attributed to the shrinkage of the refined TFP growth rate, the results from Table 2: IV-Part B assign 21 percent of the decrease in (augmented) output per manhour to the diminished rate of increase of total capital-intensity growth. Thus, 79 percent is left to be "explained" by the contraction of the multifactor productivity residual. All of the diminished contribution from capital-intensity growth since the late 1960s, however, is traceable to the reduced contribution made by intangible capital-intensity, so that the movements in that component may be rightly said to have played the pivotal role in both the acceleration of labor productivity growth between 1890-1927 and 1929-66, and its subsequent deceleration.

Although the growth of intangibles per manhour and tangible capital per manhour were roughly on a par in terms of their contributions to labor productivity growth during 1890-1927, the former has been seen to have become more important in absolute and relative terms after 1929. This shift, brought out clearly by Table 2: IV, reflected the underlying influence of demand-side forces favoring the accumulation of intangible rather than tangible assets. Evidently, the rise of the intangible capital stock in relationship to both the tangible stock and to real gross product during the twentieth century evidently did not depress the real gross rate of return on intangible enough to prevent the expansion of those assets earnings share; indeed, the proportionate increase in the latter share over the course of the century was actually greater than the near doubling of the intangible capital-output ratio. On the face of it the implication would appear to be clear: there must have been powerful forces offsetting the tendency for the relative accumulation of intangibles to lower the marginal productivity of such assets.

The argument that the opposing force in question was an overall intangibles-using bias of innovations, is not quite as straightforward, however, as the one we were able to advance in support of the inference that technological progress during the nineteenth century was strongly biased in the tangible capital-using direction. Although there is still ample basis for supposing that the elasticity of substitution between "raw manhours" and tangible capital inputs is less than unitary, the same cannot be said for the elasticity of substitution between the "raw manhours" and the intangible (human capital) components of labor inputs. Since the elasticity of substitution between "skilled " (or higher education attainment) labor and unskilled labor inputs has been found to exceed unity in many econometric studies,[99] it is possible that the rapid growth of intangible (human) capital per manhour bore some responsibility for the increasing share of intangible capital in (augmented) gross output.

In other words, with three (main) factor inputs to consider, and no clear basis for supposing that the elasticity of substitution between intangibles and the other (tangible) inputs was less than unitary, in order to infer the existence of an intangible capital-using bias of innovation, it is necessary to consider the quantitative relationships among the several input-specific rates of efficiency growth, and their collective relationship to the residual measure of multifactor productivity when intangibles as well as tangible inputs

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[99] See David, "Tale of Two Traverses," (1988); Technical Appendix Note 2, footnote 5 for references to this recent literature in the labor economics field, from which it appears that the elasticity of substitution between skilled (educated) and unskilled (low educational-attainment) workers in the post-World War II period lay between 1 and 2.

are included among the inputs. The exact details of the results that have been obtained by such calculations need not detain us, but their general qualitative import is quite clear and bears directly on the point at issue here.[100] Throughout the era since 1929 the index of average efficiency of intangibles has trended downwards, and its rate of decline became much more pronounced during 1966-89 than it had been during 1929-66. This worked to raise the real rate of return on intangible assets, given the ratio of intangibles to other, tangible inputs (and real output), and thereby supported the continuing relative accumulation of that broad class of assets. Prior to 1929, however, the trend in the efficiency of intangibles appears to have been upwards at a pace and not very different from that of the efficiency of tangible capital; other things being equal, this operated to lower the real rate of return on intangible assets.[101]

The bias of technological and organizational changes towards intangible capital-using innovations has been seen to have encouraged the extension of capital formation activity to include new classes of productivity assets, and so contributed to the growth of overall capital intensity among the sources of rising labor productivity. Indirectly, these interrelated developments in technology and input growth also affected the magnitude of their impact upon labor productivity because the share of the most rapidly growing input – intangible capital services – was not depressed, but grew larger especially between 1890-1927 and 1929-66. These "interactions" show the limitations of attempting to parse out the supply side of the long-run development process into cleanly separable "contributions" that reflect the influence of forces affecting the supplies of inputs, on the one hand, and the advance of technological knowledge, on the other. That message will be seen to be more fully borne out by a closer examination of the determinants of the supply of savings, the subject to which we turn in the following sub-section.

2.4 The Behavior of Private Saving: Binding Constraints or Adaptive Responses?

Rising flows of investment in intangibles and a diminished rate of net capital formation in tangible assets bear proximate responsiblity for the differentially faster growth of the real stock of intangibles. Mainstream thinking regarding U.S. macroeconomic growth in the second half of the twentieth century has focused upon the retarded pace of tangible capital accumulation as a consequence of decisions about the allocation of (conventional) income between present and future consumption, and has analyzed the phenomenon of a declining rate of private domestic investment (conventionally defined) without reference to the rise of intangibles. The explanation has been sought by considering such developments in the U.S. economy that could have adversely affected capital formation by constraining the supply of savings. Our view of the

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100 David, "A Tale of Two Traverses" (1998): Technical and Statistical Appendix 3: Estimates of Trend Growth Rates of Efficiency of Intangible Inputs, sets out the methodology, data, and resulting estimates. The calculations are carried out in a manner consistent with the framework of the augumented production function model and the data employed here.

101 The latter effect combined with that of the rapid rise in the real stock of intangibles per manhour over the period 1890-1927 to exert downwards pressure on the rate of return on intangibles relative to the remuneration of unskilled ("raw") labor services. In sub-section 2.4 of this Part, the discussion of "the behavior of real rates of return on the intangibles stock" notices corroborative evidence of a decline over the period from 1895 to 1939 in the differential in wage rates between education-associated skilled labor and unskilled workers.

matter, however, is rather different. In emphasizing the interconnected influences operating upon the demands for tangible and intangible capital, our interpretation suggests that it is more illuminating to examine saving behavior within a broader framework that considers the financing requirements of non-conventional as well as conventional productive assets.

The post-World War II era has seen the expansion of demand for new productive assets that are not particularly well suited for financing through the mechanisms that are available in organized capital markets and private financial institutions. The financing of investment in general forms of human capital, through education, through private capital markets, is virtually impossible in a society of free men and women. Such investments carry very significant risks, arising from the asymmetric distribution of information about the intellectual capabilities and motivations of the student, as well as problems of moral hazard and debt default. It has proved possible to mobilize substantial amounts of private capital for “student loans” only through a combination of highly selective screening in the case of leading to finance professional training, and the government intermediation in the form of guarantees of the principle and interest. Health investments are even more imperfectly served by private capital markets, and so must be paid for out of current incomes either directly, or through the purchase of insurance. Likewise, intangibility and the uncertainties that surround the research and development activities, mean that R&D performance cannot be debt-financed to any very large extent, and so must compete for external equity financing, or be funded internally through the retention of corporate earnings.[102]

The financing problems posed by this secular development in the U.S. economy have exacerbated the rather more transient effects of government fiscal operations affecting the flow of funds available from domestic sources for conventional capital formation. Yet, in our view, there remains no persuasive evidence that the rate of tangible capital formation has been reduced by an increasingly binding constraint imposed by the increased unwillingness of Americans to forego current consumption. This much may be concluded from even a cursory review of private savings behavior over the course of the present century, and secondly, from the absence of any long-term upward trend in the real net rate of return on investment.[103]

The Supply of Savings in the Long-run: Is there a Problem?

A recurring theme in discussions about capital formation and long-term economic growth since World War II has been the worry that structural changes in the U.S. economy may have reduced the private sector’s propensity to save. Indeed, the view that the savings rate has been the active, quasi-exogenous element to whose behavior the tangible capital-output ratio and the pace of capital accumulation have passively responded, antedated the widespread adoption of neoclassical growth theory among macroeconomic analysts. It had been articulated clearly by Simon Kuznet’s historical survey *Capital in the American Economy* (1961). Kuznets regarded the falling rate of net national savings as the consequence of the

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102 See Endnote 12 to Part Two.

103 The argument in the following sub-section draws upon the fuller presentation in David, “A Tale of Two Traverses” (1998).

combination of tightened constraints on the supply of private savings and growing government deficits. Both were depicted as developments that had restrained the pace of conventional capital accumulation and productivity growth, especially after 1929; and such views have continued to be influential in recent debates over U.S. macroeconomic policy.[104]

Although the notion of secularly tightening savings-supply constraints formed a background of concern for the specific worries that began to be voiced with greater urgency during the 1980s in regard to the effects of federal government fiscal policies upon net national savings, it properly should be distinguished from the latter.[105] Ballooning federal deficits undoubtedly were a matter for serious concern, but the supposed profligacy of the household sector, which some analysts have read in the downward secular trend in the personal savings rate that appears in the national income and product accounts, has been the more enduring theme. Yet, as may be seen from a dispassionate examination of the data, the "official" personal savings rate is a seriously inadequate indicator of the behavior of the overall rate of private savings in the US economy.

To follow the historical course of the ratios of personal savings to GNP, and to disposable personal income (DPI) over the twentieth century, one can turn to Panel B of Table 2: V-Part A. These figures might give some momentary appearance of substance to the hypothesis of a rise in American households' average propensity to consume. Upon closer inspection, however, they reveal two difficulties with that argument, and immediately call into doubt the surmise that the household savings rate was reduced by the institution of the social security system and kindred public policy changes. In the first place, and most obviously, the decline that appears from the table's comparison between these savings rates for the "pre-WWI and "Interwar" periods, long preceeded the establishment of the Social Security Act of 1935.

Secondly, the apparent decrease in personal savings rates is an artifact of the official national income accounting conventions, which fail to register the marked changes that were taking place after WWI in the forms in which households were actually accumulating assets. An increasing proportion of income was flowing into expenditures on consumer durables – the range of which had been widened dramatically during the 1920s with the introduction of radios, phonographs and a variety of household appliances similarly powered by electricity, as well as private automobiles. Thus, between the pre-World War I and the Interwar periods, the personal savings rate of DPI fell by almost 2 percentage points, whereas the ratio of consumer durables expenditures to DPI had increased by 5 percentage points. This appears to have been a once-and-for-all shift in household behavior, rather than the first step in a steady enlargement of the share of durables spending in income. A comparison between the period 1898-1916 and the post-World War II period shows changes of just about the same magnitudes (the personal savings fraction in

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104 See, e.g. Michael J. Boskin, "Macroeconomics, Technology, and Economic Growth: An Introduction to Some Important Issues," in The Positive Sum Strategy: Harnessing Technology for Economic Growth, Ralph Landau and Nathan Rosenberg, Eds., Washington, D.C.:National Academy Press, 1986: pp. 33-56, for an expression of this argument. It predates the "new growth theory" view that a higher rate of capital formation could in itself increase the rate of efficiency growth in the economy.

105 See Endnote 13 to Part Two.

DPI moves from 0.0804 to 0.0627, whereas CED/DPI increases from 0.0657 to 0.0970).[106] The shift seems to have been a response to the dramatic fall in the supply prices of the new range of durable goods, and the new and more attractive installment credit arrangements that were introduced during the 1920s.[107]

Stability in the Comprehensively Measured Gross Private Savings Rate

When this is taken into account by defining gross private savings more comprehensively to include consumer expenditures on durables, and augmenting GNP by adding the flow of gross rental services on the stock of consumer durables, one arrives at the GPSRA measure shown in the second row of Panel A.[108] Strikingly, the level of this savings rate in the post-World War I era turns out to be essentially identical to the 23-24 percent rate that prevailed in the pre-1916 era. Indeed, as may be seen from the first column of Table 2: VI, the temporal constancy of the average augmented gross private savings rate has characterized the entire century from 1869 to 1969.

The remarkable nature of that stability during the twentieth century is brought out by probing beneath the aggregate savings relationship known as "Denison's Law," which holds that the level of the GPSR in the U.S. remains in the neighborhood of 15-16 percent for years of "full employment," as the top row of Table 2: V-Part A (Panel A) shows it to have done from the 1920s up to 1969.[109] This phenomenon seems all the more arresting in view of the shifts that have taken place in its underlying components: the personal savings rate out of DPI rose slightly from the interwar level (excluding durables), but this was offset by the fall in disposable personal income as a fraction of GNP. At the same time, the rise in gross corporate savings rate out of gross corporate earnings net of taxes was sufficient to offset the decline in the share of after tax gross corporate earnings in GNP.

This story continued, with only minor deviations, during the following two decades: in Part B of Table 2: V the same set of average ratios for the GPSR and its underlying components are presented for "full employment" years between 1970 and 1990, so as to enable direct comparison with the earlier entries in Part A. Although during the 1970s the personal savings rate out of DPI shot up to a level not seen since the pre-World War I era, and this combined with a slight rise in the gross business savings rate out of gross

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[106] See Endnote 14 to Part Two.

[107] See Endnote 15 to Part Two.

[108] For productivity studies, it is more satisfactory to move towards the private domestic business concept, excluding the imputed returns on residential structures and consumer durables from output. Nevertheless, we include savings in the form of durables expenditures here in order to make the point that there has been remarkable stability in the private sector's savings rate across the whole of the present century.

[109] The entries in Panel A of the table were obtained (in Paul A. David and John L Scadding, "Private savings: Ultrationality, aggregation and Denison's Law," Journal of Political Economy, 82 (March-April), 1974: pp. 225-49, see Table 1) from regression estimates based upon annual data for years when the unemployment rate for civilian workers was below 6.1 percentage points, within the various periods shown. The differences between the GPSR rates for sub-periods 1921-1940 and 1948-1969 are not statistically significant.

after tax business income to boost the GPSR temporarily to 16.8 percent, by the end of the 1980s, the latter had returned to its long-term trend level of 15.4 percent.

The pattern of opposing movements in the underlying business and personal savings rates has suggested that American households' personal savings behavior in the present century may have been affected by the increased attractions of accumulating wealth indirectly, via ownership of the corporate sector. Equity holders might thus be seen to have tolerated an increase in the rate of retention of corporate after tax earnings, and accepted the relative expansion of capital consumption allowances, in exchange for the escape this provided from double taxation of income from property. The contention that households have no trouble in peering through the "corporate veil", and so take account of the net worth changes in the enterprises whose equity they own, has prompted many empirical studies and generated a distribution of findings on both sides of the question. On balance, the hypothesis that personal and business savings are linked by some such a mechanism has found empirical support from macro-level analyses for the U.S. in the post World War II era.[110] Still, one cannot accept as a literal description of that mechanism the theoretical model of a super-rational representative household – one that has maintained an essentially constant consumption rate out of gross income while opportunistically adjusting its forms of consumption and its asset portfolio.[111]

The nature of the mechanism that has maintained the long-term stability of the U.S. gross private savings rate remains very much a mystery, but, the obtrusive empirical fact is that it is not possible to blame the slowed rate of growth of the domestic capital stock on the private sector's supposedly rising current consumption propensities. What should be said, instead, is that the U.S. private sector's gross savings rate has not been rising to accommodate the secular increase in the share of aggregate output that is claimed by capital consumption allowances. Nor did it rise to offset the public sector dissaving that occurred when the federal government deficit mushroomed in the 1980s.

The stablity of the GPSR ("Denison's Law") is not, however, the only striking long-run constancy that appears in the record of U.S. aggregate saving over the course of the twentieth century. Furthermore, it may be pointed out that the persisting readiness of the private sector to forego current consumption is greatly understated by the statistics we just have reviewed. Actually, a 23 percent rate of gross savings has been maintained since the first post-Civil War decade. This fact is brought out by first column of Table 2: VI, which shows an augmented GPSR that takes into account savings in the form of consumer durables); and the figures in the second column of that table press the point even further by presenting a still more

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110 See, e.g., James M. Poterba, "Dividends, Capital Gains, and the Corporate Veil: Evidence from Britain, Canada, and the United States," Ch.2 in National Saving and Economic Performance, B. Douglas Bernheim and John B. Shoven, Eds., Chicago: University of Chicago Press for N.B.E.R., 1991: pp. 49-71.

111 One would have to envisage this "household" as shifting its sources of current utility between public and private consumption, and altering the corporate retentions rate (via its control of corporate policy), as well as the balance between its holdings of financial and real (tangible) wealth, in response to technologically driven changes in real rates of return, as well as in government tax policies and other exogenous developments. Such an "hypothesis" was put forward by David and Scadding (1974) in a tongue-in-cheek manner. At best this fantasy could be regarded as merely another parable, but, in this case, one that served primarily to call attention to the absence of a more satisfactory explanation of the data.

comprehensive measure of the gross private savings. The latter has been formed by adding the total resource costs of investments in education to gross private savings inclusive of expenditures on consumer durables, and expressing that total as a fraction of GNP augmented by inclusion of the estimated gross rental services from the stock of consumer durables (the same denominator as used for the rates in Column 1). This shows that a comprehensive savings rate in the near neighborhood of 27-28 percent has been maintained throughout the period stretching from the 1880s to the early 1960s.[112]

[112] We have chosen to use the same denominator in columns 1 and 2 of Table 2: V-Part B, so that the magnitude of the relative total resource costs of education can be inferred directly by subtracting column 1 from column 2. If one expresses the comprehensive measure of gross private savings as a ratio of the "fully augmented GNP" estimates (which form the denominator of the rates shown in column 4 of the same table) the result is to lower the level slightly, without materially disturbing its long-term stability.

Table 2: V-Part A
U.S. Gross Private Savings Rate (GSPR) and Its Components, 1898-1969

Rates and Ratios	**"Pre-World War I"**	**"Post-World War I"**	**"Interwar"**	**"Post-World War II"**
	1898-1916	**1921-40 and 1948-69**	**1921-1940**	**1948-1969**
Panel A: *Mean Savings Rates for Full Employment Years within Major Eras of the Twentieth Century*				
Conventional (Commerce Department): GPSR = GPS/GNP	.1835	.1552	.1492	.1554
Augmented Definition, including Consumer Durables. Expenditures: GPSRA = (GPS+CED)/GNP	.2326	.2260	.2171	.2262

Panel B: *Average Rates and Ratios for All Years within Major Periods of the Twentieth Century*

Ratios of Components of the Augmented Personal Savings Rate:	**1898-1916 "Pre-World War I"**	**1921-1929 "Interwar"**	**1949-1969 "Post-World War II"**
(PS +CED) / (GNP + GRD)	.121	.117	.126
Personal Savings Rate Components:			
PerS / GNP	.067	.040	.044
PerS / DPI	.080	.049	.063
DPI / GNP	.837	.816	.698
Gross Business Savings Rate Components:			
GBS / GNP	.110	.106	.111
GBS / GBP after tax	.663	.711	.807
GBP after tax / GNP	.166	.149	.137

Definitions:
PerSA (Augmented Personal Savings) = CED (Consumer Expenditures on Durables) + PerS .
GNPA (Augmented GNP, Durables only) = GRD (Gross Rental Flow on Stock of Durables) + GNP.
GPS (Gross Private Savings) - PerS (Personal Savings) + GBS (Gross Business Savings)
GBS = Undistributed Corporate Profits + Corporate and Non-Corporate Consumption of Fixed Capital
DPI (Disposable Personal Income).
GBP after tax (Gross Business Profits after Taxes) = Business Proprietors' Income + Rental Incomes of Persons with Capital Consumption Adjustments + Corporate Profits - Corporate Tax Liability.
Source: Underlying data from P.A. David and J.L. Scadding, "Ultra-Rationality, Aggregation and "Denison's Law," Journal of Political Economy, 82(2, Pt.1), March/April, 1974: Tables 1 & 2 for Panel A; Table 3 for Panel B.

Table 2: V-Part B
The U.S. Gross Private Savings Rate, from 1970 to 1990

Average Ratios For "Full Employment Years":	1970-74, 1978-79	1986-90
Gross Private Savings Rate:		
(PerS + GBS) / GNP	.168	.154
Personal Savings Rate Components:		
PerS / GNP	.055	.038
PerS / DPI	.080	.053
DPI / GNP	.689	.718
Gross Business Savings Rate Components:		
GBS / GNP	.113	.116
GBS / GBP after tax	.828	.927
GBP after tax / GNP	.136	.125

Notes and Sources: Underlying data from U.S. Department of Commerce, Bureau of Economic Analysis, NIPA, as recapitulated in *Economic Report of the President*, (February) 1997, Tables B-24, B-26, B-28. For comparability with the "full employment" for estimates in Table II.4.4 Panel A, the selected years are those in which the unemployment rate among white male and female workers was at or below 6.1%.

Table 2: VI
U.S. Educational Investment and Capital Formation Rates in the Nineteenth and Twentieth Centuries
(Current Dollar Ratios)

Year or Period	Gross Private Savings Including Consumer Durables as a Fraction of: *Durables-Augmented GNP*[a]	Gross Private Savings Including C- Durables and Education Costs, as a Fraction of: *Durables-Augmented GNP*[a]	Total Educational Resource Costs as Fraction of : *GNP Augmented by Students' Earnings Foregone*[b]	Total Educational Resource Costs as Fraction of: *Fully Augmented GNP*[c]
1869-1878	.225	.247	.027	.025
1879-1888	.239	.268	.036	.034
1889-1898	.245	.282	.046	.043
1899-1908	.237	.280	.047	.044
1923-1929	.217[2]	.287[3]	.030	.027
1940	.205	.253	.050	.046
1948	.235	.272	.055	.040
1956	.234	.278	.053	.048
1962	.224	.283	.069	.063

Notes: [a]Augmented GNP includes imputed rental flow on stock of durables.
[b]GNP plus foregone earnings costs of education.
[c]GNP plus imputed rental flow on stock of durables plus foregone earnings costs of education.

[1]Period averages for educational investment costs based on terminal Census years, e.g., 1899-1908 uses the value of numerators in columns 3 and 4 uses average of 1900 and 1910 estimates..

[2] Estimated average GPSRA for full employment years (1923-29) in the 1921-1940 interval, from Table 2: V-Part A.

[3] Weighted average of 1920 and 1930: for col. 3, (.021) and (.045); for col. 4. (.020) and (.041).

Sources: Estimates of augmented gross private savings inclusive of consumer durables, and GNP plus rental flow on consumer durables from underlying data for David and Scadding (1974). Estimates of direct costs and foregone earnings cost of schooling from M. Abramovitz and P.A. David, Appendix 8-B to "Economic Bases of the Rise in Labor Quality" (unpublished MS., Stanford University), and underlying worksheets (June 1974/ November 1997). See text for discussion of conceptual basis of estimates.

There is thus a very substantial margin of gross domestic capital formation taking place in the U.S. economy, over and above conventional gross private savings flows directed to tangible capital formation. This observation inveighs strongly against the notion that the aggregate supply of savings is inadequate to maintain the former growth rate of the tangible capital stock. Rather, it suggests that there are other, more attractive investment uses, and that these have continued to absorb the large share of America's growing productive capacity that the private sector continues to divert from current consumption.

The Growing Burden of Financing Education and Training Investments

The extension of secondary education of some form throughout the population, and the opening of colleges' doors to more than half of high school graduates, rank among the great social and economic achievements of American society during the present century. But these have not come cheaply. The annual resource costs of this educational effort have grown enormously in absolute volume and in proportion to the size of the national economy. When one considers not only the direct expenditures by households, nonprofit organizations and government, but also the foregone earnings of students, it must be recognized that at the beginning of the present century it was still legal in many states for children to enter regular work at age 11 or 12. Consequently, even at the beginnings of this movement, the earnings foregone by the families of the youngsters sent to school, already bulked quite large in comparison with their relative proportions in modern times. It is estimated that even as early as the last two decades of the nineteenth century (see entries for 1879-98 in Table 2: VI, col. 3) the average total educational resource cost stood as high as 4.6 percent of GNP adjusted to include the imputed value of the foregone earnings of students.

The beginnings of the rise in high school enrollments in this period entailed an upward step in the national educational investment rate from the level a bit under 3.0 percent that had prevailed in the immediate post-Civil War decade. That the share of augmented GNP being devoted to sending Americans through grade school and elementary school already was so big at this time was due primarily to the large costs estimated for the foregone earnings component of the total, reflecting the fact that the opportunity costs of school attendance had yet to be curtailed by compulsory schooling laws and restrictions on the employment of juveniles, and that in many states where schooling was compulsory this did not extend through high school.[113] By the 1920s, however, the situation had changed, and the lowered level of the rates estimated for that decade in the central row of Table 2: VI (cols. 3 and 4) are accordingly lower, although they would show a further rise over those at the beginning of the century were they to have been made on the same basis.[114]

The point just noted, regarding the effect of shifting social regulations affecting school attendance and the opportunity for juvenile employment, means that the level of the educational investment rates shown for 1940 onwards is not immediately comparable with those for earlier periods except as measuring educational resource costs within the legal and institutional context that has prevailed more or less unchanged throughout the second half of the present century. Focusing attention on the estimates for that

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[113] See Endnote 17 to Part Two.

[114] See Endnote 18 to Part Two.

period (the lower panel of the table), the beginnings of a second and more pronounced rise of the educational investment rate are visible. As the post-World War II "higher education boom" got underway, the absolute resource costs soared: in real (constant price) terms the U.S. total resource costs devoted to formal schooling expanded 10-fold between 1948 and 1962, as increasing college attendance contributed strongly to a 6-fold rise in real resource costs per student.

By the early 1960s, the relative national burden represented by the total resource costs of these educational investments had been pushed upwards from the neighborhood of 5 percent in the 1950s, to reach 7 percent of GNP inclusive of foregone earnings. An upward shift of similarly substantial proportions is seen when total educational resource costs in current prices are expressed as a ratio of the corresponding current value of *GNP fully augmented* (that is aggregate productive potential including both the gross rental services of consumer durables and foregone earnings of students): this measure of relative national burden rose from approximately 4.4 percent in the 1950s to 6.3 percent in the early 1960s. But that was just the beginning; by 1981 the corresponding proportional burden had been fully doubled and stood at 12.7 percent.[115]

Viewing the private costs of schooling in relationship to the flow of income available to American households provides another perspective on the massive scale of the income reallocation which has been entailed just in financing the growth of human capital formation through formal education. Leaving aside the direct costs that have been paid for by tax revenues, and financed by state and local bond issues secured by the prospect of future taxes, and netting out scholarships and grants received by college students, virtually all the private costs of high school education and approximately 80 per cent of the private costs of college education take the form of foregone earnings. Considering the ratio of the latter to the level of disposable personal income *plus* foregone earnings thus provides a lower-bound estimate of the rising relative claims made upon households' potential income by private investments in schooling. Starting at an average of 6 percent in 1889-1908, the share was reduced to 4 percent during the prosperous 1920s, partly as a result of the markedly reduced birth rate in the early years of the century. By 1962, however, the minimal size of the proportional educational burden had risen to 11 percent, and by 1981 it represented 20 percent of disposable personal income plus foregone student earnings. Allowing for the swelling direct private costs of college attendance, the full extent of the burden moved into the range upwards of 25 percent during the 1980s.[116]

Over the course of the present century the education investment component has not been the only component of intangible capital formation that has claimed a growing share of the U.S. gross savings potential, but has been far and away the dominant claimant. According to recent estimates made by John Kendrick (1994), by 1990 the share of educational investment in total tangible conventional *plus* non-tangible investment, which adds R&D to the educational component, had reached the neighborhood of 35

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[115] See Endnote 19 to Part Two.

[116] See Endnote 20 to Part Two.

percent.[117] The corresponding share (as calculated from the estimates in Table 2: II-Part A) had been 22 percent in 1962, and was around 16 percent in 1900-10.

Thus, although the twentieth century has seen appreciably more than a doubling in the proportional claims made for education upon the comprehensively measured gross flow of savings in the U.S. economy, during the past three decades the relative expansion of that share has been particularly rapid. It has far exceeded the long-term growth of the claims on savings for the other significant intangible investment form, R&D, although it is the latter that has been claiming more and more theoretical and empirical attention from economists in recent years. To be sure, R&D expenditures and the estimated real stock of (cumulated) R&D have been growing at a spectacular rate from their negligible pre-1929 levels. But, even so, according to the available estimates for 1990 (in Table 2: II - Parts A,B) the volume of investment in organized R&D remained merely a tenth of the concurrent educational resource costs, and the ratio between the R&D stock and fully augmented GDP was only one-twelfth of the corresponding ratio for education and training capital.[118]

In large measure the emphasis that the foregoing discussion has given to human capital formation within the class of intangible investments, follows from the preponderant weight that the latter carries within the accounting framework of our augmented Solow-model. Yet it should be borne in mind that the continued strength of the derived demand for investment in human capital itself reflects consequences that have flowed from the other, quantitatively minor component of intangible capital formation. The significance of the rapid rise of investment in organized R&D following World War II lies less on the input side than on the output side of the growth accounts; it is seen in the persistingly high private and social rates of return that have come to be expected from the generation of designs for new goods and services, production methods, and modes of organization.

As we have seen, and as "new growth" theorists lately have been seeking to model,[119] there are great externalities from the fruits of investments in scientific knowledge, in the engineering of ways to realize economies of scale and scope, and in the development of new products that enhance consumers' sense of well-being – even though the full extent of such benefits may not be fully recorded in the official national product accounts. Ideas of those kinds, especially when they have been codified and validated, are likely to generate effects that readily "spill over" among individuals, firms and industries; they can be repeatedly used and re-used by successive generations, and thereby contribute to maintaining the economy-wide marginal rates of return on tangible and intangible factors of production alike.

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117 See, John W. Kendrick, "Total Capital and Economic Growth," Atlantic Economic Journal, 22(1), 1996.

118 See Endnote 21 to Part Two.

119 See, e.g., Paul M. Romer, "Endogenous Technological Change," Journal of Political Economy, 98(5), October, 1990: pp. S71-S102; Charles I. Jones, "The Upcoming Slowdown in U.S. Economic Growth," Department of Economics Working Paper, Stanford University, (September) 1997; Charles I. Jones, Introduction to Economic Growth, New York: W. W. Norton & Co., 1997, esp. Ch. 5.

The Course of Real Rates of Return on Intangible Capital

What has been the effect of the massive formation of educational capital, and the accompanying accelerated growth of the total stock of education and training assets relative to manhour labor inputs, upon the average real rate of return to these intangible assets? The central and striking fact is that the differentials in the average earnings rates of college graduates relative to high school graduates have remained remarkably stable, despite an enormous increase in the population's educational attainments, and particularly in the face of the tremendous pace of increases in average educational attainments during the post-1929 era.

It would indeed be remarkable, had there been no compression whatsoever in education-associated earnings differentials during the earlier part of the century, especially at the higher educational attainment levels which initially were so thinly populated. This expectation is confirmed by the findings of Claudia Goldin and Lawrence Katz's recent systematic survey of the available wage data bearing on this question: the schooling premium for male clerical and office workers did indeed decline between 1895 and 1939.[120] Nevertheless, when – during the era that followed – the rise of the educational capital stock would have been exercising its most powerful depressing effects on the differential rate of return to human capital formation, that downwards pressure appears to have been offset entirely by the forces that we have identified as operating on the demand side of the labor market. For white male workers there has been a remarkable degree of stability during the 1940-80 period in the ratios of lifetime earnings between high school and elementary school graduates, and between college and high school graduates, save for a still puzzling collapse in these differentials during the 1950s. Furthermore, in Table 2: VII one may examine the results of some rather careful calculations that we have made of the private rates of return to educational investment, based on corrected earnings data for educational groups reported in U.S. census samples, which show that these inducements remained remarkably stable over the period up to 1960 in the U.S.

These findings carry two direct implications. The first and rather transparent point is that economic gains from high school and college completion were sufficiently high to mobilize political support in the electorate for public programs to subsidize schooling at all levels, and to induce families to meet heavy private costs, including the foregone earnings of their young college-bound youngsters. The second inference is that the stability of the education-associated earnings differentials in the face of the relative growth in the shares of the (male) civilian labor force who had completed high school and college during the decades of the 1940s and 1950s was most likely due to favorable demand-side shifts.[121] In the same way, the constancy of the educational rates of return in the face of a rapid rise in the ratio of the stock of education and training capital to real gross product (augmented by educational production) is most plausibly explained for the period in question on the supposition that technological and related innovations, and organizational changes were working to raise the demand for the stock of educated workers.

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[120] See Endnote 22 to Part Two.

[121] This is supported by the analysis of the detailed pattern of increases and decreases in the age-education composition of the labor force for these decades in Abramovitz and David ("Technological Change and the Rise of Intangible Investment,"1996: Table 8) and the accompanying discussion.

A further important indicator of the human capital-using bias that operated in this era is to be read in the change in the occupational composition of the workforce.[122] Using a grouping by broad occupational classes and the schooling levels of the different occupations observed from the 1950 Census, one may calculate by how much the average level of schooling of the whole work force would have increased simply as a result of the shift in occupational composition. This is a crude measure but it alone accounts for approximately half the actual rise in the average school level of the workforce that occurred between 1900 and 1960. Of course some of the occupational shift, especially that between 1900 and 1929, can be thought to have been induced by the reduced earnings differentials paid for workers who held high school diplomas, so on that score rather less than half the observed increase might more properly be attributable to a demand shift affecting the compression in educational premia, and the gaps between the earnings of high school and college graduates were widening just in the period when significant increases in college completion rates were beginning to affect the labor force.

[122] See Abramovitz and David, "Technological Change and the Rise of Intangible Investment," 1996: Table ; and Stephen R. Barley, "The Rise of the Technical Labor Force in the United States, Canada and the United Kingdom," Working Paper from the Department of Industrial Engineering and Engineering Management, Stanford University. November, 1994.

Table 2: VII
Rates of Return on U.S. Investment in Education and on Tangible and Intangible Capital Stocks

Part A :
Private Internal Rates of Return for Different Levels of Schooling: U.S. Urban White Males
(Percent per Annum)

Years of Schooling	1939	1959
9-11	10.3	10.2
12: High School Grads	12.9	14.5
13-15	9.4	10
16+: College Grads	14.6	13.4

Part B :
Average Gross Social Rates of Return on Gross Capital Stocks by Major Category:
U.S. Private Domestic Business Economy
(Percent per Annum)

	1929	1948	1981
Aggregate Intangible Stock Embodied in Humans (excluding R&D capital)	4.6	5.5	4.2
Aggregate Tangible and R&D Capital Stock (Nonhuman)	8.3	10.5	8.7

Notes and Sources:

Part A: Abramovitz and David, "Rise of Intangible Investment," 1996: Table 7.

Part B: Gross returns on the Intangible Stock (comprising Education and Training, and Health, Safety and Mobility) were computed from data in Kendrick (1994), Table 7, for the total (Tangible and Intangible) Human stock earnings, adjusted by the average ratios of (α_L/θ_L), from data in Table II.3.1A: - α_L/θ_L = 0.388, 0.431, and 0.431 were the averages for periods centered approximately on 1929, 1948 and 1981 respectively. Gross rates of return for the "Nonhuman" aggregate stock are those given by Kendrick (1994), Table 7.

The stability in the earnings premium for education in itself is not conclusive evidence that the relative marginal *social* product of schooling was tending to be raised, in the absence of a responsive increase in the supply of educated workers.[123] If employers view education as a signal that workers have other desirable qualities – such as high IQ, ambition, energy, a capacity for absorbing codified instructions and a toleration of organizational discipline – the demand for schooled workers may rise with the extension of education regardless of its contribution to "labor quality" viewed as the possession of cognitive skills.

Putting the point in a somewhat different way, the pure "signaling" value of educational attainments renders the interpretation of these rates of return calculations problematic, as the work of Michael Spence has suggested.[124] Yet, it should be borne in mind that the mere existence of a screening function that educational qualifications serves does not vitiate the grounds for attributing some measure of social productivity to educational expenditures. For one thing, getting the right workers matched to the right occupations and job slots will be a source of allocative efficiency gains for the whole of the economy. Furthermore, although we have no way of knowing how important the screening process has been in supporting the turns to secondary and post-secondary education, if only the signaling motive for seeking further education to preserve relative earnings position were at work on the supply side, the value of high school and college diplomas should have been much depressed by extending those "indicia" to people of progressively lower abilities.

The interpretation of U.S. labor market developments in the pre-1960 era is also broadly applicable to the subsequent American experience: on our view, the upward trend of education-associated earnings differentials over the period since the 1960s, and especially the explosion of those differentials that began in the 1980s, was driven by net shifts in derived labor demands that were shaped primarily by technical change. That is to say, it represented the latest phase of a long-standing process, involving deep and powerful forces arising in the biased character of modern technological change, and the changes in the industrial composition of employment associated with the growth of aggregate and per capita income in the economy at large. This view of the factor-market impacts of the intangible (human) capital-using bias of technological innovation during the period 1966-89 is consistent with the implications of a related argument, namely, that skill-technology complementarity effects – presumptively associated with the introduction of new, computer-based information technologies – have been working also to widen wage differentials within age, occupational, and educational attainment groups in the U.S. labor force.[125]

This particular question remains far from conclusively settled. Nevertheless, the evidence assessing various suggested causes of the growth of wage and earnings inequalities in the U.S. points to the

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123. See the discussion accompanying Figures 1A and 1B in Abramovitz and David, "Technological Change and the Rise of Intangible Investment,"1996 .

124. Spence, Michael A., Market Signaling: Informational Transfer in Hiring and Related Processes, Cambridge: Harvard University Press, 1974; Weiss, Andrew, "Human Capital vs. Signalling Explanations of Wages," Journal of Economic Perspectives, 9(4), 1995: pp. 133-54. Spence (1974).

125. See Abramovitz and David, "Technological Change and the Rise of Intangible Investment,"1996 for discussion of the literature on increasing wage inequality in the post-1967 period.

preponderance of the influence coming from demand-side shifts stemming from the introduction of new technologies and their complementarity with certain skills and capabilities for problem-solving that are likely to develop with increased educational attainments. The consensus of recent expert opinion is that during the period from the mid-1980s to the mid-1990s, the intensification of this biased form of "technological change" has resulted in greater premia being paid to workers with the appropriate qualifications *within* each of a wide range of industrial sectors and broad occupational categories. This trend, rather than decline of unionization and industry-wide wage bargaining, or the increased intensity of international competition, that appears to have been the dominant factor responsible for the widening of differentials within the upper half of the distribution of earnings among male high school graduates, although it must be acknowledged that this, in its nature, is something of a residual explanation.[126]

The evolution of modern wage structures has been characterized by the economist Jan Tinbergen (1975) as "a race between technological development and access to education."[127] The insightful nature of that remark is amply borne out by the long-term experience of the U.S. during the twentieth century. That experience might be described more specifically if less succinctly as a race between the human-capital using bias of technological and organizational innovation, on the one hand, and, on the other, the accumulation of intangible capital through education and training investments. Major changes in the economic circumstances and behaviors of American households, and critical public measures affecting access to and financing of education, were entailed in the process that kept this race an approximately even one for most of the century. But, the untoward resurgence of earnings as the century draws to its close points to the possibility that the inherited infrastructure of institutions, public programs, and financing mechanisms, may no longer be adequate to enable the U.S. economy to fully exploit the potential synergetic interaction between technological developments and the formation of complementary productive assets.

Problems of this kind may be seen to be manifesting themselves in the persisting slowdown of technological advance that can be realized as multifactor productivity growth, and so form a part of the complex and puzzling phenomenon that has marked the final quarter of the twentieth century. It therefore is appropriate that the remainder of this Part should look more closely at the phenomenon of the so-called "productivity slowdown," and the challenge that has posed for U.S. economic policy-makers and all who seek a deeper understanding of the historical process of long-term growth.

126 See Endnote 23 to Part Two.

127 See Jan Tinbergen, Income Differences: Recent Research, Amsterdam: North-Holland, 1975; also, on this theme, Jan Tinbergen, "Substitution of Academically Trained by Other Manpower," Weltwirtschaftliches-Archiv, 111(3), 1975: pp. 466-76.

3. The Puzzling Productivity "Slowdown"

The 23 years from 1966 to 1989 mark an important break in the long trend of acceleration in labor productivity growth. Compared with the preceding "long-swing" interval (1948-66), the recent growth rate was over 60 percent slower. Had growth continued at its 1948-66 rate, the level of labor productivity would have been 54 percent higher in 1989 than it actually was. Other things being equal, so would output per capita, and so would people's incomes. There have been some new indications that labor productivity growth has become somewhat more rapid in the years since 1989 than it was in the especially poor decade of the eighties, but it still remains far slower than its pace during the growth boom of 1948-66 or, indeed, during the longer period from 1929 to 1966. With regard to the rate of increase in conventionally measured total factor productivity, the decline recorded after the late 1960s is still more dramatic. Although some observers, basing themselves on the "official" output figures of the National Income and Product Accounts, have suggested the emergence of a significant revival during the 1990s, the picture presented by the Bureau of Labor Statistic's chain-weighted measures of output growth actually points to the opposite, considerably less optimistic conclusion.[130]

Economists remain uncertain about the reasons for the persistence of the productivity slowdown. What follows is a brief account of what can be said on the question with some degree of assurance, and of other things that may be important but that we cannot either measure or otherwise verify with confidence.

3.1 What the Growth Accounts Reveal

The roles played by the various proximate sources of growth, insofar as these can be identified and measured by growth accounting methods, are revealed in Table 2: VIII – which has been directly derived from the accounts in Tables 1: IV and 1: IVA. Consider, first, the results of comparing the sources of labor productivity growth in the long-swing intervals, 1948-66 and 1966-89. Of the total decline in the labor productivity growth rate, amounting to 1.88 percentage points, a minor fraction can be attributed directly to a lower rate of increase in tangible capital inputs per hour of labor. That leaves 87 percent of the drop attributable to the shrinkage of the crude TFP residual, concerning the process of economic growth.

Nonetheless, the "refining" calculations presented by this table do help to dispel some of the mystery, however limited a part. One can see that the slowed growth of labor quality was a minor contributor to the retardation of the labor productivity growth rate, and the contraction in the crude TFP residual between 1948-66 and 1966-89. Although the contribution of rising educational attainment in the labor force remained as strong as ever after 1966, shifts in the age- and sex-composition of the working population were an offsetting force. When the first wave of "baby boomers" began to come of age at the

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130 The measures of both labor productivity and refined TFP based upon "chain-weighted" output indexes for the non-farm business sector reveal substantially *slower* growth during 1988-96, compared with the period 1966-88. See U.S Department of Labor, Bureau of Labor Statistics, News Release USDL 98-187 (May 6, 1998). The indicated retardation in chain-weighted indexes of labor productivity also holds for the whole of the private non-farm economy. See Endnote 24 for comparisons with the period 1950-72, and further discussion.

end of the 1960s, the entrance into the American labor market of successive large cohorts of young and inexperienced workers exerted an adverse impact of average "labor quality." This negative impact upon labor productivity growth, however, was concentrated during the 1970s; it operated with diminished strength in the following decade. Another essentially transient development was the effect of the acceleration in the rate of entry of women into the workforce: as women's earnings rates are lower than men's, their increased relative numbers adversely affected the (composition) index of labor quality. A similar drag upon labor productive growth was exerted after the ending of the 1960s investment boom by the slowed pace of improvement in the "quality" of input services yielded by the tangible capital stock. The upshot is that more than three-fourths of the retardation that occurred in the pace of labor productivity advance (comparing 1966-89 with 1948-66) is attributable to the collapse of the refined TFP residual.

At least a portion of the latter contraction may be ascribed to the fact that the average age of the tangible capital stock, which had been reduced rapidly during the postwar boom, ceased being driven still lower during the 1970s and 1980s. But the "vintage effect" can account for only 8-9 percent of the labor productivity slowdown between "the golden age" of 1948-66 and the "tarnished age" that ensued. Over two-thirds of the fall in that growth rate remains to be ascribed to the "age-neutral" refined TFP residual.

From the left-most columns of Table 2: VIII it may be seen that the contrast between the 1966-89 trend period and the preceding "long period" 1929-66 was still more dramatic, and, if anything, deepens the mystery of the slowdown's sources. Taking that basis for comparisons, only the reduced growth rate of labor input "quality" due to composition changes appears as a factor contributing to the retardation of the trend rate of labor productivity growth. Indeed, more than the entirety of the latter change is "explained" by the fall in the conventional (refined) measure of TFP growth, and the vintage effect's part in that movement was quite negligible.

Table 2: VIII
Sources of the Slowdown in Labor Productivity Growth: U.S. Private Domestic Economy

		Change from 1929-66 to 1966-89		Change from 1948-66 to 1966-89	
		Percentage points	Percent of change in labor productivity growth	Percentage points	Percent of change in labor productivity growth
1.	Output per manhour	-1.29	100.0	-1.88	100.0
	Sources				
2.	Capital per manhour	+0.14	-10.8	-0.24	12.8
3.	Crude TFP	-1.43	110.8	-1.64	87.2
4.	Labor quality	-0.09	7.0	-0.12	6.4
5.	Capital quality	+0.07	-5.4	-0.09	4.8
6.	Refined TFP	-1.41	109.3	-1.43	76.1
	Addenda				
7.	Vintage effect	-0.04	3.1	-0.16	8.5
8.	Age-neutral refined TFP	-1.37	106.2	-1.27	67.5

Source: Tables 1: IV and 1: IVA. We have deleted here the changes in the growth of Labor Quality (and those in subsequent lines of the table) that might be calculated from the parenthetical figures in Tables IV and IVA.

It is figures such as the foregoing that have led many commentators to regard the slowdown as something of an unfathomed riddle. Certainly it must be admitted that this sudden pronounced change in a magnitude that once was described as "a measure of our ignorance" simply exposes a new and different dimension of that ignorance, even though the change has been in the direction of erasing the residual itself.[131] But, inasmuch as it reflects the net effect of all the remaining errors of measurement affecting the

131 On the problem of productivity surges and relapses, see David and Wright, "Early Twentieth Century Productivity Dynamics" (1999).

other items in the account, the refined TFP residual is a magnitude that must be handled with considerable care. To the extent that those errors are not unsystematic and therefore bias intertemporal comparisons, the residual will not be a good indicator of the true change in the multifactor productivity growth trend – let alone of changes in the underlying pace of technological progress, that is, of the advance of knowledge actually incorporated into production. It is important in this connection to stress that to the degree to which we look to the existence of measurement errors to account for the slowdown, it must be with the possibility of *a post-1966 increase* in the magnitude of a net downward bias that we are concerned.

Taking account of inputs that are excluded from the conventional growth accounts is a straightforward way to address a potential measurement bias of that kind. From Table 2: IV-Part A, where we present the results of the augmented growth accounting exercise, one may compare the contributions made by increasing tangible- and intangible-capital-intensity during 1966-89 with that during the preceding long period, 1929-66. This strongly underscores the indications provided by the conventional growth account as to where the proximate responsibility can be placed for the fall in output per manhour: tangible capital-intensity was rising somewhat more rapidly, whereas the growth rate of intangible capital-intensity fell quite perceptibly (decreasing by almost 0.4 percentage points). The resulting slowdown in overall capital-intensity growth may be seen (from Part B of Table 2: IV) to account for a bit more than one-fifth of the 1.43 percentage point drop in the annual growth rate of output per manhour after 1966. But the four-fifths that remains to be ascribed to a slowdown in refined multifactor productivity (MFP) is still a very substantial phenomenon calling for explanation. The absolute magnitude of this "MFP slowdown" stands at 1.13 percentage points, whereas the drop in the conventionally measured (refined) residual found in Table 2: VIII is 1.41 percentage points. So, by extending the growth accounting framework to consider the trends in the intangible inputs, it has been possible to account for another 0.28 percentage points, or about 20 percent of the observed post-1966 contraction in the growth rate of the conventional index of (refined) TFP.

What might have caused this 1 percentage point fall in the annual pace of advances in the overall efficiency of the private sector's use of productive resources? More than one well-known economic analyst has suspected a slowing down of the rate of technological innovation. For example, in a recent discussion of the role of new goods in economic growth, Timothy Bresnahan and Robert Gordon[132] rhetorically ask:

> Is it merely a coincidence that the period of most rapid growth of productivity in US history corresponded to the interval between roughly 1920 and 1965 when such fundamental inventions as the motor car, air transport, electric machines, light and appliances, radio and TV, chemicals, plastics, and antibiotics were, together with their supplementary and subsidiary inventions, spreading through the economic fabric?

By implication, then, the slowing of TFP growth is thought to reflect a slowing in the rate at which the impacts of "fundamental inventions" have spread through the U.S. economy.

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[132] See the Editors' Introduction in The Economics of New Goods, Timothy F. Bresnahan and Robert J. Gordon, Eds, Chicago: The University of Chicago Press for the National Bureau of Economic Research, 1996.

Of course, what is meant by "fundamental invention" is a difficult subject, and there is some real danger of circularity if the definitional approach taken is one that rests upon assessments of the impact upon productivity growth of various innovations in goods and processes. But even were one to suppose that there had been a slowdown in the rate of advance of knowledge proper, it would be important to know why that suddenly had happened. Did it stem from a decline in efforts devoted to research and development, or from the misdirection of such efforts? Or was it because, in the existing state of knowledge, the potential for further advance had become more limited than hitherto? Or could the problem lie in the greater difficulties and associated resource costs entailed in exploiting the more recent technological breakthrough in ways that would enhance productivity? This gives us quite an extensive agenda for discussion in the remainder of this section.

But, before proceeding to take up these potential explanations for somewhat closer examination, it is necessary first to consider the possibility that the mysterious slowdown is more apparent than real; that it stems from errors of measurement on the output growth side of the accounts.

3.2 Is the Slowdown an Artifact of Mis-measurement?

The suggestion has been put forward, with increasing frequency in the past decade, that the "official" statistics from the National Income and Product Accounts may seriously underestimate the true growth of real output and, hence the productivity growth measures; and that the downward bias deriving from this source has become more severe in recent years. As to the first part of this proposition, the substantial *negative* MFP residual (- 0.31 percentage points per annum) for the 1966-89 interval, which emerges from the augmented growth accounting calculations in Table 2: IV, does indeed suggest the presence of some output understatement. Indeed, unless one is prepared to believe that the U.S. has been suffering a form of sustained "technological retrogression" that would have reduced the overall efficiency of inputs by 6 percent over two decades – it is necessary to suppose that our estimate of the growth rate of (augmented real gross product) for that period is too low, at least by something on the order of 0.3 percentage points per annum.

This in itself is not implausible, as we shall see shortly. But it tells us nothing which would support the second, and crucial part of the "Mis-measurement" explanation for the productivity slowdown. There is a different argument, however, which directly addresses the latter phenomena. It rests on the dual observations that the declines of labor productivity growth were concentrated in a group of service sectors in which real output growth is especially "hard-to-measure," and that those sectors grew substantially in importance rapidly during the very decades of the observed slowdown.[133] Although those assertions are

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[133] For this argument, see Zvi Griliches ("Productivity, R&D and the Data Constraint," American Economic Review, 84(1), March, 1994: pp. 1-23.) The distinction between the two groups is significant, but less sharp than the statement in the text suggests. For more disaggregated labor productivity growth data, using a four-fold classification of industries by degree of data quality, see Robert J. Gordon, "Monetary Policy in the Age of Information Technology: Computers and the Solow Paradox," Paper presented to Bank of Japan Conference, Monetary Policy in a World of Knowledge-based Growth, Quality Change, and Uncertain Measurement. (18-19 June), 1998: esp. Table 4. Gordon's analysis reveals that the post-1973 decline in

empirically well-founded, the question remains whether the effects of this structural change have been quantitatively appreciable in relation to the magnitude of the slowdown. It turns out that, taken by themselves, those considerations are not sufficient to establish that this source of under-estimation of real output growth has been a major quantitative contributor to the appearance of a slowdown in the conventional measures. Alternative impact assessment calculations concur in finding that only a very small portion of the retardation in the growth of aggregate labor productivity in the private domestic economy, specifically between one-eight and one-ninth, can be attributed to the effects of its increasing drift towards "unmeasurability" during the 1970s and 1980s.[134] From both the nature and outcome of those calculations it follows that were Mismeasurement really at the core of the slowdown, this would have to be so because the inherent underestimation biases affecting the standard measures of real output and productivity growth at the sectoral level– whatever their source – have secularly become more severe. In other words, the supposed Mismeasurement bias cannot simply be a matter of the economy's changing sectoral composition.

There is, however, a rather different line of argument, which recognizes that and contends that the key mismeasurement problem really is one of "over-deflation being exacerbated by an increase in the relative rate of introduction of new goods and services. This turns on the notion that new goods in particular create problems of unmeasured quality change, which would, according to this line of reasoning, have grown more pronounced in the US economy than had been the case formerly.[135] Of course, the era that stretched from the aftermath of WWI through the post-WWII period witnesses the introduction and elaboration of many major innovations, as is emphasized in the passage we quoted from Bresnahan and Gordon (1996) previously, in section 3.1. So the claim that there has been a speed-up in the rate of product innovation is not one that is obvious on its face. Nevertheless, the 1970s and 1980s have yielded their own harvest of quality gains and new goods, as the spectacular declines in the measured price-performance ratio of computer hardware, and of rapidly diffusing telecommunications equipment such as digital switches and mobile phones, might suggest. In the case of computers some of these have indeed been captured, by the use of so-called "hedonic" price deflators, and so are reflected in the national product growth accounts. But that has been the exception, rather than the statistical rule.[136] Elsewhere, the fragmentary data that are available do indeed indicate that there has been a marked acceleration since the mid-1970s in the rate at which new goods are being introduced into the flow of commodities passing through wholesale and retail channels. This development may be linked in some degree with the rapid movement towards "mass

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productivity growth rates was experienced widely, across all the data-quality groups.

134 See the calculations presented in Endnote 25 to Part Two.

135 See Endnote 26 to Part Two, for references and further explication.

136 Note, however, that the great gains in computer speed and memory are now amply recognized by the "hedonic" deflators used to establish the real increase in computer output. It is the gains that stem from the use made of computers which may not be taken into account adequately.

customization" as an American business strategy, and with the enabling effects of applying advanced information technologies in the industrial R&D process itself.[137]

Although this is a line of inquiry that is sufficiently promising to merit further empirical investigation, one also must acknowledge that the precise meaning of "new product" remains difficult to pin down, especially in the context of inter-temporal and inter-industry comparisons. Moreover, even if it could be accepted on its face, the supporting evidence adduced to date remains too scantly a basis on which to claim that the recent productivity slowdown is largely illusory. Thus there is a presumption that the increased strength of the over-deflation bias in the era of the perceived slowdown was not large enough to justify searching for the latter's explanation elsewhere, in real developments that were adversely affecting the efficiency of resource use in the US economy.

3.3 Seeking "Real" Causes: A Line-up of Some of the Suspects

What sort of developments must be considered? The message of the growth accounts directs our attention to the sorts of changes that might reflect themselves in the rapid shrinkage of the refined TFP residual, which means possible causes of an alteration in the underlying rate and direction of technological innovations, and in the speed with which such innovations were being implemented and potential scale economies were being exploited.[138]

Flagging Technological Efforts?

Did the measured advance of technology slow down because fewer resources were devoted to the search for improved methods of production? Measured by expenditure for organized research, the answer is "no". Although the percentage of GDP devoted to research and development during the seventies may have been about 25 percent smaller than in 1965, there was a recovery thereafter. By 1985, the percentage was almost back to the 1965 level and has remained so since. More to the point, these figures include the very large portion of all expenditures financed by the federal government. During the 1960s, this comprised over 50 percent of the total. And since the great bulk of federal expenditures supported research for improved products supporting defense, space, and health, in which improvements, however valuable they may be, do not register fully, if at all, in measured output, a decline in such expenditures does not affect the growth of productivity as measured. In fact, the decline in the percentage of GDP devoted to research and development (R&D) was confined to federal expenditures. The fraction supported by industry, the universities and other nonprofit institutions leveled off but did not fall during the 1970s before resuming

137 In addition to the evidence presented in the works referred to by Endnote 26 to Part Two, see W. Michael Cox and Richard Alm, "The Right Stuff: America's Move to Mass Customization," Federal Reserve Bank of Dallas Annual Report, 1998: pp. 3-23.

138 See Endnote 27 to Part Two.

its growth in the 1980s. By 1987 the organized private R&D fraction of GDP was 40 percent higher than in 1965.[139]

Clear judgments about the trend of technological effort are, nevertheless, hard to make. This is true, first, because the statistics of private organized R&D cover only a portion of the total effort. They neglect the work of independent inventors and engineering consulting firms and also the work that takes place in those smaller firms that do not have separately organized R&D departments or laboratories. The important work now directed to the invention of improved computer software by firms other than those integrated companies that also produce computers is another neglected segment. Perhaps most important, the statistics do not include the efforts made by managers, engineers, technicians, accountants, and others to improve the efficiency of production and of all the ancillary departments of firms while they are engaged in the ordinary routines of their jobs.[140]

If a decline of organized R&D is not a major source of the slowdown, we must ask where causes of the collapse in refined TFP can be found. A failure to incorporate the gains from advancing knowledge fully into production is one such possible source. Insofar as incorporation means embodiment in tangible capital and intangible human capabilities through education and training investments, this already has been addressed by assessment of vintage effects and the augmented growth accounts. There are, however, advances in knowledge that do not require new investments in tangible capital. We must ask first why management would not take advantage of them. Then we consider the possibility that some previously important technological efforts that were not formally organized and, therefore, not represented in the statistics of R&D, might have been diverted, in part, to deal with other pressing concerns. Next, it could be that technological effort of whatever sort, organized or informal, may have become misdirected, less well organized, or aimed in less fruitful directions. Finally, the emerging science-based technology may have reached a state such that even though it holds out great potential payoffs, the adjustments in terms of the organization of economic activities and social institutions remain more difficult to effect, and costlier than was the case when, previously, technological progress consisted of continuing to advance incrementally along well-explored economic paths. This last suggestion leads us to entertain the thesis that the paradoxical conjunction of the computer revolution and the productivity slowdown reflects the opening phase of an extended techno-economic regime transition.

Managerial Misdirection of the Innovation Process?

In a much noticed book published in 1989, the MIT Commission on Industrial Productivity[141] argued that managerial practice during the 1970s had become marked by "short time horizons," so that decision-

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139 National Science Board, Science & Engineering Indicators – 1998. Arlington, VA: National Science Foundation, 1998 (NSB 98-1): Appendix Tables 4-6 through 4-19.

140 See Endnote 28 to Part Two.

141 Michael L. Dertouzos, Richard K. Lester and Robert M. Solow, Made in America: Regaining the Productive Edge, (Report of the MIT Commission on Industrial Productivity), Cambridge, MA,: MIT Press, 1989.

making became unduly focused on current and near-term profits, and on the prices of company shares with which executive compensation was linked. This was thought to have detrimental consequences for the pace of introduction of major innovations. Many important new products and processes, when first designed, did not have the forms, the reliability, the durability, the distribution and service capabilities, and the price to attract a large market, and therefore immediately to realize large private and social payoffs that would be reflected in the productivity statistics. The early transistorized computers of the 1950s are perhaps the classic example. Moreover, ancillary innovations are usually needed to complement the basic innovation, as highly developed software is needed to make computers easy to use, and time-sharing was significant in reducing the large-fixed cost barriers to the widespread adoption of mainframes for business use. Years of expense are required to develop the complementary innovations and to build the intellectual competence and the corporate organization needed to create complex products and to build markets large enough to reduce their cost, and without the vision required to sustain those investments, commensurately large gains might not be forthcoming.

A number of reasons why American firms have displayed inadequate staying power, or an inability to appreciate the profit potential of a long-term outlook, were reviewed by the MIT Commission's Report. The cost of finance, as measured by real interest rates, was high in the United States during the 1980s, a result of large federal budget deficits, the absence of compensatory increases in household savings rates, and the consequent need to attract foreign capital. The profit rates – over and above the cost of finance – demanded by American firms have also been high – usually as measured against a Japanese standard, because the uncertainties of the long-term future are exaggerated. In a sense, these risks are realistically gauged as high from the vantage-point of private managers, because American corporate finance and a widespread public stock market leave firms open to takeover if their rates of current profit stay too low. But it is possible that not all take-overs enhance productivity, so that private and social perspectives may diverge in that assessment of risk.

These managerial changes may have been aggravated by still other conditions that tended to divert the attention of corporate managers from the search for efficiency. According to Edward Denison,[142] the cumulation of government regulations and the intricacies of a complicated tax code have consumed the attention of corporate chiefs and their staffs. Their energies have been drawn to meeting these problems, to defending their firms from still heavier taxation and more costly regulation, and to seeking the benefits of governmental favor. The bottom-line urgency of these matters has meant that the people who rose in the corporate hierarchy were more likely to reflect a talent for dealing with governments and the public than for reducing costs of production. Robert Hayes and William Abernathy, in a widely-noticed and influential article, emphasized the harmful effects of what has become a standard doctrine of management.[143] Organization is decentralized into "profit centers" whose efficiency can be judged month by month by a small set of financial measures that permit management by "remote control," but in which "no one feels he or she can afford a failure or even a momentary dip in the bottom line." The professional

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[142] Edward F. Denison, Accounting for United States Economic Growth, 1929-1969, Washington, D.C.: The Brookings Institution, 1974, p. 127 et seq.; Edward F. Denison, Trends in American Economic Growth, Washington D.C.: The Brookings Trust, 1985, p.44.

[143] "Managing our way to economic decline," Harvard Business Review, 58 (July-Aug, 1980).

manager has come to be viewed as "an individual having no special expertise in any particular industry or technology [who] can nevertheless step into an unfamiliar company and run it successfully through strict application of financial controls, portfolio concepts and a market-driven strategy."

Along with others surveying the US situation in this period,[144] the MIT Commission attributed the great success of the American economy in the twentieth century to "a system of mass production of standard products for a large domestic market." It was "a system of interdependent and mutually reinforcing elements": inexpensive and undifferentiated products, long production runs of the same basic models extended over years with only minor changes, and emphasis on price to the neglect of quality improvement or design. It was based on a labor policy that sought control of the workplace through the simplification of jobs, therefore a semi-skilled workforce, and through labor saving based on specialized machinery, for which long runs of standard products were needed to spread capital cost. This mass production model, with all its hierarchical organization and its managerial doctrine and outlook, had, however, persisted into an era in which there is a new market demand for quality and variety and for frequent change in product design and in which new technologies demand a more skilled workforce and closer relations between firms and their suppliers, together with an ability to sell, to buy, and to produce abroad. Whether even R&D-intensive firms, if left to themselves, would be able to adapt rapidly enough to the requirements of "flexible manufacturing" was a question about which contemporary commentators were far from sanguine.

Many of the perceived deficiencies in the management of industrial R&D were seen at the time to be exacerbated, or at least not redressed by what was going on in the laboratories of America's research universities. There, in the view of some concerned industry leaders, the influence of a national policy of federally subsidized support for basic research had resulted in the advancement of fundamental knowledge was emphasized to the neglect of industrial applications of science and technology.[145] They deplored the undue emphasis of engineering schools on the analytics of materials, electricity and electronics, and biology while underemphasizing the problems of manufacturing. They were distressed by the poor preparation of American youth both at secondary and university levels in foreign languages and history as well as mathematics and science. They expressed concerned with the fact that American industry, judged by the standards of German and Japanese firms, neglected the continuing education and training of its own workers. The MIT Commission, however, was not primarily concerned to argue that after the 1960s what actually were rather long-standing American deficiencies became much more pronounced. The connection

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144 See, for example, Michael J. Piore and Charles F. Sabel, The Second Industrial Divide, New York: Basic Books, 1984.

145 The MIT Commission's (1989) work was concerned explicitly with "industrial productivity," and insofar as it directed criticism to the universities, it focused upon the character of research in engineering, and the nature of training for technical personnel (see, e.g., pp. 77-80, and 84-86). Concern with the neglect of manufacturing technology in the nation's schools of engineering and of business administration emerged in U.S. corporate and government policy circles at this time. Echos of the efforts undertaken in the 1980s to re-orient the country's technology policy may be seen, for example, in Lewis M. Branscomb, ed., Empowering Technology: Implementing a U.S. Strategy, Cambridge MA: MIT Press 1993; Lewis M. Branscomb and James H. Keller, Investing in Innovation: Creating a Research and Innovation Policy that Works, Cambridge MA: MIT Press, 1998.

between its diagnosis of threats to the international competitiveness of American manufacturing and the slowdown in U.S. productivity growth is, therefore, problematic. Moreover, it left open the question whether the technological advance potentially open to the country even in the absence of these impediments would itself be strong. That is the issue to which we turn next.

Reduced Innovation Potential?

The real values of both total and private-sector expenditures on R&D have risen, not only in absolute terms, but as a percentage of GDP, while the final residual in the growth accounts, presumably the fruit of R&D, suffered a severe decline. There is a similar indication from the fact that the number of patents issued to American firms and inventors has decreased and, indeed, decreased even more severely when measured against the number of scientists and engineers engaged in research and development.

These are strong signs that the yield of technological effort in terms of new knowledge may have fallen. Yet some authorities hesitate to accept this inference. Edward Denison [146] argues that it is hard to believe that the potential advance of knowledge, responding, as it does, to the myriad unanswered questions posed by earlier advances in basic science and practical technology, should have fallen so severely and so rapidly as did the growth accounting residual after 1973. Zvi Griliches[147] points out that econometric studies of the relation between R&D and patents in individual firms and industries yield inconsistent results. He traced the decline in patents issued to Americans during the 1970s to the fact that the staff of patent examiners remained limited while the number of patent applications (including those by foreigners) vaulted. Moreover, the value of patents is highly variable both within each year and between years. The time when a patent issued in a given year will, in fact, produce profit for the patent holder is again uncertain and variable. And since most patents are for new products whose value is poorly represented in measures of output, rather than for cost-reducing processes of production, the relation between profits and measured productivity may differ widely from patent to patent.

Such considerations make it hard to infer with any assurance that the decline in the aggregate growth accounts' final residual in the face of rising expenditure for R&D means that the potential yield of technological effort per dollar of expenditure had become smaller. If one rejects that inference, the solution to the mystery of the slowdown would lie with the impediments to technical advance or the misdirection of effort already reviewed. But we do not know how far the "impediments" can take us. In the remainder of this section, therefore, we take up the hypothesis that the U.S. has been experiencing a reduction in the rate at which new technological possibilities could be translated into realized advances in productive efficiency, and we ask why that might have been so.

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[146] See Denison, Trends in American Economic Growth (1985): p. 29.

[147] Zvi Griliches, "Productivity puzzles and R and D: another non-explanation," Journal of Economic Perspectives, 4(Fall) 1988: pp. 9-21 "Patent Statistics as economic indicators: A survey," Journal of Economic Literature, 28(4), 1990: pp. 1661-1707.

The Techno-Economic Regime Transition Hypothesis

The notion that the U.S., along with other advanced industrial societies, has been suffering the effects of a prolonged dry spell in the possibilities of realizing large innovation-based advances in productive efficiency is one that starts from the observation that the history of the past two hundred years has not been one of smooth and continuous advance in the frontier of technological knowledge. Rather, it has been punctuated by a sequence of major innovations. These are deemed "major" in the sense that they proved to be of economy-wide significance, carrying implications for productivity growth in many or all sectors of the economy; and also, that they proved to be disruptive of existing industrial structures and a source of sometime profound reorientation of economic activities.[148]

None of these major innovations, however, revealed its power at once or even quickly. The steam locomotive as first built would never have had a widespread impact on transportation even if it could have been duplicated cheaply. Many improvements and ancillary inventions were needed. The boilers of the early locomotives could not withstand the high pressures needed to haul heavy loads at high speed. The early iron rails were too weak to bear the strain of heavy, fast-moving trains. Air brakes had to be invented to control and reduce speed reliably and quickly. Automatic coupling devices, when invented, speeded the assembly and disassembly of long trains and reduced their dangers. Single-track railroads were not safe or efficient until the telegraph was invented and signaling systems could be devised and installed. Political and financial problems had to be overcome – political in that the acquisition of rights of way demanded governmental chartering; financial as well as political in that the huge capital expenses of railways strained the capacity of financial markets and imposed risks, especially to build the Western roads, greater than private investors were prepared to take. The development of steam power for use in heavy manufacturing posed similar technical, organizational and institutional challenges during the middle decades of the nineteenth century; and so did the application of dynamo technology in central electricity-generating stations, to lay the basis for a new, electric-powered regime of factory production during the first quarter of the twentieth century.

By drawing an explicit analogy between "the dynamo and the computer," one of us (David, 1990, 1991) sought to use the U.S. historical experience to give a measure of concreteness to the general observation that an extended phase of techno-economic regime transition may be required to fully accommodate the digital computer as a general-purpose engine. This "regime transition hypothesis" has suggested itself as a possible resolution of the so-called "productivity paradox," wherein new computer and information technologies (now commonly designated as ICT) have been rapidly and visibly diffusing

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148 These ideas, which owe much to the writings of Schumpeter, have received sympathetic discussion from Christopher Freeman and Carlotta Perez, "The diffusion of technical innovations and changes in techno-economic paradigm," Science Policy Research Unit Paper, University of Sussex. January 1986; Christopher Freeman and Carlotta Perez "Structural crises of adjustment, business cycles and investment behavior," in Technical Change and Economic Theory, G. Dosi et al., (Eds.). London: Pinter Publishers, 1989; Christopher Freeman and Luc Soete, The Economics of Industrial Innovation, Third Edition. London: Pinter Publishers, 1997. See also the account of the role of "macro-inventions," as distinguished from incremental technological advances, in Joel Mokyr, The Lever of Riches: Technological Creativity and Economic Progress. Oxford: Oxford University Press, 1990.

through the American economy at the very same time that the growth rate of TFP has fallen to historic lows. An understanding of the way in which the transmission of power in the form of electricity came to revolutionize industrial production processes tells us that far more was involved than the simple substitution of a new form of productive input for an older alternative. In the current regime transition, as in the case of the dynamo revolution which was stretched out for over 40 years between the opening of Edison's first central generating plant for electric lighting and the beginnings of the upsurge of multifactor productivity growth throughout the U.S. manufacturing sector, the pace of the transformation must be seen to be governed by the ease or difficulty of altering many other technologically and organizationally related features of the new production systems involved.

Recent estimates of the growth of computer stocks, and the flow of services therefrom, are consistent with the view that when the "productivity paradox" began to attract attention, the US economy could be said to have still been in the early phase of the deployment of ICT. Figures developed by Dale Jorgenson and Kevin Stiroh reveal that in 1979, when computers had not yet evolved so far beyond their limited role in information processing machinery, computer equipment and the larger category of office, accounting and computing machinery (OCAM) were providing only 0.56 percent and 1.5 percent, respectively, of the total flow of real services from the (non-residential) producer durable equipment stock. But these measures rose at 4.9 percent in 1985, and had ballooned to 13.8 percent by 1990, and 18.4 percent two years after that.[149] Thus, the extent of "computerization" that had been achieved in the whole economy by the late 1980s was roughly comparable with the degree to which the American manufacturing sector had become electrified at the beginning of the twentieth century. When the historical comparison is narrowed more appropriately to the diffusion of secondary motors, a proxy for the spread of the unit drive, the growth rate for 1899-1914 is almost precisely the same as that for the ratio of computer equipment services to all producers' durable equipment services in the US.[150] At that stage, although the pace of diffusion is rapid, the tangible capital embodying the new technology still bulked too small within the domestic economy's productive assets for its growth to exert more than a marginal impact upon overall performance.[151]

We may use this historical analogy of the dynamo revolution quite legitimately when suggesting that it is still too early to be disappointed that the computer revolution has not unleashed a sustained surge of readily discernible productivity growth throughout the economy. But that is not to ignore the important economic differences between electric current and digitized information. Nor is it the same thing as

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149 See Dale W., Jorgenson, and Kevin Stiroh, "Computers and Growth," Economics of Innovation and New Technology 3(3-4), 1995 :pp. 295-316.

150 See Endnote 29 to Part Two.

151 This point is developed more fully by Daniel E. Sichel, The Computer Revolution: An Economic Perspective, Washington D.C.: Brookings Institution Press, 1997. But, for further discussion of Sichel's effort to resolve the "productivity paradox" with that quantitative argument, see also Paul A. David and W. E. Steinmueller, "Understanding the Paradoxes and Payoffs of the Computer Revolution: Information Technology and the Productivity Slowdown Revisited," (April 1999), forthcoming as Ch.1 in Information Technology and Productivity--From Paradoxes to Payoffs, P. A. David and W. E. Steinmueller, Eds., Harwood Academic Publishers, forthcoming in 1999.

predicting that the continuing relative growth of computerized equipment must eventually cause a surge of productivity growth to materialize, and it says nothing whatsoever about the future pace of the digital computer's diffusion. Least of all does it tell us that the detailed shape of the diffusion path that lies ahead will mirror the curve traced out by the electric dynamo over the first half of the twentieth century. One cannot simply infer the detailed future shape of the diffusion path in the case of the ICT revolution from the experience of previous analogous episodes, because the very nature of the underlying process renders that path contingent upon events flowing from private actions and public policy decisions, as well as upon the expectations that are thereby engendered – all of which still lie before us in time.

Analysis of a contemporary problem's history formation, as well as the examination of analogous historical experience, provides a way in which the economic historian can speak to present issues. Rather than reiterating the litany of complaints and disappointments of the "computer-skeptics," who have "resolved the productivity paradox" by dismissing computer technology as largely a snare and delusion from the viewpoint of business users, portraying "the paradox" as merely the figment of the over-inflated expectations created by the technology's designers and purveyors, we can try to draw some further insights by briefly examining the course which the evolution of computer technology has followed up to the present. In particular, it seems useful to consider the way in which the personal computer's commercial triumph has affected the linkage between this form of capital equipment and measured productivity change. Here there is a case to be made for viewing the path taken in the present as only one among a number of available alternatives – a path whose selection, viewed in retrospect, was responsive to considerations that led away from a tight coupling between new technological artifacts and the task productivity of the individuals and work groups to whom those tools were offered.[152]

The widespread diffusion of the stored program digital computer is intimately related to the popularization of the personal computer as a "general purpose" technology for information processing, and the incremental transformation of this "information appliance" into the dominant technology of information processing. The historical process by which this was achieved in the case of the personal computer has had major implications not only for the success of personal computer technology and the hardware and software industries based upon it, but also economic functionality of the business organizations that have sought to utilize it profitably. For the personal computer, as for its parent the mainframe, and its cousin the minicomputer, adaptation and specialization have been required to apply a general purpose information processing machine to *particular* purposes or tasks. Such adaptations have proved costly, especially so in the case of the personal computer. There is something of an historical irony that the core elements of the adaptation problems attending this GPT's diffusion into widespread business application may be seen to derive from the historical selection of the trajectory of innovation that emphasized the "general purpose" character of the paradigmatic hardware and software components.

152 The following draws upon the more detailed treatment of the co-evolution of computer hardware and software technology from the mainframe to the personal computer, in W. Edward Steinmueller, "The U.S. Software Industry: An Analysis and Interpretive History," in The International Computer Software Industry, D.C. Mowery, Ed., Oxford: Oxford University Press, 1996: pp. 15-52; and also upon the discussion of the implications of that history for the relationship between computer use and task productivity of the sort that is most readily measured, in Paul A. David and W. E. Steinmueller, "Understanding the Paradoxes and Payoffs" (1999).

The origins of the personal computer required the invention of the microprocessor which was a technical solution to the problem of creating a more general purpose integrated circuit to serve a specific purpose, a more flexible portable calculator – a foundational application that ultimately proved uneconomical, due to the lower relative costs of more specialized integrated circuits. During the 1970s it was recognized that the microprocessor provided a general solution to the problem of the electronic system designer confronted by an ever growing array of application demands. During the same period, efforts to down-scale mainframe computers to allow their use for specialized control and computation applications supported the birth of the minicomputer industry. These two developments provided the key trajectories for the birth of the personal computer. As microprocessors became cheaper and more sophisticated and applications for dedicated information processing continued to expand, a variety of task-specific computers came into existence.

One of the largest markets for such task-specific computers created during the 1970s was that for dedicated word-processing systems, which appeared as an incremental step in office automation, aimed at the task of producing documents repetitive in content or format such as contracts, purchase orders, legal briefs, and insurance forms, that could be quickly modified and customized based upon stored formats and texts. But, dedicated word processors were rapidly displaced by personal computers during the mid–-1980s, as the latter were perceived to be more "flexible" and more likely to be "upgrade-able" as new generations of software were offered by sources other than the computer vendors. Moreover, personal computers could use many of the same peripherals, such as printers: because the widespread adoption of the new technology raised the demand for compatible printers, the dedicated word processors found themselves unprotected by any persisting special advantages in printing technology.

Sequels to the dedicated word processor's displacement were re-enacted during the 1980s in numerous other market niches where dedicated "task-specific" data processing systems had begun to emerge.[153] Thus, by the end of that decade the disappearance of task-based computing in favor of general purpose personal computers and general purpose (or multi-purpose) packaged software was thus largely completed. [154] The early evolution of the personal computer can therefore be seen as having effectively blocked the commercial development of an entire family of technically-feasible information processing systems that focused on the improvement of "task-productivity" – in applications ranging from word processing to manufacturing operations control. In many cases, it has also precluded the effective development of collective "work group" processes whose synergies would support multifactor productivity improvement. Instead of "breaking free" from the mainframe, these general purpose engines often wound

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153 See Endnote 30 to Part Two.

154 In the medium and large enterprises of 1990, what remained was a deep chasm between the "mission critical" application embedded in mainframe computers and the growing proliferation of personal computers. The primary bridge between these application environments was the widespread use of the IBM 3270, the DEC VT-100 and other standards for "intelligent" data display terminals, the basis for interactive data display and entry to mainframe and minicomputer systems. From their introduction, personal computers had software enabling the emulation of these terminals, providing further justification for the PC's adoption.

up "slaved" to the mainframe, using a small fraction of their capabilities to emulate the operations of their less expensive (and less intelligent) cousins, the so-called intelligent display terminals.[155]

By 1990, then, the "personal computing revolutionaries" had delivered on the promise that the their would match, and even surpass the computing performance of the mainframes of yesteryear. What was not achieved, and could not be achieved by this technological revolution was a wholesale reconstruction of the information processing activities of the varieties of business organizations that previously had embraced mainframe technology. Rather than contributing to the rethinking of organizational routines, the spread of partially networked personal computers supported the development of new database and data entry tasks, new analytical and reporting tasks, and new demands for "user support" to make the general purpose technology deliver its potential.

The point of this narrative is not to claim that the process should be regarded as socially sub-optimal, or mistaken from the private business perspective. A quantitative basis for such judgements, one way or the other, does not exist, as yet. It appears that what was easiest in an organizational sense tended to be the most attractive thing to undertake first. The local activities within the organization that were identified as candidates for personal computer applications often could and did improve the flexibility and variety of services offered internally within the company, and externally to customers that would, through the intermediation of personnel with appropriate information system access, receive an array of service quality improvements. Arguably, many of these improvements are part of the productivity measurement problem, because they are simply not captured in the real output statistics even though they might enhance the revenue generating capacity of the firms in which they are deployed.[156]

3.4 Summing Up: The Persisting Puzzle

The preceding discussion has pointed to the possible persistence of a substantial unrealized potential for accelerated technological progress in the application of the cluster of techniques that has formed around the ever-faster digital microprocessor, and, in particular, a direction for technical advance that would translate more immediately into resurgent productivity improvements. The gap reflects the decline of an aging regime based on mass production, electric-powered machinery, combustion engines, and chemicals, still not counter-balanced by an emerging but still immature regime built on the application of computers and enhanced communication throughout the economy. That such a gap exists seems to us a very plausible hypothesis, but sadly it is not one that can claim to have been established on quantitative foundations. Indeed, it would be possible to do that now only through a residual procedure – removing the effects of all other candidate "causes" and thereby determining how much of the MFP slowdown remained to be attributed to the explanation at hand. How much a "regime transition gap" has been contributing to the

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156 The availability of 24-hour telephone reservation desks for airlines, or the construction of worldwide networks for securing hotel, rental automobile, or entertainment reservations, represent welfare improvements for the customer. But these do not appear in the measured real GDP originating in those sectors, nor in the real value expenditures on final goods and services.

productivity slowdown experienced in the U.S. since the later 1970s simply remains beyond our ability to gauge at this point.

If, therefore, the enigma of the slowdown lies mainly in our inability to fathom the reasons for the decline in the residual component of the slowdown, the puzzle remains. Summing up this admittedly rather unsatisfactory state of affairs, we can say with some assurance that the post-1966 collapse of the MFP residual cannot be attributed in any large proportion to errors in measuring the growth of real output within the scope of the conventional National Product Accounts. While there is reason enough to believe that the available measures lately have understated the real output growth rate, at least by something on the order of 0.3 percentage points per annum, the evidence has yet to be produced that would establish that this represents a recent and not a long-standing state of affairs.

Neither does it appear that the reality of the productivity slowdown is traceable to a decline in the volume of resources being devoted to research and development activities, nor to the weakening of what we have referred to as “technological effort” more broadly conceived. There remain two classes of possible causes. The first, which the MIT commission and others emphasize, is that the trouble lies with a variety of “impediments” that have caused technological effort to be misdirected or its yield diminished in a search for near-term returns at the expense of longer-term opportunities, and with a managerial doctrine and industrial organization that remain devoted to a search for profit by the methods of mass production of standardized products, with all its implications for educational standards, to the neglect of a changing market. The second class is the possible gap in technological potential caused by the senescence of an older technological pathway and the slow maturation of an emerging regime.

These alternatives are probably wide enough to envelop the actual possible causes, and they may all have been involved in some degree. Major, sustained economic phenomena, such as the slowdown, almost invariably are found to have been “over-determined,” in the sense of having many concurrent causes. But until we can distribute responsibility between the two contending classes of “real” explanations considered here, and among the elements that compose them, our historical understanding remains less than complete and so of only limited use as a guide to the future.

4. After the Slowdown, A "New Economy"?

Many of the worrisome puzzles surrounding the productivity slowdown of the later 1970's and 1980's faded from view during the US economy's recovery from the 1991 recession, and they were all but forgotten by the late 1990's, when the labor productivity growth rate in the private domestic economy was once again above the 2 percent per annum mark. The prolonged expansion, and the sharp revival of the pace of aggregate productivity advances, appeared to signal a discontinuity in macroeconomic performance, and soon had elicited much talk about the so-called New Economy, its nature, the forces that might have created it, and its future trajectory. The term "new economy" itself acquired a variety of quite different connotations: for many commentators, it continues to refer primarily to the altered macroeconomic configuration that saw an accelerating rate of growth of real GDP and a steadily falling unemployment rate which, unexpectedly, did not give rise to inflationary pressures on wages and prices. Some connected this with evidence of the revival of labor productivity growth that became increasingly visible in the aggregate statistics for the private sector, and emphasized that as the key development heralding a permanent escape from the US economy's poor performance record during the preceding two decades.

For others, however, the productivity growth picture beneath the aggregate level was less than entirely clear, and the core of the "New Economy" was peculiarly associated with the growth of output and employment in "hi-tech" industries, particularly those involving information technologies and computer-mediated telecommunications, and with the on-going restructuring of business organizations and markets that are driven by advances in the latter (ICTs). The high and rising stock market valuations of companies in this sector, and the wave of venture capital that poured into new enterprises launched after 1993 to exploit the commercial possibilities of the explosively expanding Internet, seemed for still other observers to be the very essence of what was new and positive in these developments. Indeed, in the exuberance that marked the century's close, the Nasdaq stock market index came to be identified with the New Economy, whereas the comparatively weak performance of the Dow-Jones index was disparaged as representative of "the Old Economy."

This welter of associations only serves to multiply the potential issues that might be addressed in responding to such a question as "Whither the New Economy?" Not the least among these is the logically anterior issue of whether or not, and in what sense (or senses) such a thing usefully can be said to exist. In June of 2000 the OECD was taking a "wait and see" position on the question of whether or not there was a new dynamic of growth among the world's industrial economies, particularly those in Europe. There appeared to be less doubt that if "the New Economy" existed anywhere, it was thriving in the US.[155]

[155] See OECD, Is There a New Economy?, Paris: Organisation for Economic Co-operation and Development, (June 14) 2000, p.1: The question in the title [Is There a New Economy?] is promoted, in particular, by the remarkable performance of the US economy in recent years….The answer is probably 'yes – in some respects'. Some of the features associated with the 'New Economy' can actually be observed: stronger non-inflationary growth linked to a rising influence of ICT. But this picture applies mainly to the United States and does not generalize across countries [in the OECD]."

Nevertheless, by the following Fall, Internet business watchers, stock market analysts, and the surviving "dot-com" principals themselves no longer were so convinced, even on the latter point.[156]

The question of the sustainability of the high and rising rates of aggregate productivity growth in the US economy raises an intriguing set of issues. Was this productivity surge a phenomenon that will pass into the annals of history (along with "the dot.com bubble") as a remarkable but transient concomitant of the final phase of the most protracted US expansion of the post-WWII era? This question, and particularly its connections with the role that digital information technologies are playing in transforming the structure of the economy, presents a fitting focal subject on which to conclude the discussion in Part Two.

4.1 Towards Understanding the Productivity Growth Revival of the 1990's

The recent US statistics of labor productivity growth and total factor productivity (TFP) growth presented in Table 2:IX suffice both to make that question more concrete, and to suggest the beginnings of an answer. According to the Bureau of Labor Statistics' estimates, the average rate increase of real output per person hour worked in the private business economy during 1995-98 was a full percentage point above the 1.5 percent per annum rate maintained during the first half of the decade (1990-95). Hence, it exceeded the average productivity growth rate that characterized the decade of the 1980's by essentially the same, 1 percentage point margin. The corresponding data for TFP growth records almost as big an acceleration in absolute terms, that is, a jump of 0.8 percentage points. Relative to its previous level (of 0.5 – 0.6 percentage points) during the 1980's and the 1990-95 intervals (respectively), this measure of the pace of TFP growth therefore underwent a proportionate recovery in the late 1990's that was considerably more pronounced than the revival in the labor productivity growth rate.[157]

In the private business *non-farm* sector the acceleration of the corresponding TFP measure (from the same BLS source) was slightly less pronounced between 1990-95 and 1995-98: the rate rose from 0.6 to 1.3 percent per annum. There had been a more substantial pick-up in the pace of TFP advance, however, amounting to a 0.3 percentage point rise between the average rates during 1979-90 and 1950-95. Thus, reckoning from the experience of the 1980's as a base, the following decade saw a quickening, two-step acceleration that cumulated into a 1 percentage point gain in the annual pace of TFP increase, accounting for nearly all the gain registered by the labor productivity growth rate of the private business non-farm sector.

The picture just drawn serves to focus attention upon the prospects for future total factor productivity (or multifactor productivity) gains, because these were the proximate agencies responsible for

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[156] The leading publication of the Silicon Valley trade press offered its anxious readers an assortment of expert opinion on its question: "Has the death of the dot-coms been greatly exaggerated?" See The Industry Standard, 6 November, 2000: pp. 133ff.

[157] As noted in Table 2: IX, the most recent BLS TFP growth rates (cited above) are "semi-refined," whereas the figures shown as "refined" in Tables 2 and 3 reflect full adjustments for the contribution to output growth attributable to changes in the composition of capital inputs.

returning labor productivity growth during 1995-98 to the long-term average pace that was achieved over the whole period stretching from 1948 to 1995.[158] The other side of this coin, however, is the duration and severity of the *deceleration* in the growth of measured TFP that had marked the decades following the 1960's. The latter experience is brought out more starkly by a slightly different, and more exacting set of BLS measures for "refined" TFP growth in the private business non-farm economy. Those figures (in Table 2: IX) reflect a more complete correction for the effects of compositional changes in capital inputs, as well as in the labor inputs.

The underlying rates also indicate that there was a two-step process of acceleration in the (refined measure of) TFP growth, with a 0.5 percentage point gain recorded between the pace in 1972-88 and that in 1988-92, followed by a 0.3 percentage point quickening between 1988-92 and 1992-96. Yet, as can be seen from Table 2: IX, this revival was not sufficiently strong to erase the effects of the preceding "slowdown": the average annual growth rate of measured TFP for the period 1988-96 actually continued to fall to the negligible 0.11 percentage point level – lower than the average rate recorded for the long interval of the "productivity slowdown" itself (1972-88).

The foregoing observations permit an initial response to the original question: clearly, these productivity indicators for the US economy aren't going to go on *accelerating* in the way they have done since the early 1990's. The BLS has yet to release its estimates for TFP growth beyond 1998, and so we must wait a while to learn whether the acceleration continued throughout the twentieth century's final years. Nonetheless, while it is not inconceivable that a further acceleration by as much as 0.5 percentage points could have been achieved in the private business non-farm economy, it seems most unlikely that the higher growth rate which would have been established by such a change could be sustained as a new, long-term trend.

One way to arrive at this conclusion is to notice that the result of such a scenario (i.e., continued acceleration) would be tantamount to the US economy staging a cumulative productivity revival amounting to 1.3–1.5 percentage points, thereby bringing the average annual rate of aggregate (refined) TFP growth all the way back up to the trend rate that had characterized the immediate post-World War II era, the so-called "golden age of productivity improvements."[159] In the latter era, however, many quite special conditions circumstances prevailed in both the US and the international economy which contributed to boosting productivity growth; that in their very nature those conditions were not self-renewing, and so gave

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[158] The average annual rates reported for TFP during 1948-98 are 1.4 percent in the private business sector, and 1.2 in the private business non-farm sector; the corresponding rates for 1995-98 are 1.4 percent and 1.3 percent. See U.S. Department of Commerce, News Release USDL 00-27 (September 21), 2000.

[159] This point (conveniently) holds in regard to the array of variant TPF growth measures in Tables 1, 2 and 3. The "golden age" of post-WII growth referred to in the text is dated variously as 1948-73 and 1950-72 in the BLS periodization, and as 1948-66 in the Abramovitz-David growth trend chronology employed by Appendix Tables 1: IA and 1: IVA.

way eventually to a subsequent macroeconomic environment characterized by reduced investment rates, sluggish productivity advance and recurring inflationary pressures.[160]

Should we entertain the notion that the consequences of the technologies of digital computing and computer-mediated communications – associated with the dawning of the "Age of the Internet"– constitute the basis for the return of another extraordinary episode, featuring a comparably strong surge of productivity advance? That, of course, is the view advanced by some advocates of the "New Economy" hypothesis who see new information processing and telecommunications technologies as having played the central role in accelerating the US economy's growth while holding inflation in abeyance.[161] The most recent *Economic Report of the President* for 2001 placed itself quite forthrightly in this camp, declaring:[162]

> "At the heart of the New Economy lie the many dramatic technological innovations of the last several decades. Advances in computing, information storage, and communications have reduced firms' costs, created markets for new products and services, expanded existing markets, and intensified competition at home and abroad….Indeed, the rapid growth of the information technology sector was one of the most remarkable features of the 1990's."

Yet, that conclusion also has been criticized as lacking in solid empirical foundations, and not only by economists who have steadily expressed skepticism about the "ICT revolution," as well as a disposition to debunk the whole idea of "the New Economy" as being more "hype" than reality.[163] Rather than

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[160] See Moses Abramovitz, "Notes on Postwar Productivity Growth: The Play of Potential and Realization," Center for Economic Policy Research Publication No. 156, Stanford University, March 1989, and Part III, section 3 below, for a compact exposition.

[161] Former Federal Reserve Board member Alan Blinder ("The Internet and the New Economy," Brookings Policy Brief # 60, Washington, DC: The Brookings Institution, June 2000), for example, noted the temporal coincidence in referring to the "tantalizing fact – that productivity accelerated at just about the time the Internet burst on the scene." But, he cautiously hesitated to infer that there was a causal connection: "Whether or not the Internet was the cause of the speedup in productivity growth will be a matter for economic historians to sort out some years from now….For now, however, it appears that the economy can sustain a higher growth rate than most people thought plausible just a year or two ago. In that limited respect, at least, we appear to be in a 'New Economy'."

[162] Economic Report of the President, 2001: Ch.3, p. 95; on productivity growth, see Ch.1, pp. 25-33.

[163] Paul Krugman's ("Dynamo and Microchip," New York Times, February 24, 2000a) enthusiasm about the reality of a technology driven surge in productivity did not suffice to quell his skepticism ("The Ponzi Paradigm," New York Times, March 12, 2000b) about the soundness of the macroeconomic arguments advanced by believers in the existence of a "new paradigm." Robert Gordon ("US Economic Growth Since 1870: One Big Wave?," American Economic Review 89 (May), 1999: 123-128; "Interpreting the 'One Big Wave' in US Long-Term Productivity Growth," in Productivity, Technology, and Economic Growth, Bart van Ark, Simon Kuipers and Gerard Kuper, eds., Amsterdam: 2000b) has maintained, on a variety of grounds, that the "information revolution" is not an economic phenomenon whose consequences will approach the magnitude of the transformations wrought by technological innovations in the late 19th and early 20th centuries. See also, e.g., John Cassidy, "The Productivity Mirage: Are Computers Really that Important?," The New Yorker, November 27, 2000, for a review of the recent recurrence of

engaging with the technical details of that debate, the following discussion takes to a somewhat more analytical look backward, before venturing upon some concluding conjectures about the road that lies ahead. This approach reflects more than the historian's characteristic diffidence when asked to predict. We are likely to form a better grasp of the present prospects for sustained rapid productivity growth, and hence for the continuation of the US economy's remarkable non-inflationary expansion in the years immediately ahead, by making the effort to delve first into the causes of the recovery in measured TFP growth that occurred during the second half of the 1990's. Furthermore, as will become evident, without a satisfactory account of what happened in the preceding period of the productivity slowdown, it is going to be difficult to understand the underlying sources of the revival.

Links between new technologies and sources of the late 1990's acceleration in measured TFP

There are at least three proximate sources of the revival of measured TFP growth that occurred during the later years of the 1990's that we may link with the effects of technological change, and, more specifically, with innovations in information processing and computer-mediated telecommunications. The connections to which I wish to draw attention here, however, are rather less direct than those which economists typically emphasize when they interpret the TFP growth rate itself as measuring "the rate of technological innovation."

Some part of the apparent speed-up certainly was due to the strength of demand growth, fueled by the high gross private domestic investment rate, and the wealth effects upon consumption that derived from the stock market boom. The move toward more intensive utilization of the employed labor force, and of the existing stock of plant and equipment, has contributed to increasing measured productivity. In one sense, this aspect of "the New Economy" isn't really new, because there is a long historical record of pro-cyclical movements in the growth of TFP as well as of average labor productivity.[164]

But, how large an effect this can be said to have contributed to the recent surge of productivity growth remains a matter of some controversy among economists. By extrapolating from the U.S. historical record, Robert Gordon (2000a) arrived at estimates showing the "cyclical component" accounted for almost two-fifths of the post-1995 acceleration. For the non-farm private business economy, according to Gordon, this component contributed 0.5 percentage points of the 1.3 percentage point rise observed in the annual rate of growth of real GDP per hour; and the corresponding share was as much as three-fourths of

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ICT-skepticism. On a rather different level is Gordon's observation that labor productivity growth failed to recover in many sectors of the US economy, so that the sharp acceleration of the late 1990's actually has been quite patchy, and concentrated heavily in the computer and telecommunications equipment, and software branches within manufacturing.

[164] This has been recognized in the literature at least since Thor Hultgren, "Changes in Labor Costs during Cycles in Production and Business," Occasional Paper 74, New York: National Bureau of Economic Research, 1960.; and, since Walter Oi, "Labor as a Quasi-Fixed Factor," Journal of Political Economy, 70(4), December 1962: pp.538-55), it has been explained in terms of the changing intensity with which "quasi-fixed" elements of the work force, as well as other fixed factors of production are utilized.

the smaller (0.86 percentage point) acceleration experienced in the part of the non-farm private business sector not engaged in manufacturing durables.

Jorgenson and Stiroh (2000b), however, take the view that Gordon's estimate over-states the "cyclical" correction, and therefore yields too low a residual figure for the "structural component" of the acceleration in the TFP growth rate. Disagreements of this kind reflect the deeper problem of extrapolating from statistical relationships that prevailed in the past, when the pace and manner in which technologies are diffused, and their effects upon the structure of the economy all have been changing. Gauged by historical standards the strength of the pro-cyclical upswing on this occasion, and the duration over which the productivity rises have continued to offset upward pressure on input costs, would appear to be *something new*. Moreover, there are some good reasons to believe that the large "cyclical component" arrived at by Gordon's calculations itself may reflect the application of digital information technologies (from computers and databases to broadband telecommunication networks).

For example, these applications contributed to reducing required levels of inventory holdings of both goods in process and finished products. In the durable goods industries the inventory-sales ratios-output ratio has exhibited a secular decline since the early 1980's, but after the early 1990's its downward course became particularly pronounced.[165] In addition, "smarter" scheduling of transportation and production operations, and better coordination of work within and among business firms, reduces the need to hold "inventories" of partially utilized workers and avoids plant and equipment being idled while awaiting the delivery of supplies. All of that makes possible the fuller utilization of the capacity of the "fixed" inputs in production, and it shows up in measured TFP gains.

These sources of accelerated productivity growth, however, are the kind that are unlikely to be sustainable. In the first place, the aggregate demand may not keep up with the expansion of supply capacity, and the resulting accumulation of unwanted inventory holding is then likely to reduce utilization rates. A further consideration, also suggesting the limited sustainability of rapid productivity gains achieved in response to demand pressures on capacity, is that the easier changes in the organization of production and distribution tend to be the first ones to be exploited. As the low-hanging fruit get picked off first, so the incremental gains become smaller and smaller. Similarly, when experienced workers no longer will take on more overtime, new workers need to be found, hired and instructed, and that means the employing firms must incur the added fixed labor costs which such activities impose.

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[165] See Margaret M. McConnell, and Gabriel Perez Quiros, "Output Fluctuations in the United States: What Has Changed Since the Early 1980's?," American Economic Review, 90(5), December 2000: pp. 1464-74, who attribute the decreased short term volatility of real GDP growth in the US after 1983 to this development in the durable goods sector. Between the successive peak levels of the inventory-sales ratio in the years 1981-83, and 1991-92, the proportional decrease amounted to 10 percent, but the downward trend resumed thereafter and brought the ratio down by another 25 percent, to an unprecedentedly low level of 1.5 by 1998. Interestingly, the 1990's also witnessed the first persisting departure of the movements in the inventory-sales ratio for durable goods from the ratio for non-durable goods. The latter continued to fluctuate around a stationary level (approximately 1.14) throughout the 1990's.

The difficulty of making detailed time-series adjustments for the influence of such changes on measured productivity growth encourages cautious practitioners of the growth accountants' art to view their results as most reliable for gauging the longer-term trend rates, particularly those which emerge from comparisons between points in the growth record where the economy is found to have been operating at equivalently high rates of capacity utilization. Applying growth accounting methods for the analysis of economic performance over comparative short time intervals, therefore, must be regarded as somewhat more of a "risky business" than casual readers of the results often are left to suppose.[166]

There is a second "new" element to be noted in the recent US productivity growth story, one that is not unconnected with the strength and the nature of technological changes accompanying the recent economic expansion. A much larger share of aggregate production now involves intangible goods, such as software and other digital information-goods, whose unit costs of production tend to fall rapidly with growth in the volume of production. This has undoubtedly contributed to reinforce the pro-cyclical productivity effect. In this sense one may say that the information technology revolution has been contributing towards maintaining the importance of the sector of the US economy in which production is characterized by conventional, old-fashioned economies of scale. Of course, the downside is that this source of productivity growth is likely to be jeopardized by a weakening of demand and declining sales volumes in the new information-goods sector industries.

Summing up the foregoing discussion, one may remark that trying to quantify the various "sources of growth" on the supply side, in the way that conventional growth accounting encourages us to do, is less than wholly enlightening about the behavior of the economy over the short and medium run, which is to say, within the course of normal 4-5 year business cycle movements.[167] Much of what has been taking place within the time frame on which recent analysts have been focusing, appears to reflect interactions between demand side and supply side changes, and the interactions among various supply side phenomena. Under rather exacting assumptions, each of the latter factors could be quantified as neatly as they may be distinguished for purely conceptual purposes. But, in practice, the conditions required to separate them for purposes of measurement are more typically not fulfilled. Thus, it has been noted that the effects of technological innovation can alter the quantitative importance at the aggregate level of productivity gains

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[166] See, e.g., the chronology developed for this purpose by Moses Abramovitz and Paul A. David, "American Macroeconomic Growth in the Era of Knowledge-Based Progress: The Long-Run Perspective," Stanford Institute for Economic Policy Research, Discussion Paper Series, No. 99-3, Stanford University, August 1999, 180 pp. [Published in part, under the same title, in The Cambridge Economic History of the United States, R. E. Gallman and S. L. Engerman, eds., Vol. 3, Cambridge and New York: Cambridge University Press, 1999, pp. 1-92.; Dale W. Jorgenson and Kevin J. Stiroh, "U.S. Economic Growth at the Industry Level," American Economic Review, 90(2), May 2000: pp. 161-7, make essentially the same point in connection with their application of growth accounting at lower levels of aggregation.

[167] This caveat may be taken to apply equally to the contributions of Robert J. Gordon, "Does the 'New Economy' Measure up to the Great Inventions of the Past?," Journal of Economic Perspectives, 14(4), 2000a: pp.49-75, Stephen D. Oliner and Daniel E. Sichel, "The Resurgence of Growth in the Late 1990's: Is Information Technology the Story?," Journal of Economic Perspectives, 14(4), 2000: pp. 3-32, and the US Department of Labor 2000, to the interpretation of the sources of the post-1995 acceleration in productivity growth.

that are derived from economies of scale; whereas the latter, in turn may alter the sensitivity of macroeconomic performance to changes in demand conditions.

We should turn now to examine a third, and rather different development that underlay the acceleration recently observed in measured productivity, one that is more likely to persist, if only because it brought the cessation of increasingly serious measurement errors that had been contributing to the apparent "slowdown" of the productivity growth rate during the 1970's and 1980's. It will be seen that this, too, has a connection with developments in the sphere of information technologies and their manner of application. But on this point the argument is somewhat more intricate than it was in the first two cases, and to present it properly requires that we first provide a little background on the vexed subject of productivity measurement errors.

As has been seen, ever since the emergence of the "computer productivity paradox," or "the productivity slowdown puzzle" as it should properly be called, economists recurrently considered the possibility that the shrinkage of the TFP residual was in whole or part an artifact of biases in the indices of aggregate real product growth.[168] Among the more popular suspects in this regard is the problem of obtaining unit prices for the products of service industries, and the consequent difficulty of measuring real product movements in a part of the US private business economy whose share in the current value of production has been expanding. Suspicion also has fallen on the likely failure of the price series used as deflators for the current value of production in a large number of commodity producing industries and services to take sufficient account of the improvements in product quality. As a result, the rate of price increases would tend to be overstated, leading to a downward bias in the measured growth of real output and productivity.[169] The magnitude of the difference in measured real output growth that resulted when the Bureau of Economic Analysis (in the US Commerce Department) introduced quality adjusted (so-called "hedonic") price deflators for just one industrial branch – the manufacture of computer equipment, has served to underscore this more general worry.[170]

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[168] See above, Part 2, sect.3, for a more detailed treatment of the issues summarized here.

[169] It is important to make it clear that this problem is quite distinct from the main source of upward bias in the official "inflation rate" for the US, to which public attention was drawn by the 1997 report of the so-called "Boskin Commission," which criticized the BLS methodology formerly used in constructing the US Consumer Price Index (see Jeff Madrick, "The Cost of Living: A New Myth," The New York Review, March 6, 1997). Of the approximate 1 percentage point per annum "overstatement" in the CPI's average growth, about 0.7 percentage points were ascribed to the effect of employing fixed quantity weights, i.e., calculating the (Laspeyres) price index for an invariant "basket of goods." The GDP deflator, by contrast, is defined as a (Paasche) variable weight price index, to which this critique did not apply.

[170] See, e.g., Brent R. Moulton, "GDP and the Digital Economy: Keeping up with the Changes," in Understanding the Digital Economy, E. Brynolfsson and B. Kahin, eds., Cambridge MA: MIT Press, 2000: pp. 34-48. This correction for quality improvements, however, being confined to one branch of manufacturing (and extended subsequently to cover digital telecommunications equipment and software, creates statistical distortions in the "real" (constant price) measures of the structure of the economy, and also has made the interpretation of comparative international indicator of output growth and productivity much more problematic than it had been formerly. For an excellent treatment of this little-recognized issue, see Andrew W. Wykoff, "The Impact of

The first of these two suspicions of serious measurement bias was emphasized by Griliches (1994), who drew attention to the existence of a substantial gap between average labor productivity growth rates in the better-measured, commodity-producing sector on the one hand, and a collection of "hard-to-measure" service industries, on the other. He suggested that the expanding share represented by the FIRE bloc (Construction, Trade, Finance, Insurance, and Real Estate), and miscellaneous other service industries, would have exerted an increasing drag on the economy's aggregate labor productivity growth rate. To the extent that the differentially slower productivity growth in services was the consequence of understating the growth of services output, the magnitude of the overall downward bias would have increased during the 1970's and 1980's.

Now, it is not immediately apparent how those specific sources of measurement bias might bear upon our understanding of the subsequent *revival* of productivity growth. Taking them in reverse order, the hypothesized impact of the economy's structural drift towards "un-measurability" turns out to be quantitatively weak; at most it could have been responsible for only a tenth of the 1.3 percentage point slowdown in the average annual rate of measured aggregate productivity growth after the 1960's.[171] Consequently, even if the relative expansion of "poorly measured" service industries had halted completely after the early 1990's, which was not the case, the effect could not have contributed much to the apparent rebound in productivity.[172]

A comparable difficulty is encountered by proponents of the other suggestion, namely the objection that quality improvements have been going largely unrecorded in the official figures for real product growth until lately. In other words, it was not so easy to come up with persuasive reasons for supposing that the downward bias on this account had become *more pronounced* after the 1960's, and so was responsible for the appearance of slower productivity growth. Indeed, according to Bresnahan and Gordon (1996), the rate of unmeasured quality improvements in durable goods was high during the early post-WWII decades, and there were no *a priori* grounds for believing that the dimensions of the overall problem became more serious during the 1970's and 1980's – especially not in view of the introduction by the Bureau of Economic Analysis of GDP deflators that reflected "quality adjusted price indices" for computer

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Computer Prices on International Comparisons of Labor Productivity," Economics of Innovation and New Technology, 3(3-4), 1995: pp. 277-294.

[171] See above, Part Two, Section 3, and also David 2000, sect. 2.2, for details of alternative calculations leading to this conclusion.

[172] A different and deeper set of unresolved measurement issues, nonetheless, deserves to be noticed. As W.E. Diewert and K. J. Fox, "Can Measurement Error Explain the Productivity Paradox?," Canadian Journal of Economics, 32(2), 1999: pp. 251-80, have pointed out, these particularly affect the expanding provision of *customized information services* – whether in free-standing form, or in bundled with tangible commodities. The core problems involve those of measuring the incremental utility that consumers derive from applications of information technologies that lower the costs of reducing risk, whether by increasing the availablity of information to decision-agents, or by reducing marginal costs of providing highly specialized forms of insurance.

and peripheral equipment (and, more recently for telephone switching equipment, semiconductors and so types of software).[173]

A point that had emerged more clearly by the mid-1990's and that deserves recognition here, however, directly contests the latter view. It indicates the existence of analytical and empirical reasons for us to entertain the view that the relative magnitude of the underestimation of quality improvements, and the consequent understatement of the real output growth rate, have not remained constant. Even though the argument is somewhat novel, the two-fold claim advanced in the following paragraphs can be summarized simply: firstly, the downward measurement bias in the US real output growth rate grew significantly after the early 1970’s, but by the early 1990’s its magnitude had stabilized; secondly, this temporal pattern arising from the underestimation of productivity quality improvements, was related causally to the course of the ICT revolution.

From the middle of the 1970’s through to the early 1990’s new information technologies increasingly were being applied in ways that enabled firms to cut the costs of introducing new goods and services, thereby encouraging firms to shorten their average product life-cycles, and to experiment with "mass customization."[174] The proportion of sales revenues that were generated by newly introduced products was therefore increasing. As economists have long been aware, the official government price series tend to miss a good portion of the rapid fall that typically occurs in the relative prices of new products when they still are very young. Because those price series are used to deflate the total sales revenues of the industries introducing these novel goods, the resulting estimates of growth in the industries’ real output, and in their productivity, tends to be understated.

Although this was not a "new" problem in the qualitative sense, it became a quantitatively more serious source of bias, precisely because the relative importance of new goods and services was increasing. During the rapid transition to mass customization that was underway in the U.S. during the 1980's, the average age of product lines was falling and the downward measurement bias in the output growth rate therefore became more and more pronounced. These developments reflected in good measure the application of new information technologies, and related organizational reconfigurations in R&D-intensive businesses. By enabling the integration of market research, new product design, production engineering, and marketing, ICT use contributed to reducing the fixed costs of new product innovation, and shortened the innovation cycle.

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[173] See above, Part Two, section 3.1, on new durable goods; R. Cole, Y. C. Chen, J. A. Barquin-Stolleman et al., “Quality-Adjusted Price Indexes for Computer Processors and Peripheral Equipment,” Survey of Current Business, 66(1), 1986: pp. 41-50. on the introduction of quality corrections using the “hedonic” price index methodology; Brent R. Moulton, “GDP and the Digital Economy: Keeping up with the Changes,” in Understanding the Digital Economy, E. Brynolfsson and B. Kahin, eds., Cambridge MA: MIT Press, 2000: pp. 34-48, for subsequent extensions of this initiative by the BEA.

[174] See Paul A. David, "Understanding Digital Technology’s Evolution and the Path of Measured Productivity Growth: Present and Future in the Mirror of the Past," in Understanding the Digital Economy, E. Brynolfsson and B. Kahin, eds., Cambridge MA: MIT Press, 2000: pp. 61-5, for further discussion and references on mass customization, and on the data supporting the particular hypothesis about measurement bias that is advanced here.

The phase in the evolution of digital technology that characterized the 1980's as the era of "the PC revolution" may not have done much to promote readily measurable gains in task productivity, for reasons that already have been set out (above in Part Two, section 3.3). Yet, what is of moment here is that it quite evidently had unshackled innovative product design and marketing groups within many large organizations, in part by freeing them from dependence upon (and, hence, from the tighter constraints imposed by) hierarchically structured, mainframe-based information systems that served the control functions of central management.

Therefore, mass customization, along with all that it entailed in the way of modern manufacturing and inventory control, justly can be regarded among the palpable consequences of the ICT revolution of the 1980's. Yet, this was not appreciated at the time by economic analysts who tended to regard the proliferation of PCs on office desks as little more than the miniaturization of mainframe computing; a development which they saw as failing to deliver the sort of measurable task productivity payoffs that had been realized in the late 1960's and 1970's, when mainframe systems released labor by taking over many back-room "number crunching" functions in banking and financial transactions, payroll and record processing, and the like.

But, the movement towards mass customization which ICT advances had facilitated, in addition to being directed towards other, more creative activities in which the notion of task productivity was a more elusive concept and its measurement faced significant obstacles, turned out to have a perverse effect upon the measured productivity growth rate of the economy. This was the result of its interaction with the prevailing, official routines for tracking the prices of new products. Putting the matter most simply, the mass customization movement in this phase of the computer revolution, paradoxically, widened the gap between the actual and the *measured* productivity growth rate even further than had been the case historically. How big was this added downward bias? The preliminary estimates that I have made indicate that during the 1977-92 interval the increase in the magnitude of the underestimation bias may have been very substantial, indeed: perhaps big enough to push the measured annual growth rate in the private non-farm business economy downwards by 0.3-0.5 percentage points, in comparison to what would have been recorded had the effect of the bias in the price deflators remained unchanged.[175]

Yet, this ballooning of the gap between the actual and the measured growth rate of productivity does not seem to have continued after the early 1990's, certainly not at anything approaching its former pace. Under the conditions envisaged for the calculations that were just cited, the magnitude of the upward bias of the official price deflators was being enlarged simply due to enlarged share that sales of newly

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[175] See Paul A. David, "Understanding Digital Technology's Evolution and the Path of Measured Productivity Growth: Present and Future in the Mirror of the Past," in Understanding the Digital Economy, E. Brynolfsson and B. Kahin, eds., Cambridge MA: MIT Press, 2000: pp. 62-3, for discussion of underlying preliminary estimates of the movement in the share of newly introduced products in the total product flow through US retail distribution channels: this fraction was stable over the 1964-75 interval, rose dramatically between 1975 and 1992, and appears to have substantially stabilized thereafter. A supporting memorandum is available on request from Paul David, setting out the assumptions and preliminary calculations used to derive the implications of those movements for the *temporary expansion during 1975-1992* in the magnitude of the understatement of the rate of growth in real GPDP.

introduced goods represented in the total value of commodities goods (other than computers and peripheral equipment). For that to have continued, the pace of new product innovation would have had to go on *accelerating* sufficiently to continue the upward trend in the average rate at which product lines turned over. But, by the early 1990's the force of the wave of "mass customization" appears to have been largely spent: the average age of product lines no longer was dropping as quickly as had been the norm in the 1980's, and the proliferation of variety within product lines began exerting stronger downward pressure on the mark-ups initially commanded by newly "customized" products.

Consequently, this source of downward bias in the measured productivity growth rate was once again stabilized – albeit at a substantially higher level (namely, by the added 0.3-0.5 percentage points) than that which characterized the era preceding the "slowdown" of 1974-90. Had the drag exerted on the measured growth rate continued to increase through the 1990's, it would have masked some part of the revival in the rate of growth of measured TFP that has been observable in the years since 1992. At this point, perhaps, it should be emphasized that the burden of the preceding argument is that the magnitude of the slowdown in measured TFP growth from the rates maintained during the "golden age" (variously dated 1948-69, or 1950-72) was exaggerated by the worsening bias in the price deflators. Yet, the recent acceleration of measured TFP growth – compared to the pace of the latter during the late 1980's and early 1990's – cannot be attributed to a reduced degree of underestimation of the true rate of growth of output.

The first implication to be drawn from this is that *the rebound* of the measured TFP growth rate is rightly viewed as a real phenomenon, calling for an explanation as such. But, a second implication is that if one wants to make historical comparisons with the "golden age" of productivity growth, it would be necessary to adjust for the enlargement in the gap between the "true" and the measured rates of output growth that had contributed to the apparent productivity slowdown. One may then notice that adding an upward adjustment of as much as 0.3-0.5 percentage points to the growth rates presently found (in Table 2: IX) for the entire period from the mid-1980's onwards, would bring the estimated pace of TFP growth during the most recent sub-period back up into the neighborhood of the high average rates recorded for the 1950-72 "golden age."[176]

As has been previously remarked, some substantial component of this "historically comparable" adjusted TFP growth rate of 1.5 to 1.7 percent per annum in the years 1996-99, is cyclically inflated above the sustainable trend. But, because the source of the upward adjustment is one that can be read as reflecting

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[176] To make this rough calculation on the basis of the BLS estimates in Table 2: IX, one can start simply by adding 0.3 to 0.5 percentage points to the 1.4 percent per annum figure shown for 1996-8, obtaining a "corrected" range of 1.7-1.9 percent per annum for the latter period. But the Table 2: IX estimates are "semi-refined", whereas the 1.98 percent per annum average rate shown for 1950-72 by Table 2: IX, is the BLS's "refined" estimate. Two further "adjustments" are thus in order. In place of the BLS figure for 1996-8, we may start from the fully refined TFP growth rate of 1.2 percent per annum that Stephen D. Oliner and Daniel E. Sichel ("The Resurgence of Growth in the Late 1990's: Is Information Technology the Story?," Journal of Economic Perspectives, 14(4), 2000: Table 4) provide for 1996-9. That yields an "corrected range" of 1.5 –1.7 percent per annum for this recent period. Secondly, in place of the rather high BLS estimate in Table 2 for the period 1950-72, we may substitute the more "refined" TFP growth rate estimate of 1.7-1.8 for these years. The latter accords with the underlying (input composition adjusted) estimates used by Robert J. Gordon, "Does the 'New Economy' Measure up to the Great Inventions of the Past?," Journal of Economic Perspectives, 14(4), 2000a: pp .49-75.

multifactor productivity growth in sectors of the economy other than the vertically integrated computer sector, this correction carries the further implication that the direct impact of product quality improvements in the latter sector now appears less crucial a source of the elevated rate of TFP growth. According to the estimates made by Stephen Oliner and Daniel Sichel (2000), multifactor productivity growth in "other non-farm business" contributed 0.5 percentage points to the total growth rate attained during 1996-99. The adjustments for the under-estimated quality improvements (apart from semiconductors, computer and peripheral equipment) would thus push the other non-farm business sector's contribution up toward the 0.7 to 0.9 percentage point level.[177]

This goes some way towards removing the puzzling concentration of multifactor productivity growth in the "computer-producing" industries, and its corresponding absence from the "computer-using" sectors, which has been remarked upon by a number of recent studies. Kevin Stiroh (1997, 1998), and Dale Jorgenson (2000) have taken the view that the low rates of multifactor productivity growth outside the computer-producing sector are no "puzzle," but an entirely understandable consequence of the rapid fall in the relative (quality adjusted) price of computer capital services, which has induced substitution of the latter for the services of labor inputs.[178] It is through that channel that they, along with Oliner and Sichel (2000), now see the information revolution as contributing indirectly to raising the growth rates of output and labor productivity in the economy at large; whereas it is the direct effects of multifactor productivity advances concentrated in the industries producing semiconductors and "computer investment-goods" that have been responsible for the spectacular fall of the price-performance ratios in those products.

By re-balancing that rather lop-sided picture in the way I have suggested here, one begins to form a view of the digital technology revolution as a source of efficiency improvements that gradually have been increasing in magnitude and permeating the economy. Such a view conforms more closely with our expectations of the way in which fundamental technological breakthroughs eventually precipitate cascades of technical and organizational innovation, which, in turn, are reflected in surge-like movements of the economy's total factor productivity growth rate. Whether or not the recent acceleration is to be seen as a harbinger of developments of this kind remains a matter of speculation. The study of historical experience, however, can afford us considerable guidance in understanding the mechanisms, and the conditions that may promote such far-reaching transformations of the economic regime.

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[177] The proportionate contribution attributable to the "other non-farm business" sector after making these corrections also is raised somewhat: it lies in the range from 47 to 52 percent, whereas the fraction (0.5/1.2) suggested by the figures from Oliner and Sichel (2000: Table 4), implies a contribution of 42 percent.

[178] See Stiroh (1998); Jorgenson (2000); Robert H. McGuckin, Kevin J. Stiroh and Bart van Art, "Perspectives on a Global Economy: Technology, Productivity and Growth – U.S. and German Issues," The Conference Board Europe Report Number 206-97-RR, (Winter), 1997, esp. pp. 3-16 ("Computers, Productivity and Economic Growth in the U.S.").

4.2 General Purpose Technologies and Productivity Surges: A Backward Glance

Putting aside the vexed issues of measurement, and the disentangling of transitory from the sustained components in measured productivity growth rates that have occupied the preceding discussion, we now can give closer consideration to the longer-term processes linking technological innovation, capital formation, structural change and sustained productivity growth. Consequently, it seems quite appropriate to draw upon some of the interpretive insights that an historical perspective can bring to this subject; and to focus particularly upon the ways in which the advent of "general purpose engines" has been seen to precipitate transitions to new techno-economic regimes in which significantly higher levels of productivity became attainable.[179]

General purpose engines are the paradigmatic form of what economists today have labelled "general purpose technologies".[180] These typically are key functional components embodied in hardware which can be applied as elements or modular units of the engineering designs developed for a wide variety of specific interrelated operations or processes. Accordingly, a general purpose engine will be found to be ubiquitously distributed throughout such a system, and to be embedded in numerous and diverse complementary technical and organizational relationships when the techno-economic regime to which it gives rise has attained its fully elaborated, mature state. The notion of a general purpose engine, used in that sense, constitutes the primitive of the more extended concept of a GPT, or "general purpose technology" – a conceptualization that has been gaining popularity recently in the literature of endogenous economic growth models.[181] According to the formulation proposed originally by Bresnahan and Trajtenberg (1995: p. 84):

> "Most GPTs play the role of 'enabling technologies,' opening up new opportunities rather than offering complete, final solutions. For example, the productivity gains associated with the introduction of electric motors in manufacturing were not limited to a reduction in energy costs. The new energy sources fostered the more efficient design of factories, taking

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[179] This is the other, more optimistic side of the "regime transition" hypothesis that is presented above, in Part Two, section 3.3.

[180] See the prescient comments by Herbert A. Simon, "The Steam Engine and the Computer: What Makes Technology Revolutionary?", EDUCOM Bulletin, vol. 22, pp. 2-5, whose use of the term "general purpose engine" inspired the generalizations in Paul A. David, "General Purpose Engines, Investment, and Productivity Growth: From the Dynamo Revolution to the Computer Revolution," in Technology and Investment - Crucial Issues for the 90's, E. Deiaco, E. Hörner and G. Vickery, (eds.), London: Pinter Publishers, 1991b, upon which Bresnahan and Trajtenberg 1995, Helpman 1998, and others subsequently have built.

[181] See, particularly, Elhanan Helpman and Manuel Trajtenberg, "A Time to Sow and a Time to Reap: GPT's and the Dynamics of Economic Growth," Ch. 3 in General Purpose Technologies and Economic Growth, E. Helpman (ed.), Cambridge, MA: MIT Press, 1998, and Aghion and Howitt, "On the Macroeconomic Effects of Major Technological Change, Ch.5 in Elhanan Helpman (ed.), General Purpose Technologies and Economic Growth, Cambridge, MA: MIT Press, 1998.

advantage of the newfound flexibility of electric power. Similarly, the users of micro-electronics benefit from the surging power of silicon by wrapping around the integrated circuits their own technical advances. This phenomenon involves what we call 'innovational complementarities' (IC), that is, the productivity of R&D in a downstream sector increases as a consequence of innovation in the GPT technology. These complementarities magnify the effects of innovation in the GPT, and help propagate them throughout the economy."

Economists working in the spirit of the new growth theory have sought to generalize these ideas, by identifying a range of GPTs that not only find applications in diverse sectors of the economy, but which act as catalysts, inducing complementary innovations in those other sectors. The interest in generalization has in turn stimulated efforts to extend the list of historical examples, as well as to consolidate our understanding of the defining features of GPTs.[182] According to the carefully developed criteria proposed by Lipsey, Bekar, and Carlaw (1998), GPTs share the following characteristics: (1) wide scope for improvement and elaboration; (2) applicability across a broad range of uses; (3) potential for use in a wide variety of products and processes; (4) strong complementarities with existing or potential new technologies.

James Watt's (separate condenser) steam engine design springs to mind readily as an example of an innovation that meets these criteria, and, indeed, it is widely accepted as the GPT that is emblematic of the first industrial revolution. One might notice that while this seminal invention dates from the early 1780's, the elaboration of steam power technology extended over the next three quarters of a century: the automatic variable cut-off device, invented by the American, George Corliss, who patented the device in 1849, resulted in very significant gains in fuel economies; it also greatly enhanced the effectiveness of this power source in applications requiring both regular continuous rotary power, and adjustment to sudden variations of the load placed on the engine.

As Nathan Rosenberg and Manuel Trajtenberg recently have observed,[183] the widespread industrial utilization of steam power in the US was a phenomenon that properly belongs to the second half of the nineteenth century, and in considerable part was the consequence of the diffusion of Corliss's engine design. Prior to 1850 much the greater part of the stock of steam power capacity was devoted to marine transportation (steamboats on the lakes and rivers), and to overland railway transportation, rather than large-scale manufacturing. Factory production of textiles in the US had begun by harnessing water-power at sites along the Appalachian "fall-line" in New England, just as England's mechanized cotton-spinning

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[182] Richard G. Lipsey, Cliff Bekar, and Kenneth Carlaw, "What Requires Explanation?, Ch. 2 in Elhanan Helpman (ed.), General Purpose Technologies and Economic Growth, Cambridge, MA: MIT Press, 1998. pp. 38-43, identify an extensive list of historical and contemporary GPTs, from power delivery systems (waterwheel, steam, electricity, internal combustion) and transport innovations (railways and motor vehicles) to lasers and the Internet. The concept has been extended to encompass "organizational techniques" (the factory system, mass production, flexible manufacturing, and even the unit system for continuous process production). David and Wright (1999b), on the other hand, argue against indefinitely lengthening the list, and recommend seeking in each historical context to understand the hierarchical structure of the technological elements that were formed into systems around a core GPT.

[183] See Rosenberg and Trajtenberg (2000).

factories of the later eighteenth century had arisen initially along the swift-flowing streams of the Derbyshire dales. The great urban-industrial agglomerations of the Lancashire cotton textile industry emerged only subsequently, when the falling costs of steam-power released the mills from those rural surroundings and the constraints of inelastic local supplies of labor.

Numerous additional observations concerning the technical and economic implications of steam power would deserve notice in a separate treatment of that trajectory of technological development.[184] But, the line of argument we wish to develop is better served by focusing on the parallels between the modern digital computer (microprocessor) and another general purpose engine, one that figured prominently in what sometimes is referred to as the "Second Industrial Revolution." Of course, we refer here to the electric dynamo. Although the analogy between information technology and electrical technology would have many limitations were it to be taken very literally, it nonetheless proves illuminating.[185]

The electric dynamos of the late nineteenth century, like modern-day computers, formed nodal elements of physically distributed (transmission) networks. Both of them occupy key positions in webs of strongly complementary technical relationships that give rise to "network externality effects" of various kinds, and so make issues such as induced innovation and compatibility standardization important for business strategy and public policy.[186] In both instances we can recognize the emergence of a temporally extended trajectory of incremental technical improvements, the gradual and protracted process of diffusion into widespread use, and the confluence with other streams of technological innovation – all of which are interdependent features of the dynamic process through which a general purpose engine acquires a broad domain of specific applications. In each epoch, the successful exploitation of the new technology's evolving productivity potential has entailed the design and financing of investment projects whose novelty, in terms of scale, technical requirements, or other characteristics, posed significant challenges for the existing agencies supplying capital goods and the established capital market institutions.

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[184] For example, it may be pointed out that the greatly increased engine speeds that were attainable with Corliss-type steam engines in the closing decades of the nineteenth century, made these machines very attractive as the power source for generating electric current in the era before the emergence of the steam turbine power plant. This illustrates the general propositions (discussed below) that the process of deploying and exploiting a GPT is typically quite prolonged, and much of its economic impact derives from the confluence with, and enhancement of the benefits derived from other technological and organizational innovations.

[185] See David 1991b on the important economic respects in which information and electricity are not analogous; David 2000: pp. 77-82, for discussion of a number of other, mis-directed criticisms that have been leveled against drawing parallels between the computer and the dynamo revolutions.

[186] With specific reference to the appearance of these issues in the context of network activities such as the electricity supply industry, see, e.g., Paul A. David, "Some New Standards for the Economics of Standardization in the Information Age," Ch. 8 in Economic Policy and Technological Performance, P. Dasgupta and P. Stoneman, eds., Cambridge: Cambridge University Press, 1987, Paul A. David and Julie A. Bunn,"The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History," (with J. A. Bunn), Information Economics and Policy, vol. 3, Winter 1988, pp. 165-202.

The transformation of industrial processes by electric power technology was a long-delayed and far from an automatic business. It did not acquire real momentum until after 1914 to 1917, when the rates charged consumers by state-regulated regional utilities fell substantially in real terms, and central station generating capacity came to predominate over generating capacity in isolated industrial plants. Rapid efficiency gains in electricity generation during 1910 to 1920 derived from major direct investments in large central power plants, but also from the scale economies realized through integration and extension of power transmission over expanded territories. These developments were not simply matters of technology, but also reflected political and institutional changes that allowed utilities largely to escape regulation by municipal and town governments, facilitating the flow of investment capital into holding companies presiding over centrally managed regional networks. Together these supply-side changes propelled the final phase of the shift to electricity as a power source in US manufacturing, from just over 50 percent in 1919 to nearly 80 percent in 1929.[187]

But, the protracted delay in electrification was not exclusively due to problems on the supply side of the market for purchased electrical power. The slow pace of adoption prior to the 1920's was attributable largely to the unprofitability of replacing still serviceable manufacturing plants adapted to the old regime of mechanical power derived from water and steam. Coexistence of older and newer forms of capital often restricted the scope for exploiting electricity's potential. Prior to the 1920's, the "group drive" system of within-plant power transmission remained in vogue. With this system – in which electric motors turned separate shafting sections, so that each motor drove related groups of machines – primary electric motors often were merely added to the existing stock of equipment.[188] When the favorable investment climate of the 1920's opened up the potential for new, fully electrified plants, firms had the opportunity to switch from group drive to "unit drive" transmission, where individual electric motors were used to run machines and tools of all sizes.

The advantages of the unit drive technology extended well beyond savings in fuel and in energy efficiency. It also made possible single-story, linear factory layouts, within which reconfiguration of machine placement permitted a flow of materials through the plant that was both more rapid and more reliable. According to the surveys of American manufacturing in the early 1930s directed by Harry Jerome at the NBER, the rearrangement of the factory contributed to widespread cost savings in materials handling operations, serializing machines and thereby reducing or eliminating "back-tracking".[189]

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[187] See Paul A. David and Gavin Wright, "Early Twentieth Century Growth Dynamics: An Inquiry into the Economic History of 'Our Ignorance'." SIEPR Discussion Paper No. 98-3, Stanford University, Institute for Economic Policy Research, (April) 1999a: Figure E1, and text discussion.

[188] For further technological details see W. Devine, Jr., "From Shafts to Wires," Journal of Economic History, 43, 1983: pp. 347-72, and W. Devine, Jr., "Electrified Mechanical Drive: The Historical Power Distribution Revolution," in S. Schurr et al., Electricity in the American Economy, New York: Greenwood Press, 1990. and Devine 1990.

[189] See H. Jerome, Mechanization in Industry. New York: National Bureau of Economic Research, 1934, esp. pp. 190-1.

It is important to emphasize (especially for the benefit of economists engaged in modelling the dynamics of growth driven by GPTs) that the historical transformation of the technical features of the American factory regime involved more than the simple "diffusion" of a particular general purpose engine in the form of the electric motor. Rather, a new system of manufacturing, characterized by higher and more rapidly rising levels of input efficiency, emerged from the confluence, or convergence, of factory electrification with other trajectories of industrial innovation. Each of these had its own developmental history and inventive momentum. Yet each received new impetus and acquired enhanced economic signficance through its interactions with the dynamo – the core GPT in this era. Three distinct elements which thus acquired complementary roles in the industrial transformation are especially worthy of mention in this connection:[190]

(a) The fixed transfer-line layout of assembly operations that came into full fruition in the Ford Highland Park plant on the eve of World War I diffused rapidly and widely during the 1920's, because Henry Ford was deliberately open in promoting the logic and engineering specifics of this system of mass production by means of interchangeable parts. Electric power transmission by wire, rather than by drive-shafts, was better suited to this new manufacturing regime, as was evident from the use made of group and unit drives at Highland Park itself.

(b) Automated materials handling was a generic labor-saving development that featured prominently among the new innovations of manufacturing mechanization in the 1920's and early 1930's; these too did not require electrification, although in some cases such as the use of battery powered fork-lifts, the availability of cheap purchased power for recharging was important.

(c) Continuous process chemical technologies, which implemented the "unit system" principles of Arthur D. Little, made extensive use of electro-mechanical and electro-chemical relays for control; further, and many of the processes to which the unit system approach came to be applied also were heat-using, and so were dependent upon purchased electricity for large-scale operations.

The confluence among these technological developments which transformed American manufacturing practices during the Interwar era, quite obviously finds a modern counterpart in the "information revolution's" converging advances in the technology of semiconductors and microprocessor fabrication, in fibre-optic cables, laser applications (for reading and recording digitized data in compressed formats, and in laser-pumped broadband optical networks), low-power cellular digital telecommunication systems, and myriad innovations in computer programming and data storage and retrieval technologies.

The package of electricity-based industrial process innovations that came into use during the 1920's could well serve as a textbook illustration of *capital-saving* technological change. Electrification saved fixed capital by eliminating heavy shafts and belting, a change that also allowed factory buildings themselves to be more lightly constructed, because they were more likely to be single-storey structures whose walls no longer had to be braced to support the overhead transmission apparatus. The faster pace

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[190] See David A. Hounshell, From the American System to Mass Production. Baltimore: The Johns Hopkins University Press, 1984, on Ford's plant at Highland Park, Michigan; Jerome (1934) on overhead cranes, forklift trucks, etc.; Nathan Rosenberg, "Chemical Engineering as a General Purpose Technology," ch. 7 in Helpman (1998), on the "unit process"; David (1991a, p. 344, for electric automatic controls and the unit process.

of material throughput amounted to an increase in the effective utilization of the capital stock. Further, the frequency of downtime was reduced by the modularity of the unit drive system and the flexibility of wiring; the entire plant no longer had to be shut down in order to make changes in one department or section of the factory.[191] Notice too that Henry Ford's transfer-line technique, and the speed-up of work that it permitted, was a contributory element of the high throughput manufacturing regime, as were the new continuous process technologies that grew in importance during this era.

The consequent effects of factory electrification upon industrial productivity are confirmed by the sharp fall recorded in the manufacturing sector's capital-output ratio during the 1920's, a development that contributed significantly in the early twentieth century to reversing the nineteenth-century trend towards economy-wide capital deepening. A pattern of capital-saving movements emerged quite pervasively throughout American manufacturing: all but two of seventeen major industry groups experienced a fall in the capital-output ratio during the 1919-29 interval, whereas the ratio had been rising in every one of these groups during 1899 to 1909, and in twelve of the seventeen during 1909 to 1919. Furthermore, as David and Wright recently have shown,[192] this increase in the average productivity of fixed capital in industry was directly associated with the electrification of primary horsepower, and that correlation became stronger in the course of the 1920's.

At the same time, there was an equally pervasive surge in the growth average labor productivity. The aggregate productivity growth rate for manufacturing in the 1920's was over 5 percentage points higher than the trend rate in the previous two decades, and, rather than being concentrated in a few lines of industry, the contributions to this acceleration were very evenly distributed among all the industrial groups. With both capital productivity and labor productivity rising concurrently throughout manufacturing, it is not surprising that even when multifactor productivity growth is calculated for each of the major branches – thereby making allowance for the growth in purchased inputs of energy in the form of electricity supplied by central power stations – a widespread acceleration in the rates of growth of MFP is observed to have occurred between the "'teens" and the "twenties".

Moreover, a significant positive statistical relationship is found between the magnitude of the acceleration in the rate of TFP growth and the increase in the fraction of mechanical power derived from secondary electric motors. The latter ratio in this era provides an indicator of the diffusion of the unit drive system of factory electrification. Its positive cross-section relationship with the measure of acceleration

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[191] S. H. Schurr et al., Electricity in the American Economy. New York: Greenwood Press, 1990, esp. pp. 29-30 and 292-93.

[192] See Paul A. David and Gavin Wright, "General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution," University of Oxford Discussion Paper No. 31, (September) 1999b.

in the MFP growth rate implies that *at least* one-half of the temporal acceleration during the 1919-29 interval can be attributed to this phase of the electrification process.[193]

In terms of the metaphors recently employed by Arnold Harberger to characterize two contrasting ways in which aggregate productivity growth occurs,[194] the 1920's productivity surge was a "yeast-like" expansion that involved essentially the entire US manufacturing sector, rather than the result of rapid efficiency gains that had popped up in a small number of industries for idiosyncratic reasons, like "mushrooms" shooting up at random places in a field. David and Wright recently have suggested that a "yeast-like" process is exactly what would be expected where rapid productivity growth was surging under the coordinating influence of a new GPT,[195] whereas the "mushroom-like" pattern that Harberger (1998) observed in US manufacturing during the 1970's and 1980's was more typical of interludes when the overall pace of productivity advance remained sluggish.

If we may reasonably characterize the pattern of multifactor productivity advances in the US economy during the 1990's as moving from "mushrooms" toward "yeast," is there warrant for anticipating a future surge? Should we accept the view of "the new economy" as a restricted sector comprising a handful of industries that are achieving spectacular growth and productivity gains in the production of ICT-intensive goods and services? Or, discard that picture in favor of the more "yeasty," GPT conceptualization of the entire economy being "digitally *re-newed*." In the following section we will conclude this discussion by venturing several historically informed speculations on these intriguing questions.

Reflections on the Future: From ICT Productivity Growth Paradoxes to Payoffs

It is likely that the U.S. will have to look to the further development of digital information technologies, and their diffusion throughout the economy to sustain the future trend growth rate of TFP at the levels that have been achieved in the US economy at the very close of the twentieth century. Certainly, any further acceleration in TFP growth would have to come from that direction. This is not meant as a discouraging view, either for the US or for the western European economies. Even in the immediately foreseeable future, several promising technological trajectories appear to offer still largely untapped potentials for productivity growth, especially productivity gains of the kind that our conventional statistical indicators will be able to register.

Our vision of these has not been formed simply by extrapolating from previous historical experience with the diffusion and elaboration of general purpose technologies. Nevertheless, from the

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[193] See Paul A. David, "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror," in Technology and Productivity: The Challenge for Economic Policy, Organization for Economic Co-operation and Development, Paris, 1991a, pp. 315-48. pp. 343-4 especially, on the cross-section regression model and its quantitative implications.

[194] See Harberger (1998).

[195] See David and Wright (1999a).

following comments on three of these emerging areas of ICT application, it will be apparent that the recurrence of a pervasive alteration in the bias of factor efficiency growth – toward augmenting the efficiency of conventional tangible capital inputs, and of routine labor services – is what is being anticipated here. The effects of this upon measured TFP in many branches of the economy would then bear a resemblance to the productivity effects associated with the diffusion of the unit drive system of factory electrification during the 1930's.

One of the more rapidly emerging among these trajectories is the much-discussed expansion of inter-organizational computing via the Internet. Such portents for the future involving what eventually would amount to major structural transformations, may be seen in the expansion of inter-organizational computing for the mass of transactions involving purchase ordering, invoicing, shipment tracking, and payments. All of those activities presently absorb much specialist white-collar labor time, and it is not clear that its displacement can be managed so easily by companies whose day-to-day operations depend in some degree upon the un-codified expertise of those employees. Nevertheless, the potential gains create an attraction: recent estimates indicate that in many branches of economic activity 10-15% cost savings in procurement activities will be available through the diffusion of business-to-business e-commerce. Still higher percentage cost-savings in procurement and related inter-firm transactions are estimated, not only for manufacturing, but for service activities such as freight transport, and media and advertising. Service occupations such as these might be viewed as the modern day counterparts of the ubiquitous materials-handling tasks in the manufacturing sector which became the target of innovative dynamo-based mechanization during the 1920's.[196]

A second significant cost saving trajectory is likely to emerge with the development and increasingly widespread diffusion of new, specialized, robust, and comparatively inexpensive digital "information appliances." This new generation of appliances includes not only the enhanced PDA's (personal digital assistants) that already are coming into use among PC users, but a variety of function specific hand-held devices, and other robust specialized tools that will be carried on belts, sown into garments, and worn as head-gear. They will embody advanced microprocessors and telecommunications components that enable them to be linked through sophisticated networks to other such appliances, as well as to mainframe computers and distributed databases, thereby creating complex and interactive intelligent systems.[197]

The proliferation of interconnected special-purpose applicants of this sort also is likely to be reinforced by "network externality" effects upon demand, and so would expand new market niches for vendors of successive generations of "computer-related" hardware – the quality-adjusted prices of which

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[196] See David and Wright (1999b), for fuller discussion of the interrelatedness of mechanization of materials handling and factory electrification in the U.S. during the 1920's and 1930's.

[197] See W. Wyatt Gibbs, "Taking Computers to Task," Scientific American 277, no. 1 (July 1997): pp. 82-9, and especially Donald A. Norman, The Invisible Computer: Why Good Products Can Fail, the Personal Computer is So Complex, and Information Appliances are the Solution, Cambridge, MA: MIT Press, 1998., Ch. 11.

are likely to fall far faster than the costs of the inputs used in their manufacture.[198] But perhaps even more significantly, this emerging trajectory of convergent information and communications technology developments is one that is likely to directly impinge upon the specific task performance of workers equipped with such devices, and hence boost conventional measures of productivity improvement in a wide array of industries.[199]

The diffusion of tele-working represents a third trajectory with a potential to yield substantial long-term gains in measured multifactor productivity, most notably from savings in infrastructure capital, as well as through the reduction of the costs of measures required to abate pollution and environmental degradation in congested urban areas. At present, "tele-working" remains still far from fully deployed in the US: only about a fifth of the workforce time in large service sector firms are providing data communications network links with employees' homes, and many of those are trying out "mixed systems" of central office and "outside" work. As was the case historically with the group drive system of factory electrification, substantial duplication of fixed facilities characterizes this stage in the new GPT's diffusion. So, significant capital-savings through reductions of required commercial office space and transport infrastructures are likely to result for the whole service sector only as "tele-working" becomes much more widely and completely deployed. Moreover, many of the workers who are participating in tele-working continue to travel on some days in the week to company offices where they share a "hot desk" with co-workers who are on a different schedule. In such situations, the promised productivity gains derived when workers are relieved of the wear and tear of extended "commutes" remain at best incompletely realized.[200]

For these and still other reasons, it remains a good bet that economists who continue proclaiming their skepticism about the information revolution's ability to deliver major long-term productivity payoffs are going to be proved wrong.[201] Yet those payoffs won't come freely; they will entail much learning and

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[198] The implication, then, is that analysts who apply the "dual" approach to measuring the rate of multifactor productivity, such as Oliner and Sichel (2000), for example, are likely to find this growing branch of manufacturing "contributing" to the aggregate TFP growth rate as the "vertically integrated computer sector" presently does.

[199] In the view of informed industry participants, some aspects of this transformation are closer than might be supposed, although, characteristically, the more general purpose of the tools within this class of appliances have (again) been first to attract commercial interest. At the Davos World Economic Forum in January 2001, Microsoft's Bill Gates spoke of the coming proliferation of devices, from mobile telephones and personal digital assistants to e-books and detachable PC screens. Perhaps not surprisingly, he expressed optimism about the development of the software required "to link them together seamlessly so that consumers can communicate and have access to up-to-date information at the press of a button, whatever the device they're using…: 'We're really on the threshold of achieving all of those things,'" Gates is quoted as having announced. See, "Industry Leaders See a New Era in the Tech Revolution," International Herald Tribune, 30 January 2001, pp.1, 16.

[200] See David (2000) pp. 84-5 on 'teleworking' in the U.S.; Robin Mansell and W. Edward Steinmueller, Mobilizing the Information Society: Strategies for Growth and Opportunity, Oxford and New York: Oxford University Press, 2000, for Western European perspectives.

[201] See Robert J. Gordon, "US Economic Growth Since 1870: One Big Wave?," American Economic Review 89 (May), 1999: 123-8, and Robert J. Gordon, "Does the 'New Economy' Measure up to the Great

further, costly organizational adaptations. Nor should they be expected to materialize overnight – even if a domestic macroeconomic environment conducive to long-term investment were to be maintained, and were we lucky enough to escape real and financial shocks in the international economy of the serious kind that could be triggered by the recurrent threats to peace in the Balkans and the Middle East.

Table 2-IX: The U.S. Productivity Growth Revival of the Late 1990's in Perspective

Average Annual Percentage Growth Rates of GDP Productivity Measures
for the U.S. Private Business Economy

BLS Measures	1973-1979	1979-1990	1990-1995	**1995-1998**
Output per person hour	1.3	1.6	1.5	**2.5**
Capital services per person hour:	0.7	0.7	0.5	**0.8**
Information processing equipment and software	0.3	0.5	0.4	**0.8**
All other capital services	0.5	0.3	0.1	**0.0**
Labor input composition	0.0	0.3	0.4	**0.3**
Semi-Refined TFP Residual*	0.6	0.5	0.6	**1.4**

*Compositional change corrections are made for labor inputs, but in the case of capital inputs the only compositional changes accounted for are those between IT and non-IT capital, and changes in the quality of the IT capital stock.

Source: Derived from U.S. Department of Labor, *News Release USDL 00-267*, September 21, 2000.

Inventions of the Past?," Journal of Economic Perspectives, 14(4), 2000a: pp.49-75, who continues to maintain his position as the most throughtful and articulate economist among the "ICT skeptics."

Part Three

American Growth in an International Perspective

How does the American growth experience compare with that of other countries? The economies we hold up for historical comparison with the United States are mainly a sample of those that also began a process of industrialization during the nineteenth century. These are the U.K. and the continental countries of Western Europe. We also pay some attention to a larger group that includes not only Western Europe but also Canada, Australia, and Japan.[202]

If we look back to the situation prevailing early in the nineteenth century, the U.S. level of real GDP per capita was somewhat below that of the U.K., the pioneer of modern economic growth, and the still commercially prosperous Low Countries (The Netherlands and Belgium.) But the young Republic's citizens already enjoyed some appreciable margin of material advantage over the inhabitants of the long-settled region of Western Europe taken as a whole.[203] The estimates for this period are surrounded by particularly wide margins of uncertainty, however, so we begin our statistical comparisons in 1870 when better, if still not wholly reliable comparative data become available. At that time, it was still true that the U.S. per capita real output level lagged behind the U.K.'s, but America appears already to have established a substantial lead over the Western European average and, with some exceptions such as Switzerland, Belgium, and the Netherlands, over all the other individual countries in the Western European group.

There then followed a long wave in the relative position of the United States. For eight decades, American per capita output grew faster than that of both the U.K. and Western Europe. By 1913, America had gained the lead over the U.K. in per capita output and widened its lead over Western Europe. And then, in an era marked by two world wars and the Great Depression, the U.S. gained still larger leads. By 1950, the U.K. level of output per capita was only three-quarters that of the United States and the Western European average level was only 56 percent as high. Since 1950, the relative position of Europe and the U.S. has moved the other way. Western Europe has been catching up; by 1992, its average level was up to 81 percent of the American. The U.K., on the other hand, has only held its own since 1950.

All this is succinctly displayed by the figures in Table III: I-1. They are based upon the work of Angus Maddison (1995), whose compilation of internationally comparable estimates of real output, population, manhours, etc. provides the most widely accepted figures that trace such data

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[202] This Part draws heavily upon Moses Abramovitz and Paul A. David, "Convergence and Deferred Catch-up: Productivity Leadership and the Waning of American Exceptionalism," Ch. 2 of The Mosaic of Economic Growth, edited by Ralph Landau, Timothy Taylor and Gavin Wright, Stanford CA: Stanford University Press, 1996. Material previously published there is used here with the permission of the publishers, Stanford University Press.

[203] See Angus Maddison, Monitoring the World Economy, Paris: OECD, 1995: Table 1-3.

over long periods of time.[204] The underlying figures derive from national estimates of GDP, which are first rendered comparable across countries by converting estimates in national currency into a common currency using the purchasing power parity ratios of a base year. This is 1990 in the case of the most recent Maddison (1995) estimates. From that base, comparable figures for each country are obtained for earlier, as well as later dates, by extrapolating its converted national output value in the base year by the movement of its own deflated GDP. This procedure for rendering real output levels in different countries comparable is acceptable if the measures are understood in those terms; to read them as indicating relative levels of real income per capita, to which an economic welfare interpretation can be attached, however, would entail accepting strong assumptions about stabilities in the structure of international prices. And, indeed, those assumptions clearly are suspect. The resulting estimates, therefore, must be handled with a degree of caution that transcends the norm expected in historical reconstructions of this sort, and we rely on them only in so far as they provide some broad indications of relative levels of real output and productivity, and international differentials in the movements of the latter over time.[205]

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[204] Although the discussion here rests on Maddison's (Monitoring, 1995) estimates, it should be evident from the description of their method of derivation in the text that considerable difficulties surround the interpretation of the level of comparisons as reflecting standards of material welfare at various points in time reaching back for well more than a century. Part of the problem is the usual index number problems that are present in the various underlying national series of real output per capita for each of the countries involved. But, there is the additional difficulty of attaching a welfare interpretation to comparisons of the per capita level of output expressed in the purchasing power parity equivalents based upon the structure of prices in the U.S. c. 1990. The recent work of Leandro Prados de la Escosura ("International Comparisons of Real Product, 1820-1990: An Alternative Dataset," Universidad Carlos III de Madrid, Working Paper 98-64 (Economic History and Institutions Series 05), November 1998) undertakes to express GDP for a wide range of countries in terms of the purchasing power parities that prevailed contemporaneously. These show that the U.S. per capita GDP level already closely matched that of the U.K. during the first half of the nineteenth century.

[205] See Maddison (1995): Appendixes B and C, for a more extended discussion of the problem of achieving cross-national comparability in estimates of output levels; and Prados ("International Comparisons" 1998) for an alternative methodology that yields comparable relative levels of GDP per capita. But whereas the movements of the latter relatives over time reflect both differential rates of growth of real output and changes in the relative structure of international prices, the Maddison-type relatives reflect only the differentials in real output and productivity growth. In general, the degree of relative dispersion in these GDP per capita measures is smaller than those in the corresponding Maddison measures of *real* GDP per capita, but the two sets of dispersion observations show much the same movements over time.

Table 3: I
Relative Levels of Real GDP per Capita, and per Manhour in Europe and the U.S.A., 1870-1992
(U.S.A.=100)

	GDP per Capita		GDP per Manhour	
	Average of 11 Continental Countries[a]	U.K.	Average of 11 Continental Countries[a]	U.K.
1870	76	132	65	115
1900	67	112	-	-
1913	63	95	57	86
1929	62	76	55	74
1950	56	72	45	62
1973	70	72	70	68
1992	81	73	87	82

[a] Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland.
Source: Maddison, 1995, Tables 1-3 and 2-7 (a).

Table 3: I also includes Maddison's comparisons of levels of labor productivity. They show the same great wave in the relative position of the U.S.: a long period from 1870 to 1950 when America was forging ahead and gaining an ever larger advantage over the U.K. and Western Europe, and then a four-decade period stretching into the 1990s when both Europe and the U.K. were catching up. It is just this trend reversal in Europe and the U.K. vis-à-vis America that constitutes the main problem for understanding American growth viewed in comparison with that of other countries, and it is the major focus of the rest of this section.

We believe that the trend reversal in America's relative per capita real output position is best approached by an analysis of its comparative labor productivity growth. It is true that the growth rate of output per capita is governed by that of labor input per capita as well as that of labor productivity. Relative labor productivity growth rates, however, have been the dominant component. Their movements have been larger than those of labor input, and they have conformed consistently with those of per capita output growth. Labor input, on the other hand, has sometimes moved in agreement with per capita output and sometimes not. We believe, therefore, that it is the relative growth rates of labor productivity that have been the consistent source of national differences in per capita output growth, and the remainder of this section deals with labor productivity.[206]

1. The Theory of Catch-up and Convergence Versus the Record of Growth

The growth records of Europe and America during the long period between 1870 and 1950 present a particular problem for explanation because they fit awkwardly into, and, in some respects, run counter to the predictions of a theory now widely accepted by economists, economic historians and students of growth. This is the idea that countries that at any time find themselves behind a leading country in their levels of productivity have a greater potential for future growth than does the leader. Until 1870, the leader was the U.K.; in the following decades, the countries of Western Europe did, indeed, gain on the U.K. But in these same decades, the U.S. was visibly forging ahead. It not only overtook but surpassed the U.K., and it widened a lead over Western Europe that was already substantial in 1870. In this respect, the record is at odds with the theory.

The perception that being behind carries a potential for future productivity growth faster than a leader's has been rationalized in the theory of catch-up and convergence. Stated in its most elemental form, the theory refers to countries that differ only in their initial levels of productivity. By this we mean that they face no persistent obstacles in exploiting the advantages that backwardness is held to present.

The potential advantages of laggard countries have at least four sources:

They can modernize their capital stock by replacing their technologically obsolete equipment with state-of-the-art assets by imitating or purchasing the new state-of-the art instruments produced in leading countries.

Because their low levels of capital per worker tend to produce high marginal rates of return, laggards tend to have high rates of capital accumulation – all the more since the new capital can embody advanced technology.

Because they often have large numbers of redundant workers in farming and petty trade, they can gain more from labor transfers from farm to nonfarm occupations and from small shops to larger scale firms.

As the gains from the first three sources produce a growth in aggregate output and in the size of the domestic market, a wider horizon of gains from the economies of scale presents itself.

These foregoing considerations lead one to expect that, in the ideal circumstances envisaged by the theory, countries whose productivity levels were at anytime low relative to that of a leading country would tend to catch up. And, the rate at which catch-up would take place would vary with the size of the initial gaps.

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[206] We do, however, deal with per capita output growth and its proximate components in the lengthy Endnote 1 to Part Three.

These expectations actually were well met in the experience of the advanced, capitalist countries during the period following World War II, as may be seen from Table 3: II. When the period opened, the productivity gaps separating America from the Western European countries stood at a historically high level. They had been enlarged by the relatively rapid growth of the U.S. during the years from 1870 to 1929 and then further enlarged by the severe impact of World War II on Europe and Japan. Beginning after the war, however, there began a period of rapid catch-up, which has now gone on for over four decades. It had brought the average level of productivity in Western Europe to 87 percent of the U.S. level by 1992. Belgium, France, Germany, and the Netherlands have reached productivity relatives of 95 percent or better. And, as expected, when by 1973 the average productivity gap had narrowed substantially, the rate of catch-up declined. The Japanese record since 1950 was qualitatively similar. Moreover, since the Japanese level in 1950 stood much lower than the European, its more rapid growth since also conforms to expectation.

The record of general convergence within the group was also consistent with the predictions of the theory. The advanced countries had converged only slowly from 1870 to 1913, and then World War II had caused the variance of productivity levels to rise. But after 1950 rates of convergence were rapid, and, as the level of dispersion declined, the rates of convergence slowed down.

This record of conformity with the predictions of catch-up and convergence theory after 1950 stands in sharp contrast with experience before that time. Although the productivity levels of both European countries stood well below those of the U.S. as early as 1870, they did not catch up. Nor did Japan, except between 1913 and 1938.

The contrast between the experiences of the years before 1950 and those that followed clearly demands explanation. One may well think, as we do, that in the period, 1913 to 1950, the forces making for catch-up were quite overwhelmed by two general wars, by the territorial, political, commercial, and financial disturbances that followed World War I and by the variant impacts of the Great Depression. Such difficulties, however, cannot explain the failure of Europe to reduce its productivity lag behind the U.S. during the more than four decades of peaceful development and widening commerce between 1870 and 1913. Nor do they account for the developments that released the forces of catch-up and convergence after World War II. We go on to outline a framework within which to consider these questions.

Table 3: II
Rates of Catch-up in GDP per Manhour

12 European Countries*				Japan			
Mean Level (U.S.=100)		Rate of Catch-up** (% per Ann.)		Level (U.S.=100)		Rate of Catch-up** (% per Ann.)	
1870	69			1870	20		
1913	59	1870-13	-0.36	1913	20	1870-13	0.00
1938	56	1913-38	-0.21	1938	25	1913-38	0.89
1950	46	1938-50	-1.64	1950	16	1938-50	-3.72
1973	70	1950-73	+1.83	1973	48	1950-73	4.78
1992	87	1973-92	+1.14	1992	69	1973-92	1.91

Notes:

*The 12 European countries include the 11 named in Table 3: I, plus the United Kingdom.

**The rate of catch-up is the change per annum in the log of the mean level of productivity relative to the U.S. times 100.

2. The Elements of Catch-up Potential and Its Realization

We may group the conditions that govern the abilities of countries to achieve relatively rapid rates of productivity growth into two broad classes: those that govern the potential of countries to raise their productivity levels, and those that influence their abilities to realize that potential.

The simple catch-up hypothesis would have it that the one element governing a country's relative growth potential is the size of the productivity differential that separates it from the leader. Manifestly, however, the record of growth does not conform consistently to the predictions of this unconditional convergence hypothesis. The assumption that countries are "otherwise similar" is not fulfilled. There are often persistent conditions that have restricted countries' past growth and that continue to limit their ability to make the technological and organizational leaps that the hypothesis envisages. We divide constraints on the growth potential of laggard countries into two categories.

One constraint consists of the limitations of "technological congruence." Such limitations arise because the frontiers of technology do not advance evenly in all dimensions; that is, with equiproportional impact on the productivities of labor, capital, and natural resource endowments and with equal effect on the demands for the several factors of production and on the effectiveness of different scales of output. They advance, rather, in an unbalanced, biased fashion, reflecting the direct influence of past science and technology on the evolution of practical knowledge and the complex adaptation of that evolution to factor availabilities, as well as to the scale of markets, consumer demands and technical capabilities of those relatively advanced countries operating at or near the frontiers of technology.[207]

It can easily occur that the resource availabilities, factor supplies, technical capabilities, market scales and consumer demands in laggard countries do not conform well to those required by the technologies and organizational arrangements that have emerged in the leading country or countries. These may render it extremely difficult if not prohibitively costly, for firms, industries, and economies to switch quickly from an already established technological regime, with its associated trajectory of technical development, to exploit a quite distinct technological regime that had emerged elsewhere, under a different constellation of economic and social conditions.

The second class of constraints on the potential productivity of countries concerns a more vaguely defined set of matters that has been labeled "social capability." This term was coined by Kazushi Ohkawa and Henry Rosovsky.[208] It covers countries' levels of general education and technical competence; the commercial, industrial, and financial institutions that bear on their abilities to finance and operate modern, large-scale business; and the political and social characteristics that influence the risks, the incentives, and the personal rewards of economic activity, including those rewards in social esteem that go beyond money and wealth.

Over time there is a two-way interaction between the evolution of a nation's social capabilities and the articulation of societal conditions required for mastery of production technologies at or close to the prevailing "best practice" frontier. In the short run, a country's ability to exploit the opportunities afforded by currently prevailing best-practice techniques will remain limited by its current social capabilities. Over the longer term, however, social capabilities tend to undergo transformations that render them more complementary to the more salient among the emerging technological trajectories. Levels of general and technical education are raised. Curricula and training facilities change. New concepts of business management, including methods of managing personnel and organizing work, supplant traditional approaches. Corporate and financial institutions are established, and people learn their modes of action. Legal codes and even the very concepts of property can be modified. Moreover, experience gained in the practical implementation of a production technique enhances the technical and managerial competencies that serve it and thus supports further advances along the same path. Such mutually reinforcing interactions impart "positive feedback" to the dynamics of technological evolution. They may for a time solidify a

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[207] See David, Technical Choice (1975), Ch.1, for an introduction to the theory of "localized" technological progress and its relation to the global bias of factor-augmenting technical change and for a synthesis of some of the pertinent historical evidence. See also S.N. Broadberry (1993, 1996) in the General Bibliography.

[208] This term was coined by Kazuahi Ohkawa and Henry Rosovsky, Japanese Economic Growth: Trend Acceleration, 1868 -1968, Stanford CA: Stanford University Press, 1972.

leader's position or, in the case of followers, serve to counter the tendency for their relative growth rates to decline as catch-up proceeds.

On the other hand, the adjustments and adaptations of existing cultural attitudes, social norms, organizational forms, and institutional rules and procedures is neither necessarily automatic nor smooth. Lack of plasticity in such social structures may retard and even block an otherwise technologically progressive economy's passage to the full exploitation of a particular emergent technology. New technologies may give rise to novel forms of productive assets and business activities that find themselves trammeled by features of an inherited jurisprudential and regulatory system that had never contemplated even the possibility of their existence. For laggards, the constraints imposed by entrenched social structures may long circumscribe the opportunities for any sustained catch-up movement.

Taken together, the foregoing elements determine a country's effective potential for productivity growth. Yet another distinct group of factors governs the ability of countries to realize their respective potentials. One set of issues here involves the extent to which followers can gain access to complete and reliable information about more advanced methods, appraise them, and acquire the artifacts and rights needed to implement that knowledge for commercial purposes. A second set of issues arises because long-term, aggregate productivity growth almost always entails changes in industrial and occupational structure. As a result, the determinants of resource mobility, particularly labor mobility, are also important. And finally, macroeconomic conditions govern the intensity of use of resources and the financing of investment and, thereby, affect the choices between present and future that control the R&D and other investment horizons of businesses. By influencing the volume of gross investment expenditures, they also govern the pace and extent to which technological knowledge becomes embodied in tangible production facilities and the people who work with them.

We now put this analytical schema into use in a specific historical context: how the U.S. attained and enlarged its productivity lead from 1870 to 1950, and then what changed during these years that released the catch-up and convergence boom of the postwar period. Because space is limited, we pay most attention to technological congruence and social capability and give only brief notice to the factors supporting the realization of potential.

3. Bases of the Postwar Potential for Catch-up and Convergence

The dramatic postwar record of Western Europe and Japan creates a presumption that they began the period with a strong potential for rapid growth by exploiting American methods of production and organization. The productivity gaps separating the laggard countries from the United States were then larger than they had been in the record since 1870. However, the gains in prospect could only be realized if Europe and Japan could do what they had not been able to do before: take full advantage of America's relatively advanced methods. The insistent question, therefore, is why Europe, itself an old center of technological progress, had proved unable even to keep pace with the U.S. during the three-quarters of a century following 1870.

Technological Congruence: The Role of Primary Materials

Attention previously was drawn (in Part Two, Section 1) to the role that primary materials played in supporting the development of the American economy along a high and rising tangible capital-intensity path, and the concomitant boost this gave to the growth of labor productivity during the latter nineteenth and early twentieth centuries.

The key elements in that contribution were, on the one hand, the importance of primary materials in the costs of industrial products to final consumers and investors. On the other side was America's rich natural endowment and its success in developing it rapidly. And because transport costs were then also high, this translated into a substantial advantage over other countries in the costs of primary materials and of the final costs of many industrial products – a superiority evidenced by America's growing comparative advantage as an exporter of natural resource-intensive manufactures from 1880 to 1929.

This helps account for the fact that it was the era of the 1880-1913 "minerals economy" boom, that saw American labor productivity rising faster than that of the other advanced industrial countries and eventually surpassing the level of Britain, the former world leader. With the passing of time, however, the importance of these inter-country differences declined – for at least six reasons:

First, technological progress reduced the unit labor input requirements in the mineral mining, gas, and oil industries both absolutely and relative to the costs of processing.

Second, mineral resources were discovered and developed in many parts of the world where their existence had remained unknown at the end of the nineteenth century, so costs of materials at points of origin and use outside the United States would have tended to fall. Furthermore, technological advance increased the commercial value of mineral resource deposits that previously were neglected and added new metals and synthetic materials to the available range of primary materials and agricultural products.

Third, petroleum came to be of increasing importance as a source of power for industry and transportation and also as feedstock for the chemicals industry. This reduced the disadvantage to Europe of its well-worked mines and the lack of coal resources in Japan.

Fourth, transportation costs both by land and sea declined markedly, which reduced the cost advantages enjoyed by exporters of primary products in the further processing of such materials.

Fifth, crude materials came to be processed more elaborately and, on this account, primary products became a smaller fraction of the final cost of finished goods.

Sixth, and finally, services in which the materials component is small have become more important, compared with foods and manufactures in which the materials component is larger.

For all these reasons, differences in developed natural resource endowments have counted for less in recent decades than they had done earlier.

Technological Congruence: Capital-Using and Scale-Intensive Technology

The technology that emerged in the nineteenth and that persisted into the early twentieth century was not only resource-intensive, it was tangible capital-using and scale-dependent. Exploiting the technical advances of the time demanded heavier use of machinery per worker, especially power-driven machinery in ever more specialized forms. But it required operation on an ever-larger scale to make the use of such expensive structures and equipment economical. Furthermore, it required steam-powered transport by rail and ship, itself a capital-intensive and scale-intensive activity, to assemble materials and to distribute the growing output to wider markets.[209]

Tangible capital-using and scale-dependent methods again offered a technological path along which the American economy was drawn more strongly, and which American producers could follow more easily than their European counterparts during the late nineteenth and early twentieth centuries. The early sparse settlement of America's virgin lands and its abundant forest resources made American wages relatively high and local labor supplies inelastic. And high wages in turn encouraged the development of the era's capital-intensive mechanical technologies. American land abundance, and the level, unobstructed terrain of the Midwest and trans-Mississippi prairies, especially was well suited to the extensive cultivation of grain and livestock under climatic and topographical conditions very favorable to the mechanization of field operations. None of these developments could be replicated on anything approaching the same comparative scale within European agriculture at the time.

The heavy use of power-driven capital equipment was further supported by the relatively large, rich, and homogeneous domestic market open to American firms. By 1870 the United States already had a larger aggregate domestic economy than any of its advanced competitors. By 1913 the size of the American economy was almost two and one-half times that of the U.K. and three and one-half times as large as France or Germany. America's per capita GDP also topped the other industrial nations in 1913, exceeding that of the U.K. by 5 percent, France by 59 percent, and Germany by 38 percent.

These differences indicate the advantage that the United States enjoyed in markets for automobiles and for the other new, relatively expensive durable goods, to which the techniques of a scale-dependent, capital-using technology (like mass production) especially applied. The American domestic market was both large and well unified by an extensive transportation network. And it was unified in other ways that Europe at the time could not match. The rapid settlement of the country from a common cultural base in the Northeastern and Middle Atlantic seaboard closely circumscribed any regional differences in language, legal systems, local legislation and popular tastes. In fact, Americans sought consumer goods of unpretentious and functional design in

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[209] With some amendment, much of this section and the next follows the argument and evidence of several earlier writers. See the references in the General Bibliography to Rosenberg (1980), Wright (1990), Nelson (1991), David and Wright (1992), Nelson and Wright (1992), and previous work published individually and jointly by the present writers.

preference to products that tried to emulate the more differentiated, elaborate, and custom-finished look of the old European luxury crafts. This taste structure, which was commented on repeatedly at international expositions where American manufactures were displayed alongside the top-quality wares of the Europeans, owed much to the spirit of democratic egalitarianism that prevailed over large sections of American society and to the young nation's freedom from a heritage of feudal and aristocratic traditions and aesthetic values. It fostered the entrepreneurial strategy of catering to and actively creating large markets for the standardized products of large-scale production.

The American development of mass production methods was also encouraged by the country's higher and more widely diffused incomes, which supported an ample domestic market for the new metals-based durable goods. By contrast, Europe's lower and less equally distributed incomes initially restricted the market for such goods to its well-to-do classes, for whom standardized commodities had less appeal in any event, and thereby delayed the full application of American mass production methods.

Yet, with the passage of time these American advantages gradually waned in importance. As aggregate output expanded in Europe, the markets for more industries and products approached the scale required for most efficient production, with plants embodying technologies that had been developed to suit American conditions. Furthermore, the decline in transportation costs and the more liberal regime of international trade and finance that emerged between 1880 and 1913 encouraged producers to use international markets to achieve the scale required. From 1870 to 1913, the average growth rate of exports in continental Europe was 43 percent greater than GDP growth.[210] Of course, there was a still greater expansion of trade during the 1950s and 1960s, when the growth of European exports exceeded the growth of their collective GDP (both in constant prices) by 89 percent. In this era, rising per capita incomes also helped assure that scale requirements in the newer mass-production industries producing consumer and producer durables would be satisfied for a widening range of commodities. As larger domestic and foreign markets appeared, laggard countries could begin to switch in a thoroughgoing way to exploit the capital-using and scale-dependent techniques already explored by the United States. This was a path toward catch-up that would prove to be especially important after World War II, even though it had begun to be followed by some large industrial enterprises in Europe and Japan during the interwar period.[211]

Still another significant cause of the decline in American advantage was a gradual alteration in the nature of technological progress itself. As Part Two has shown, the former bias in the direction of tangible reproducible capital-using, scale-dependent innovations became less pronounced toward the end of the nineteenth century. And in the new century, the direction of innovation, driven in part

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[210] See Angus Maddison, Dynamic Forces of Capitalist Development, Oxford: Oxford University Press, 1991: Tables 3.2 and 3.15.

[211] See Edward F. Denison, Why Growth Rates Differ, Washington, D.C: The Brookings Institution, 1967, Ch.17; Edward F. Denison and William Chung, How Japan's Economy Grew So Fast, Washington, D. C.: The Brookings Institution, 1976: Ch.10.

by the advance of science, began to favor investment in *intangible* assets. In short, the new bias of technological and organizational progress tended to raise the rate of return on investment in the discovery and development of more advanced technology and in the creation of the more highly educated workforce and citizenry needed to make use of it.

These were trends with global dimensions. Europe and Japan exhibited them though with some lag. But it was only with the return of peace after World War II that those societies commenced rapidly to apply techniques that previously had been developed and exploited by American firms. In doing so, they positioned themselves to soon be able to keep pace with, and, indeed, contribute to the further extension of those globally shared technological trajectories contemporaneously.

Social Capability

Even in the later nineteenth century, all of the presently advanced group had certain similar features.[212] All had substantially independent national governments at least as early as 1871. Broadly speaking, all the countries except Japan shared much of the older culture of Western Europe. Most important, all the countries, again excepting Japan, have lived during the entire period under basically stable economic constitutions that provide for a system operated mainly by business enterprises coordinated by markets for goods, labor, capital, and land. In Japan, although a middle class of merchants had arisen even under the Shogunate, the country retained much of its older feudal character until the Meiji Restoration of 1868. Thereafter, however, it was rapidly transformed, and by the turn of the century had established its own form of private enterprise, market economy.[213]

Beyond their economic constitutions, however, noteworthy differences worked to impair the ability of European countries to catch up to the United States during the late nineteenth and early twentieth centuries. Nineteenth-century America presented a contrast with Western Europe in its social structure, its people's outlook, and their standards of behavior. In America, plentiful land offered a widespread opportunity to achieve a satisfactory income by the standards of the time. It fostered a relatively equal distribution of income and wealth and an egalitarian spirit. America's Puritan strain in religion tolerated and even encouraged the pursuit of wealth. The older European class structure and feeling did not survive America's wider dispersion of property and opportunity. Americans judged each other more largely on merit, and, lacking other signs of merit, wealth became the main badge of distinction. America's social and economic circumstances encouraged effort, saving, and enterprise and gave trade and the commercial life in general a status as high or higher than that of other occupations.

While the social background of economic life in the countries of nineteenth-century Europe was of course not uniform, there were certain commonalities in their divergence from American

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[212] See Endnote 2 to Part Three.

[213] See, e.g., Henry Rosovsky, Capital Formation in Japan, 1868-1940, New York: The Free Press, 1961; Ohkawa and Rosovsky, Japanese Economic Growth, 1972.

conditions of the time. In all the European countries, a traditional class structure – which separated a nobility and gentry from the peasantry, the tradesmen, and an expanding middle class – survived into the nineteenth century. Social distinction rested more on birth and the class status it conveyed than on wealth. Insofar as social distinction did turn on wealth, inherited wealth and income counted for more than earned income or the wealth gained by commerce, and landed wealth stood higher than financial wealth and still higher than industrial or commercial. The middle class who aspired to membership in the gentry or nobility bought rural seats and adopted upper-class standards of conspicuous consumption. In short, the social order of Western Europe diluted the characteristic American preoccupation with material success.

These differences in the bases of social distinction – and therefore in the priority assigned to economic attainment – influenced many kinds of behavior that matter for productivity growth. They shaped the occupational choices of both the European gentry and bourgeoisie. When family income was adequate, sons were pointed towards the occupations that the upper classes regarded as gentlemanly or honorific: the military, the civil service, the church and, well behind, the professions. Even in the sphere of business, finance held pride of place, all to the detriment of commerce and industry.

In Europe, a related tradition from pre-industrial times influenced education in a way that reinforced these preexisting patterns of occupational choice. The curricula in the secondary schools continued to emphasize the time-honored subjects of the classics and mathematics; the faculties of Europe's ancient and most prestigious universities dwelt upon these and also theology, law, and medicine. Throughout Europe, university curricula emphasized what was regarded as proper for gentlemen destined for the clergy, the civil service, and the liberal professions.[214] Although training in engineering did win a place for itself in both France and Germany early in the nineteenth century, its character in both countries was theoretical, concerned with preparing an elite cadre of engineer-candidates to serve the state in administrative and regulatory capacities. In contrast, by the late nineteenth century, engineering schools in America clearly had evolved a more practical, commercial and industrial bent.

The striving for honorific status also helped to limit the size of firms because families were eager to confine ownership and control within the circle of close kin. Moreover aristocratic standards of quality and individuality in consumption worked to inhibit the development of standardized goods and mass production, and they supported an extreme fragmentation of retail trade. Similarly, a business ethos that can be traced back to the medieval guilds discouraged aggressive innovation and price competition in favor of maintaining a high standard of quality in traditional product lines. In some countries too – England is a prominent example – class feeling delayed the spread of mass education even at the primary level.

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[214] See, e.g., Alexis De Tocqueville, Democracy in America, vol. II, 1840, (Reprint, New York: Vintage Books, 1945: First Book, Ch. X.

Neither social structure nor outlook, however, remained frozen in their nineteenth-century forms. As economic development proceeded, the social status and political power of European business rose. The occupational targets of middle-class youth gradually shifted. Business and the pursuit of wealth as a road to social distinction (as well as material satisfaction) became more appealing. Entrepreneurs became more familiar with public corporations, more receptive to outside capital as a vehicle for expansion, and more experienced in the organization, finance, and administration of large-scale business. The small, specialized retail shop retained much of its old importance into the 1930s. But after World War II, the big, fixed-price chain stores expanded beyond the beachhead that companies such as Woolworth, and Marks and Spencer, previously had established in Britain. The American-style supermarket, aided by the automobile and the home refrigerator, began to transform European retail food distribution.

The timing of this change around World War II is not accidental; the war itself had a profound impact on social structure and outlook. In the aftermath of the war, great steps were taken to democratize education. State-supported secondary schooling and universities were rapidly expanded, literally hundreds of new university campuses were constructed and staffed, and public support for the maintenance of university students was initiated. For virtually all the new students, careers in industry, trade, banking, and finance became the mecca, not the traditional honorific occupations. In France, even the *polytechniciens* joined industrial firms. Curricula were modified to fit the more practical concerns of this much-expanded student population. Schools of engineering and business administration were founded or enlarged. Even Britain, the perennial laggard in educational reform, responded by opening its new system of comprehensive secondary schools and its new redbrick universities and polytechnical colleges.

The most important change of outlook was in the public attitude towards economic growth itself. In the first half of the century, and particularly in the interwar years, the major concerns had been income distribution, trade protection, and unemployment. After the war, it was growth that gripped people’s imagination, and growth became the premier goal of public policy. Throughout Europe and in Japan, programs of public investment were undertaken to modernize and expand the infrastructure of roads, harbors, railroads, electric power and communications. The demand for output and employment was supported by monetary and fiscal policy. The supply of labor was enlarged by opening borders to immigrants and guest workers. Productivity growth was pursued by enlarging mass and technical education, by encouraging R&D, and by state support for large-scale firms in newer lines of industry. The expansion of international trade, with all its significance for industrial specialization, the equalization of factor prices and the transmission of technology, was promoted by successive General Agreement on Tariffs and Trade (GATT) rounds, and by the organization of the Common Market and the European Free Trade Association (EFTA).

We hold, therefore, that many features of European (and Japanese) social structure and outlook had tended to delay catch-up in the nineteenth century. But these inhibitions weakened in the early twentieth century, and, in the new social and political milieu of postwar reconstruction, crumbled altogether. In the aftermath of World War II, these developments joined to reinforce the vigorous catch-up process that had been released by the new concordance between the requirements of the forms of technology and organization that had appeared in America and the economic characteristics that now obtained in Western Europe and Japan.

Conditions Promoting the Realization of Potential

Following the severe disturbance of production and commerce caused by two world conflicts, the post-World War I barriers to commerce, and by the Great Depression, the return of peace in 1945 proved the beginning of a time when advances in technology and better political policy supported the rapid realization of potential growth.

New conditions favored the diffusion of technology. Transport, communications, and travel became faster and cheaper. Multinational corporate operations expanded, creating new channels for the international transfer of technology, management practices, and modes of conducting R&D. Heavier investment in R&D was encouraged by a closer connection between basic science and technological applications, while the open, international character of much of the basic science research community fostered the rapid dissemination of information about new and more powerful research techniques and instruments that were equally applicable for the purposes pursued in corporate R&D laboratories.

Industry was able to satisfy a growing demand for labor without creating the tight labor markets that might otherwise have driven up wages unduly and promoted price inflation. Some key factors here were that unions had been weakened by war, unprecedentedly rapid labor productivity growth in agriculture was freeing up workers from that sector, and Europe's borders were opened wider to immigrants and guest workers. U.S. immigration restrictions themselves helped to create more flexible labor-market conditions in Europe.

Governmental policies at both the national and international levels favored investment, trade, and the spread of technology. The dollar-exchange standard established at Bretton Woods, together with U.S. monetary and fiscal policy and U.S. capital exports, overcame the initial concentration of gold and other monetary reserves in this country. They sustained a chronic American balance-of-payments deficit that redistributed reserves and ensured an adequate growth of money supply throughout the industrialized world.

These and other matters that bear on the factors supporting "realization" in the post-World War II era deserve more ample description and discussion, which one of us sought to provide on an earlier occasion.[215] We must confine this section largely to the elements of a changing potential for rapid growth by productivity catch-up. Nonetheless, it is important to remember that the rapid and systematic productivity convergence of the postwar years rested on a fortunate historical conjuncture

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[215] For further discussion, see Moses Abramovitz, "Rapid growth potential and its realization: the experience of capitalist economies in the postwar period," in Economic Growth and Resources, vol.1, The Major Issues, Edmond Malinvaud, Ed., London: Macmillan Co., 1979. [Reprinted in Moses Abramovitz, Thinking About Growth, New York: Cambridge University Press, 1989: Ch. 6.

of strong potential for catching-up with the emergence of international and domestic economic conditions that supported its rapid realization.

Many of the elements forming that conjuncture have now weakened or disappeared; most plainly the large productivity gaps that had separated laggards from the leader have now become very much smaller. The break-up of that favorable constellation of forces has slowed both the rate of catch-up and of convergence within the group of advanced countries. The great opportunities for rapid growth by modernization now belong to the nations of Eastern Europe, South and Southeast Asia, and Latin America – *provided* they can overcome the deep-rooted political obstacles and the constraints imposed by their still-deficient levels of social capability.

Among the presently advanced capitalist nations, the question is whether the present substantial equality in productivity levels will long persist. Will a new bend in the path of technical advance again create a condition of superior technological congruence and social capability for one country? Or will conditions that support the diffusion and application of technical knowledge become even more favorable? And will technology continue to pose demands for political and social readjustment and rehabilitation that many countries can meet? For the foreseeable future, convergent tendencies appear to be dominant. But the full potential of the still-emergent age of information and communication and biological and biomedical progress is yet to be revealed. The industrialization of the huge populations of South and Southeast Asia may change the worlds of industry and commerce in ways that are now still hidden.

Afterword: The U.S. Historical Experience and Growth Theory, Old and New

The broad perspective presented here is one that long has informed our collaborative writings on American economic history (and also some of the separately authored works that were developed in the context of that collaboration).[216] It is a view that until very recently has remained unorthodox from the vantage point of growth-theorists working within the standard neoclassical tradition. Yet, it will have been seen also to diverge in some important regards from the characteristic points of emphasis in the literature devoted to "new growth theory."

Of course, this interpretation is fully in sympathy with the emphasis lately being given (by economists in quest of wholly endogenous models of long-term growth) to the role of advances in knowledge flowing from investments in organized research and product development; no less with the renewed attention to the dynamics of specialization and division of labor, and the latter's connections with the realization at the macroeconomic level of economies of scale and scope deriving from access to widened markets.[217] While those themes certainly do figure importantly in the present narrative, its subscription to some distinctive features of the applied macroeconomics literature inspired by "new growth theory" remains decidedly qualified. Several reasons for holding to "a different view" may now be indicated, by way of a conclusion.

To begin with, brief mention should be made of a technical matter that is perhaps of greater interest for time-series analysts than for most readers of descriptive economic history. Nevertheless, it concerns the key notion in our interpretative parables of successive capital-deepening "traverses" that were initiated by non-neutral technological and organizational innovations. Underlying that part of the discourse is an assumption of local dynamic stability, and of consequent convergence to the next steady-state growth path in the historical sequence.

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[216] In addition to joint publications by Abramovitz and David cited in the text and notes above, see Moses Abramovitz and Paul A. David, "Economic Bases of the Rise in Labor Quality," Ch. 8 of *Economic Growth in the US*, Appendix 8-B, Unpublished MS, Stanford University, 1968; Part Three above; also, Moses Abramovitz, "Resource and Output Trends in the United States since 1870," in Thinking about Growth, and Other Essays on Economic Growth and Welfare, New York: Cambridge University Press, 1989; Moses Abramovitz, "The Search for the Sources of Growth: Areas of Ignorance, Old and New," (Presidential Address), Journal of Economic History, 53(2), June 1993, n. 21; David (1975), Ch.1; Paul A. David, "Invention and Accumulation in America's Economic Growth: A Nineteenth Century Parable," in International Organization, National Policies and Economic Development, a supplement to the Journal of Monetary Economics, vol. 6, 1977, pp. 179-228.

[217] See, e.g., Robert E. Lucas Jr., "On the Mechanics of Economic Development," Journal of Monetary Economics, 22(3), June 1988, pp. 3-42; Paul M. Romer, "Increasing Returns and Long-run Growth," Journal of Political Economy, 98(5, part 2), October 1986, S71-S102; Paul M. Romer, "Endogenous Technological Change," Journal of Political Economy, 98(5), October 1990: pp. S71-S102; P. Aghion and P. Howitt, "A Model of Growth Through Crative Destruction," Econometrica, 60, 1992, pp. 323-51; Elhanan Helpman (ed.), General Purpose Technologies and Economic Growth, Cambridge, MA: MIT Press, 1998. See also Steven N. Durlauf and Danny T. Quah, "The New Empirics of Economic Growth," Santa Fe Institute Economics Research Program Working Paper, 1998, for careful discussion of the empirical implications of this literature, and an examination of the international comparative data relating to the post-World War II era.

That, however, is directly at variance with the spirit of the "new growth" models which endogenize all the proximate sources of rising labor productivity, including the growth of knowledge, and thereby escape the constraints of diminishing marginal returns to capital formation. Such models carry the theoretical implication that their dynamic behavior is not *convergent*. The empirical plausibility of adopting our analytical framework is therefore intimately related to the econometric question of the existence or non-existence of unit roots, and other statistical indicators of the persistence of shocks in the extended historical record of aggregate production.

Macroeconomic time-series analysts have been much occupied lately with the latter question. From some of their more recent finding for the U.S. over the period 1870-1990 it appears that within secular epochs that can be distinguished by major trend breaks, the empirical relevance of unit root hypothesis can be rejected by econometric tests. In other words, within the identified epochs – whose durations are of the same order as the "Long Periods" that figure in our account – the dynamic process at the macro level therefore may be treated as essentially convergent.[218] This lends at least a measure of technical statistical support for the assumptions that are embraced implicitly by the particular style of growth-theoretic parable that we find, on other counts as well, to have considerable heuristic value in interpreting of the American economy's long-term performance.

The next point on which we need to qualify the claims of the "new growth theory" to historical relevance concerns the differentiation between the successive American "traverses," a matter that has been central in the argument of the preceding pages. Any pretensions that the popular formulations of endogenous growth theory might possess empirical validity of a historically general and universally valid sort, simply fails to find support in the American experience. In particular, the key role in raising labor productivity and per capita real income that is now accorded to *increases* in average educational attainment and the growth of human capital-intensity more broadly, cannot be squared with the quantitative picture of U.S. economic progress throughout much of the *nineteenth* century. Maintenance of a high level of literacy in important sections of the population may have had a good bit to do with establishing a growth path characterized by high levels of labor

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[218] See, e.g., the work of C. D. Romer, "The Pre-War Business Cycle Reconsidered: New Estimates of GNP, 1869-1908," Journal of Political Economy, 97, 1989, pp. 1-25, and other contributions reviewed in D. Greasley and L. Oxley, "Explaining the United States' Industrial Growth, 1860-1991," Bulletin of Economic Research, 48, 1996b, pp. 65-82. The latter report on their own analysis of the annual industrial production series for the U.S. from the 1860s onwards, derived from W.G. Nutter's series (Growth of Industrial Production in the Soviet Union, Princeton, NJ: Princeton University Press for the NBER) based on the Frickey index, which they spliced with the Federal Reserve index of industrial production in 1919. When dummy variables are introduced to allow for structural discontinuities affecting the trend, significant "breaks" are found c. 1901 and c.1973, the former being the most pronounced. If that is treated as exogenous, Greasley and Oxley's (1996) statistical tests reject the existence of a unit root in U.S. industrial production. They point out that C. R. Nelson and C. I. Prosser's ("Trends and Random Walks in Economic Time Series," Journal of Monetary Economics, 10, 1982, pp. 139-162) contrary finding of "difference stationarity" in the U.S. industrial production data for the century preceding 1965 was based on an analysis that assumed trend stationarity. These findings are thus broadly consistent with the interpretation here, for we contend that the 1890-1905 era marked a watershed between two structurally distinct epochs of U.S. macroeconomic growth, and implicitly assume that convergent traverses were underway during the more extended periods before and following that interval, i.e., c.1835-c.1890, and c.1905-c.1989.

productivity and per capita consumption. But, that says nothing directly about education's contributions to a faster rate of growth in economic well-being. Furthermore, quite a number of studies of the nature of schooling and the extension of basic literacy and numeracy in antebellum America have raised substantial doubts about the immediate relevance of the cognitive content of education to the processes through which the productivity of the workforce was being enhanced in that era.[219] By comparison, the accumulation of workplace experience appears to have been a more important determinant of differential earnings rates.[220]

Continuing further in this vein, it would seem that there is a greater measure of empirical support – from detailed studies of the transformation of industrial technology at the plant and firm level during the nineteenth century – for putting major emphasis upon learning-by-doing as a source of increasing industrial efficiency. This, it might be recalled was the main message imparted by the pioneering economic growth literature on endogenous sources of technological advance, long before

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[219] On the consistency of this view with evaluations of the role of human capital formation through formal education in the industrial revolution in Britain, see Peter Mathias, The First Industrial Nation, London: Methuen, 1984. On the relevance of the cognitive content of the formal school curricula in the US during the nineteenth century, see e.g., Albert Fishlow, "The American Common School Revival, Fact or Fancy?" in Henry Rosovsky (ed.), Industrialization in Two Systems, New York: John Wiley and Sons, 1966; on nineteenth-century investment in education see Albert Fishlow, "Levels of Nineteenth Century American Investment in Education," reprinted in Fogel and Engerman (eds.), The Reinterpretation of American Economic History, 1971, pp. 265-73. Journal of Economic History, 1966: pp. 418-36; on education, "socialization" of the work force, and factory discipline in mid-century, see A. J. Field, "Educational Expansion in Mid-Nineteenth Century Massachusetts: Human Capital Formation or Structural Reinforcement?" Harvard Educational Review,46(4), November 1976; A.J. Field, "Economic and Demographic Determinants of Educational Commitment: Massachusetts, 1855," Journal of Economic History, 39(2), June 1979, pp. 439-59. For quantitative studies showing the absence of strong, or even weak statistically significant education-associated wage differences among manufacturing employees in northern and southern cotton textile mills in the nineteenth century, see Harold S. Luft, "New England Textile Labor in the 1840s: from Yankee Farmgirl to Irish Immigrant," Harvard Business School, unpublished working paper, 1971; Thomas Dublin, Women at Work: The Transformation of Work and Community in Lowell, Massachusetts, 1826-1860, New York: Columbia University Press; Cathy McHugh, Mill Family: The Labor System in the Southern Cotton Textile Industry, 1880-1915, New York: Oxford University Press, 1988. But see also, Susan A. Matthies, Useful Children: An Economic Study of Child Workers in the Cotton Textile Industry, 1900-1910, Unpublished Ph.D. Dissertation, Stanford University, 1991, Ch.5, for findings of positive schooling effects on earnings rates among child workers in the southern states, and northern states (separately), early in the twentieth century.

[220] In addition to the qualitative indications, there is also some econometric evidence pointing to the significant role of experience-based "learning-by-doing" among the microeconomic sources of rising labor productivity, and real earnings rates reflecting the accumulation of individual worker experience, particularly in textiles manufacturing. See, e.g., Paul A. David,"Learning by doing and tariff protection: a reconsideration of the case of the United States cotton textile industry," Journal of Economic History, 30(3), September 1970; Paul A. David, "The Use and Abuse of Prior Information in Econometric History, A Rejoinder to Professor Williamson on the Antebellum Cotton Textile Industry," Journal of Economic History, vol. 32 (3), September 1972, pp. 706-727; Paul A. David, "The 'Horndall Effect' in Lowell, 1834-1856: A Short-Run Learning Curve for Integrated Cotton Textile Mills," Explorations in Economic History, vol. 10 (2), Winter 1973, pp. 131-150. Significant experience effects on differential worker earnings are reported for the cotton textile industry by Luft, "New England Textile Labor,"(1971), McHugh, Mill Family (1988), and Matthies, Useful Children (1991).

the current popularity of mathematical models of "endogenous growth."[221] More recently, Gavin Wright (1998) has elaborated the idea of learning-by-doing in social network environments, and argued that the formation and transmission of particular design traditions, and characteristic approaches in industrial and mineral engineering, constituted a "social learning process" that was national in its scope, and which, by the early twentieth century, had created a technological culture that was distinctively American.[222]

Considering the matter from the perspective of the nineteenth century U.S. economy, then, the particular mechanisms seen by "new growth theory" as driving the process of productivity improvement and rising real per capita income appear at best to have very little explanatory power. Perhaps not surprisingly, this assessment accords with the overall judgement reached by N. F. R. Crafts' (1993) evaluation of these endogenous growth models' relevance in accounting for Britain's growth experience during the epoch of the Industrial Revolution.

But what of the more recent past, the modern experiences of the U.S. and other already advanced industrial societies, experiences that are more likely to have informed the "new" growth theory? Here the previously noted qualifications are no longer appropriate. The emphasis accorded to intangible capital formation through education, and investment in organized R&D certainly is warranted, as is the insistence that the mobilization of resources for those purposes has been at it base a response to perceived economic payoffs. But the need to register some other qualifications remains. Among these we should note doubts regarding the implicit, and sometimes explicitly

[221] A. Alchian, "Reliability of Progress Curves in Airframe Production," Econometrica, xxxi (October 1963), pp. 679-73; Kenneth J. Arrow, "The Economic Implications of Learning by Doing," Review of Economic Studies, 29(2), 1962; Robert M. Solow, "Investment and Technical Progress," in K.J. Arrow et al. (Eds.), Mathematical Methods in the Social Sciences, 1959, Stanford: Stanford University Press, pp. 89-104, 1960; Robert M. Solow, "Perspectives on Growth Theory," Journal of Economic Perspectives, 8(1), Winter 1994, pp. 45-54 are classics among the more theoretical contributions in this vein. In addition to much richly detailed descriptive material in standard historical sources for the period, such as Clark (1929) and Kirkland (1955), a number of econometric findings identifying "learning effects" in integrated cotton textile production (power spinning and weaving mills), mechanized shoe factories, and blast furnace and rolling mill operations, may be mentioned in this regard. See Paul A. David,"Labour Productivity in English Agriculture1850-1914: Some Quantitative Evidence of Regional Differences," Economic History Review, vol. 23 (3), December 1970, pp. 504-514; Paul A. David, Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the Nineteenth Century, Cambridge and New York: Cambridge University Press, 1975, Chs. 1, 4. (Second Edition forthcoming in Fall 1999 from Cambridge University Press); Peter Berck, "Hard Driving and Efficiency: Iron Production in 1890," Journal of Economic History, 38(4), December 1978, pp. 879-900, and Ross Thompson, The Path to Mechanized Shoe Production in the US, Chapel Hill: University of North Carolina Press, 1989.

[222] This view is not unrelated to the theme of American economic exceptionalism having contributed to shaping technology in ways that were "congruent" with national market characteristics and resource endowments that were not replicated elsewhere during the nineteenth and early twentieth centuries. See Moses Abramovitz and Paul A. David, "Convergence and Deferred Catch-Up: Productivity Leadership and the Waning of American Exceptionalism," Ch. 2 of Ralph Landau, Timothy Taylor and Gavin Wright (eds.), The Mosaic of Economic Growth, Stanford, CA: Stanford University Press, 1997.

formalized assumption that there exists a global stock of technologically relevant knowledge, the pace of additions to which remain highly elastic to the input of national research efforts.

Studies of the determinant of company investment in R&D in the post-World War II era repeatedly have pointed to the importance of "science-based opportunities" as well as to conditions affecting private appropriability of economic returns in affecting the pattern of research intensities across industrial sectors. But what these investigations of inter-industry differences also reveal is that where the positive statistical association between high ratios of R&D to sales and the growth rate of input efficiency emerges, the latter is largely accounted for by the indicators of strong "science-based opportunities."[223] In other words, whereas the burden of the macroeconomic formulations of the "new growth theory" has been to tell us that rapid technological advances can be endogenously generated by the investment of resources in R&D which does not encounter diminishing marginal returns, the available indications at the industrial and line-of-business level suggest that this is more true of the long-run than it is over the near term; "opportunities" for profitable investment are more constrained by the slow, incrementally transformed and path-dependent state of the existing fundamental scientific and engineering knowledge-base.

Furthermore, the growth of that knowledge-base, although surely substantially subject to economic forces over the long run, cannot usefully be portrayed – as it is in many formal models of the “new” genre – as being determined "endogenously" by the behaviors of individual agents and organizations working wholly within the context of a particular, informationally insulated (and isolated) national economy. It is, rather, a construction of the larger international systems of knowledge generation and dissemination, to which public and privately-funded research activities taking place under a variety of economic and political conditions have been contributors. This may pose a more daunting challenge than the new growth theory has accepted thus far. Yet, for some long time the way forward in theorizing about economic growth has tended to lie along the trail blazed, however roughly, by students of quantitative economic history. It would seem fruitful to continue further along that path by explicitly modeling the interactions among the knowledge-intensive economies.

Lastly, we come to a point on which the perspectives of “new” and “neoclassical” growth theorists tend to coincide, namely, in the undertaking to apportion responsibility for the growth of an economy’s productive capacity among distinct contributory factors, or “proximate sources of growth.” Taken at face value as an exercise in “growth accounting” there is nothing in this enterprise to which one could object in principle (the accuracy of the assumptions underlying the measurement procedures employed is another matter, to be sure). Yet there is something vaguely self-contradictory about emphasizing the importance of seeing all aspects of the growth process – technological

[223] See e.g., F.M. Scherer, “Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions,” in Innovation and Growth, Cambridge MA: The MIT Press, 1984, Chap. 9; Richard R. Nelson and Edward N. Wolff “Factors Behind Cross-Industry Differences in Technical Progress,” NYU Economics Department working paper, 1996.

innovation included – as “endogenous” economic processes, while carrying out calculations that seemingly accept the standard accounting approach as an informative explanatory framework.

Such clarity as the latter are able to achieve by assigning quantitative measures of absolute and relative “importance” to the various sources of the growth of real output (whether on an aggregate or a per capita basis) derives in reality from the growth accountant’s willingness to hew to a particularly simplified view of the workings of the economy: namely, to treat the identified set of “proximate sources” as though they operated quite independently of one another. That procedure rests on notions of the “neutrality of innovation” as constituting the typical state of affairs. By contrast, we have sought to put those notions firmly aside in favor of a more throughly “endogenous” interpretation of U.S. macroeconomic history, one that recognizes the shifting complex of forces which continue to make novelty and structural change the essence of long-term economic progress.

ENDNOTES

I. Endnotes for Part One

1. Our table of growth rates across "long periods" is constructed by calculating weighted averages of growth rates that combine long swing intervals during which growth was slow with those of the following long swing intervals when growth was more rapid. We regard the second swing of each pair as, in part, a rebound from the first. We might at the same time have calculated averages that combine long swings of rapid growth with following periods of slower growth. The "relapse" case for such combinations, however, is weaker. In business cycles, for example, there is a strong correlation between the severity of contractions and the strength of subsequent recoveries, but not the reverse. In any case, a comparison of our long-period series with a two-period moving average of growth rates across long swings yields the very same picture of a long acceleration beginning with the second half of the nineteenth century and continuing into the long-swing interval following World War II. There is only this difference between our series of long-period growth rates in column (2) of the following table and the moving-average series in column (5). With our procedure, the severe slowdown of the last quarter-century stands out clearly. In the moving-average series, the slowdown is hidden in an average of the growth rate from 1946 to 1966 with that from 1966 to 1989. We prefer our procedure.

Real Private GDP per Manhour: Growth Rates Across Alternative Periods

Long-Swing Intervals[1]		Long Periods[2]		Two-period Moving Average Long-Swing Intervals[3]	
		I. Nineteenth Century			
1800-35	0.41				
1835-55	0.366	1800-55	0.39	1800-55	0.39
1855-71	0.14			1835-71	0.27
1871-90	1.84	1855-90	1.06	1855-90	1.06
1890-1905	1.36			1871-1905	1.63
1905-27	2.45	1890-1927	2.01	1890-1927	2.01
		II. Twentieth Century			
1890-1905	1.93				
1905-27	2.05	1890-1927	2.00	1890-1927	2.00
1929-48	1.96			1905-48	2.01
1948-66	3.11	1929-66	2.52	1929-66	2.52
1966-89	1.23	1966-89	1.23	1948-89	2.05

[1]1800-35 and 1835-55 calculated from GDP per capita from David (1996). Table 7, Frame B, together with Population Growth from Historical Statistics and Full-time equivalent manhours from David (1996) Table 2.1. 1800-55 and 1855-1989 from Table IIA, above.
[2]From Table II above.
[3]Calculated from Col. (1) in this table.

2. Professor Solow, however, was not the first to attempt measures of crude TFP; priority belongs to Jan Tinbergen who published his results in 1942 in an article little noticed until years later. He was followed by others who studied TFP in the aggregate economy: Fabricant in 1954 and one of the present writers, Abramovitz, in 1956. Both Fabricant and Abramovitz depended on methods and data worked out by John Kendrick, whose great book on productivity trends appeared in 1961. Meanwhile still others made similar studies confined to manufacturing or agriculture. Zvi Griliches' "The Discovery of the Residual: A Historical Note", Journal of Econ. Literature, xxxiv, No. 3 (Sept. 1996), 1324-30 may be consulted for a compact historical note on the discovery of the residual.

3. A major assumption is that the returns to the factors of production do not vary with the scale of the economy, provided that factor proportions are constant. Insofar as there really are returns to scale, the factor shares used as weights in the formula will not exhaust the product, and the gains from economies of scale thus neglected in the contributions of the factors will then form part of the TFP residual along with the gains from the advance of knowledge proper and other unmeasured sources.

4. These observations suggest that the shift from an era when tangible capital accumulation was the major source of labor productivity growth to one when total factor productivity growth became dominant took place around the turn of the century. This conclusion, however, depends on the definition of "long periods" on which Table IV is based. Those who prefer instead to look at the measures across "long swing intervals" in Table IVA might reach a different conclusion and place the change a generation earlier in the long-swing interval, 1871-90.

We reject that view. We do not see the negative figure for TFP in the period spanning the Civil War as a measure of the long-term forces shaping the economy. We regard it rather as an index of the cost of the war itself, which includes not only its physical destruction, commercial disruption and inflationary finance, but also the costs of its aftermath, of demobilization, disinflation and Southern Reconstruction.

The period that followed (1871-90) saw a sharp rebound from these disturbances in which many developments took place that except for the War might have begun earlier and been carried out more slowly. The decades following 1870 saw the extension of the railway net, the resumption of westward expansion, a large increase in immigration and the reorganization of corporate scale and structure to take advantage of the emerging potential of technological progress and the economies of the country's growing scale – all of which was, in part, the more concentrated exploitation of a backlog of opportunity that had accumulated during the years of war and financial and commercial disruption. So we think that the combination of the two subperiods as in Table IV is a useful way to depict the underlying trend of growth and its sources.

The changes in the growth rate of the aggregate capital stock – as distinct from the growth of capital per manhour – is part of the same story. Between 1835 to 1855 and 1855 to 1871, the growth rate of the aggregate capital stock fell by 19 percent. As a result, the average age of the capital stock would have risen, and since most innovations in technology must be embodied in tangible capital, the pace at which new knowledge is actually incorporated into production would have been reduced. The low level of TFP growth in the period crossing the Civil War is due in part to the impact of the War and its aftermath on the rate of capital formation. Then between 1871 and 1890, the growth rate of the capital stock speeded up – by 32 percent – with the effect of reducing the average age of the stock, increasing the rate of incorporation of new knowledge into production and raising the growth rate of TFP. There is an analogous development later during the long-swing intervals 1929-48 and 1948-66. In that case, we estimate that this "vintage effect" was responsible for 30 percent of the acceleration of Labor Productivity growth between the two periods. This is probably a lower bound. The effect may have been greater. See the discussion in the Appendix note on the vintage effect below.

5. Various studies have used these methods with different degrees of refinement. Edward Denison's estimates, on which we rely for the years from 1890 to 1966, follow the methods just outlined. Denison, however, tried to make some allowance for worker characteristics generally correlated with schooling but not in themselves attributable to education, e.g. IQ and parents' income and education. Such statistics as he could bring to bear suggested some 15 to 20 percent of differences in earnings between levels of education are, in fact, due to these correlates of education. He adjusted his weighting scheme accordingly and, of course, reached a smaller estimate of the contribution of education than he otherwise would have done.

The estimates of the BLS on which we rely for the years since 1966 are made by methods more refined than Denison's in some respects. The BLS classifies manhours, not by age, but by "experience," that is by the number of years in employment after the end of formal schooling. More important, it classifies manhours into age-sex-education cells and weights the hours in each such joint cell according to the average earnings of workers who share the same three characteristics. The interactions among the three are thereby taken into account.

6. Over the years between 1925 and 1989, the constant cost value (1987$) of the stock of equipment increased from 26 percent of the total of fixed non-residential private capital to 48 percent. The service lives used to determine values by the BAE ranged from 7 to 33 years for different types of equipment and between 30 and 54 for different types of structures (except for "mobile offices," 16 years). The actual average age of equipment was almost exactly one-half that of structures in both 1925 and 1989. (Bureau of Economic Analysis, 1993.)

7. The enrolment figures for 1850 are from the Census, as reported in Historical Statistics of the United States, Series H433. The slow rise from 1800 to 1850 conforms to less comprehensive evidence presented by Albert Fishlow in "The American School Revival: Fact or Fancy"? In Industrialization in Two Systems, edited by Henry Rosovsky, New York: John Wiley and Sons, 1966. The data on school attendance are from the U.S. Department of Education, Digest of Educational Statistics, 1965, Table 5.

8. Some economists argue that the economies associated with the growing scale of the economy can be and should be separately identified and measured. This was the position of Edward Denison (1974), one of the notable pioneers of growth accounting, and his opinion is shared by others, for example Angus Maddison (1987). In this view, the growth of market scale creates a potential, within the bounds of known and available technology, to reduce costs by organizing the production of a given mix of goods and services in firms of larger scale, by increasing the number of distinct, but related, goods produced by a single enterprise which can usefully spread a common burden of overhead (economies of scope) or by confining the activity of firms to the production of a narrower, more specialized variety of goods but doing so on a larger scale – all subject to the sole proviso that the scale of the market expands. (Cf. Denison, 1974, pp. 71-75.)

This is a view which, in one form or another, has been the standard doctrine of economics since the time of Adam Smith, and we too believe that growing market scale creates a potential for productivity growth. Indeed this view is an essential part of an interpretation of modern American growth experience, as a later section will contend. Yet we do not believe that measures of the Economies of Scale should appear as a distinct source in our growth account, separate from technological progress itself. There are two general reasons.

First, no reliable measures have yet been devised. Edward Denison himself (1974, 1985) has, indeed, proposed a measure based on the assumption that the economies of scale bear a simple relation, uniform over time, to the growth of aggregate national product in the private, non-residential sector of the economy. It seems clear, however, that other factors must have a share in determining the effective size of markets – notably, the facilities for transportation and communication, both within the country and with other countries, the class and regional differences in incomes, education and tastes that control the public's tolerance for standardized commodities and services and, indeed, the success of enterprises in their merchandising efforts to create the markets for standardized goods. Since all these conditioning factors have changed substantially in the course of the two past centuries we think that the notion that there existed a stable relation between aggregate output and the economies of scale may be safely put out of mind.

Our own view, shared with others, is that the gains from an expansion of markets are not validly separable from the advance of knowledge itself. On the one hand, we believe that, for the most part, the productivity growth associated with growing scale is similar in nature to technological progress in that its potential benefits can be realized only as the result of a learning process. How to organize the production and markets of firms efficiently on a large scale or in more specialized activity is not generally known in advance, but must be learned by actual practice and experience, and sometimes by deliberate research and development. In addition, we hold that the technological advances of the last two centuries – and perhaps more particularly those of the nineteenth century – have been to a large degree scale-dependent. They could be incorporated into production only insofar as the scale, integration and specialization of firms became larger. The practical realization of the advances of knowledge, therefore, has been limited not only by the extent of markets, but also by the effort and costs required to learn how to create and exploit larger markets effectively.

9. Some growth accountants, for example, have treated movements of labor and capital among industries in which average earnings are different as an independent source of growth of output and factor productivity (Kendrick, 1961, 1973; also Denison, 1974, 1985, but only in the special case of the movement of farm labor on poor farms to nonfarm occupations). Such calculation would be justified only if average earnings differentials among industries were instances of disequilibrium differences between, say, workers of given age, sex and level of education. Our own view, however, is that, for the most part, average earnings differentials across industries stem from differences in the sex, age and educational composition of their workforces. If, therefore, one has allowed for the contributions of overall changes in sex, age and educational composition, as we have done, there would be double counting if we allowed as well for inter-industrial shifts of labor among industries in which average earnings are different.

S.N. Broadberry (1996) has presented estimates of the importance of shifts in industrial composition following a different plan. His goal is to distinguish the growth rate of aggregate productivity attributable to the growth of productivity within sectors assuming that the share of each sector in total output remains constant from the growth of productivity attributable to change in the importance of each sector, assuming that the relative levels of productivity in the various industries remain constant. (His formulae for carrying out this decomposition were first presented by Wm. N. Nordhaus (Brookings Papers on Economic Activity, 1972, No. 3, Appendix A). Broadberry's most striking finding is that only 55 percent of aggregate productivity growth was attributable to "within-sector" growth in a period running from 1870 to 1913; the other 45 percent was associated with shifts in the sectoral composition of output. In the later periods used by Broadberry, however, sectoral shift became less important, (1919-37, 33 percent; 1950-90, zero).

We have ourselves experimented with such a decomposition, using a somewhat different formula of decomposition, data sources consonant with the aggregates used elsewhere in this chapter and periods that are the same or similar to those used in the other tables of this chapter. Our own estimates of "within-sector" productivity growth as percentage of aggregate productivity growth follow:

1869/78-1913	**1913-1929**	**1929-1948**	**1948-1966**	**1966-1989**
56	87	80	95	92

The results suggest that it was only between 1870 and 1913 that compositional change was of first-rate importance, and over that period our estimate is almost exactly the same as Broadberry's. From 1913 to 1948 such shifts were a minor component of the total. And after 1948, they counted for little. The significance of structural shift even in the period when it was a large component, however, depends on the idea that the sectoral shifts arose from causes that were independent of the sources of sectoral differences in productivity growth itself (which included both the differential growth in capital-intensity and the differences in technological progress underlying that). Thus, it is important to notice that Broadberry's descriptive decomposition analysis has not established the role of inter-sectoral shift effects upon the rise of the TFP residual in the period 1870-1913, or in the other trend intervals.

Between 1870 and 1913, the shifts were of two sorts. There was a large drop in the share of agriculture in output and employment when the level of productivity in that sector was low and large gains in the importance of mining, manufacturing, transport and trade where levels of productivity were higher, in some cases much higher. The decline of agriculture was a normal consequence of the usual inelasticity of the demand for food in a time of rapidly rising per capita output and income (the "Engel effect"). The rise of mining, manufacturing, transportation and communication and trade, on the other hand, was, in part, simply the complement of the decline of agriculture as incomes increased and, in part, the economy's response to the character of the era's rapid technological progress, which was minerals-intensive and capital-using, but scale-dependent. It demanded a heavy use of mineral and capital equipment but also much transport and communication to support operations on an ever-larger scale. All this is a central theme of Part Two. For the time being, perhaps it is enough to say that the "sectoral shift effect" may simply reflect one of the channels through which "biased" technological progress of this era affected the pattern of aggregate input use, by altering the structure of consumption and the industrial composition in the economy.

10. The summary in Part One, Section 6 describes the best quantitative profile of U.S. nineteenth-century growth that we are able to draw, but it is not the only such picture of that era. Robert Gallman, whose fundamental reconstruction of the U.S. domestic product accounts for the 1834-1909 era underlies our own work, presents a notable alternative

statistical view in his chapter in Volume 2 of The Cambridge Economic History of the United States [hereinafter CEHUS, vol.2,].

(a) The Gallman figures, like our own, show a large rise in the contribution of the capital stock between the early part of the nineteenth century and the later part. It is 2.4 times as large between 1840 and 1900 than between 1800 and 1840. Its importance as a source of per capita GNP growth rises by 44 percent.

(b) TFP growth, which appears as the source of 61 percent of per capita GNP growth before 1840 in the Gallman estimates, falls to 47 percent from 1840 to 1900, which again is in accord with the direction of change in our tables although more muted in quantity.

(c) Most important of all perhaps, the striking increase between the centuries in the importance of TFP growth, which stands out so prominently in our picture, would appear as well if the Gallman figures for the nineteenth century were substituted for our own. If we depend on our own figures for the second half of the nineteenth century, TFP growth in the early part of the twentieth century was 3.5 times as fast. In the long mid-section of the twentieth century, it was almost 4 times as fast. Using the Gallman figures for the second half of the nineteenth century, the comparable twentieth century relatives are 1.8 and 2, a large acceleration even if smaller than our own.

Thus, in Gallman's tables, TFP accounts for a larger proportion of the growth of per capita output in the nineteenth century and both labor and capital for smaller fractions. These differences are more pronounced in the early part of the century than they are in the later. At the same time, there are resemblances between the Gallman estimates and those presented here, which concern matters that underlie our interpretation of changes in the sources of growth between the two halves of the nineteenth century, as well as between the two centuries.

The differences between the Gallman figures and our own reflect many differences in the procedures upon which the estimates are built. There are two principal differences:

First, Professor Gallman depends on the number of persons in the Labor Force to represent Labor Input. We estimate the annual aggregate number of hours of work. Our figures thus allow for changes in the persons engaged per member of the Labor Force and for hours of work per person engaged per year. It is a drawback of our procedure that persons engaged and hours of work can only be estimated very roughly. In the nineteenth century, however, when labor was shifting rapidly from Farms to Nonfarm jobs in which annual hours were higher, we think labor input was faster than the growth of the labor force above suggests. Our labor input, therefore, rises faster than Professor Gallman's, and total factor productivity growth is correspondingly slower.

Second, in the Gallman account, the shares of income, and thus the relative weights assigned to the growth of labor and capital, are the same in both halves of the century. Our own weights are the same as Professor Gallman's in the first half of the century. In the latter half, however, our estimate of capital's income share is higher and labor's lower. And since capital's growth was faster than labor's, the effect is again to raise the contribution of total factor input in our account and so to reduce our estimate of the growth rate of TFP.

There are still other differences that arise because our dividing line between the two halves of the century is 1855; in Professor Gallman's account it is in 1840. We end the nineteenth century in 1890, which, in accord with our practice, is the midyear of the quinquennium at the end of a long-swing expansion. Professor Gallman's terminal year is 1900. The following tables are designed to bring out the major sources of difference between the two accounts of the pace and proximate sources of the pre-1900 growth of "real output per capita."

To increase the immediate comparability between the estimates underlying our tables and the figures that appear in Table 7 of Gallman's chapter, we follow him here in taking GNP per capita as the measure of output (rather than GDP or GPDP). Similarly, throughout the step-by-step sequence of growth rate comparisons below, we work with his major period for the nineteenth century, 1800-40 and 1840-1900, rather than the more complicated periodization we have developed – with the aid of underlying annual real GDP estimates for the years 1834-1909 which rest primarily upon Professor Gallman's own pioneering research, as the Appendix on statistical sources describes.

In Panel A, we apply Gallman's income shares to the growth rate of Labor Input and Capital Input (including Land). These are Labor: 0.68 and capital 0.32, and are the same in both periods. We denote our figures as A&D.

Panel A: Comparison Adopting Gallman's Labor Input Concept and Standard Factor Shares

	Output Growth Rates and Contributions to Per Capita GNP Growth		Differences: Gallman-A&D	
	1800-1840	**1840-1900**	**1800-1840**	**1840-1900**

	Gallman	A&D	Gallman	A&D		
GNP	0.90	0.68	1.52	1.46	0.22	0.06
Labor	0.07	0.06	0.12	0.24	0.01	-0.12
Capital	0.28	0.22	0.69	0.63	0.06	0.06
TFP	0.55	0.40	0.71	0.59	0.15	0.12

These figures indicate that with these uniform assumptions the chief difference is in the rate of GNP growth between 1800 and 1840, and it is this, allowing for trifling differences in the inputs, which accounts for the higher TFP figure in the Gallman column. In the years 1840-1900, the GNP figures become very similar and the TFP difference, small even in the early period, becomes even smaller.

In Panel B, we use Labor Input figures in the A&D column based on Hours of Work, but continue to use the Gallman factor share:

Panel B: Comparison Retaining Gallman's Standard Factor Shares

	Output Growth Rate and Contributions to Per Capita GNP Growth				**Difference: Gallman-A&D**	
	1800-1840		**1840-1900**		**1800-1840**	**1840-1900**
	Gallman	A&D	Gallman	A&D		
GNP	0.90	0.68	1.52	1.46	0.22	0.06
Labor	0.07	0.28	0.12	0.35	-0.21	-0.23
Capital	0.28	0.22	0.69	0.63	0.06	0.06
TFP	0.55	0.18	0.71	0.48	0.37	0.23

Now Labor Input in the A&D columns is faster; this enlarges Total Factor Input and reduces TFP. The difference between the Gallman TFP growth and the A&D becomes larger.

In Panel C, we continue to measure Labor Input in the A&D columns by hours of work, but now we apply A&D factor shares to the growth rates of the factors in the A&D columns. This makes no difference in 1800-1840; our shares are the same as Gallman's. In 1840-1900, the A&D factor share of Capital rises to 0.44, while the Labor share falls to 0.56.

Panel C: Comparison Showing Combined Effect of Differences in Labor Input and Share Weights

	Output Growth Rates and Contributions to Per Capita GNP Growth				**Differences: Gallman-A&D**	
	1800-1840		**1840-1900**		**1800-1840**	**1840-1900**
	Gallman	A&D	Gallman	A&D		
GNP	0.90	0.68	1.52	1.46	0.22	0.06

Labor	0.07	0.28	0.12	0.29	-0.21	-0.17
Capital	0.28	0.22	0.69	0.87	0.06	-0.18
TFP	0.55	0.18	0.71	0.30	0.37	0.41

The differences between the Gallman and A&D figures from 1800 to 1840 remain the same, of course, as they were in Panel B. In 1840-1900, the A&D labor contribution declines by .06 percentage points, but the AD capital contribution rises by 0.24 points. The A&D TFP estimate is, therefore, reduced by the difference. Manifestly, this change in the factor shares (and corresponding input weights) helps account for the striking rise in Capital's contribution in the A&D growth account between the first and second halves of the nineteenth century, for the especially slow TFP growth in the second half and for the fact that the acceleration in TFP growth between the second half of the nineteenth century and that in the twentieth century shown by our estimates is even sharper than Gallman might find.

11. There were important quality changes even in the basic necessities, and these too were mainly a twentieth-century development. As late as 1940, some 45 percent of all housing units still lacked complete plumbing facilities. The fraction was certainly much higher in 1900. By 1990, however, it was just 1.1 percent (Census of Housing as reported in Statistical Abstract, 1994, Table 1214). There were other developments as well. Synthetic textiles, which first became of some importance in the 1920s brought consumers new varieties of garments, cheaper, more durable, more colorful and easier to clean than the old. New developments in the preservation and purity of foods and beverages were important in both centuries.

12. The underlying figures for years of expected life for white males run as follows:

	At birth	At 40	At 70
1900-02	48.2	27.7	9.0
1929-31	59.1	29.2	9.2
1991	72.7	35.6	13.9

Source: Historical Statistics, Tables B116 to 124; Statistical Abstract, 1994, Table 116.

13. The survival prospects for the members of the (white) male birth cohort starting life in 1991 have improved remarkably, as has been noticed, but their prospects for per capita real income growth – over the expected 73 years that the mortality table for that year would allow them – remain especially cloudy. If the 1966-89 growth rate of real GNP per manhour is projected into the future, implicitly assuming that manhours per capita remained constant, they might anticipate experiencing an average lifetime gain of only 144 percent, or substantially less than that enjoyed by the 1930-1 birth cohort. On the other hand, implicitly assuming that the lowered rate of labor productivity growth over the 1966-89 period is transitory and there will be some rebound, the (higher) growth rate of GNP per capita during 1966-89 could be projected forward, indicating a gain of 237 percent between 1991 and the year 2064. When we take the geometric average of these pessimistic and optimistic estimates, the "golden mean" figure turns out to be an expected lifetime average real income gain of 184 percent, which is, more or less, a satisfying continuation of the experience of the 1929-31 birth cohort. Of course, more of that projected proportionate measure of material improvement would be "enjoyed" by the 1991 cohort when they are at older ages. And, indeed, a larger part of it is likely to take the form of health care services.

14. Measurement reform to take account of new and improved types of capital goods is thought by some economists to mean not only a change in the growth rate of output, but also a change, for purposes of growth accounting, in the calculated measure of the capital stock as a source of output growth. The appearance of new forms of capital goods, however, is due to the progress of knowledge and its incorporation into production. To incorporate the result of such change into measures of capital as a source of growth, therefore, would be wrong. The new forms of capital goods are themselves the expression of the growth of knowledge. To inject the results of such progress into our measures of capital accumulation in the growth accounts would be to confound the contributions of the capital stock with those of

technological progress. The proper practice is to apply the results of measurement reform to estimates of output growth but not to those of the capital stock in a growth account. Edward F. Denison provides a thorough and perceptive critical discussion of the problem in his Estimates of Productivity Change by Industry, Washington, D.C.: The Brookings Institution, 1985: esp. Ch. 2.

II. Endnotes for Part Two

1. The definition of "neutrality" given by the text, specifying that technological innovations have no effect on the relative input mix (given unchanged relative input prices), is strictly speaking referred to as "Salter-neutrality" – as it is due to W.E.G. Salter (1962). This definition usually is applied in describing technical changes at the level of the individual production unit, or the industry, where it may be supposed that the choice among available techniques is made by firms that are price-takers in the markets for their inputs. But it can serve equally well for descriptive purposes at the macro-level, in the context of our acceptance of the aggregate production function metaphor.

The dual concept of the Salter-neutrality focuses explicitly upon the demand-side macro-level impacts of technological change in the input markets, and so considers the influence upon relative rates of factor remuneration (or more generally on relative productive asset prices), when aggregate relative factor proportions remain unchanged. This concept was introduced by John R. Hicks (1934). Under "Hicks-neutrality," innovation changes the marginal productivities of all inputs in exactly the same proportional degree, so that (assuming competitive factor market conditions) the relative prices of the inputs would remain unaltered – except for changes traceable to shifts in their relative supplies.

Yet a third notion of "neutrality" figures more prominently in the literature of modern growth theory, namely "Harrod-neutrality," so named after Sir Roy Harrod (1948). Under "Harrod neutrality" technological progress leaves the desired capital-output ratio undisturbed, given constancy of the marginal productivity of capital (or, equivalently, under competitive conditions, constancy of the real rate of return on capital). The same term is applied to the obversely defined condition: given the capital-output ratio, Harrod-neutral technological progress neither decreases nor increases the real rate of return on capital.

The usage of the terms "labor-saving," and "capital-using" in connection with the consequences of technological innovation may be confusing if it is not understood that these refer to the impact upon the demand for the respective inputs *in relation to the volume of real output*. Thus, the effect of innovations that are said to be (absolutely) *capital-using* when they tend (holding constant the relative price of capital services, vis-à-vis the other inputs, and output) to *raise* the desired ratio of capital services per unit of real output. Innovations that reduce the desired capital-output ratio (measuring capital in natural units) may be properly described as "capital-saving" in an absolute sense, and the corresponding holds for the absolute "labor-saving" of innovations. Hicks-neutral technical change is absolutely labor-saving and capital-saving, in equal proportionate degrees; whereas the condition of Harrod-neutrality of technical change would rule out the possibility of either capital-saving or capital-using effects, and guarantee that all innovations were relatively "labor-saving" in the Hicksian sense of that term.

In contexts where either the Hicksian or the Harrodian concepts of neutrality are implicit, economists understand the (relative) " labor-saving bias of innovation" to refer to the effect of technological change in raising the desired capital-labor input ratio (when relative input prices remain constant). Equivalently, they take a (relative) "labor-saving bias" of innovation to be one that tends to lower the ratio of the marginal productivity of labor inputs relative to that of capital inputs, and thus to depress the real wage rate in relationship to the real rate of return on capital – given the pre-existing ratio of capital to labor. Of course, a "capital-using bias of innovation" would be (Hicks) "labor-saving" in the senses just described; but it would go further, in raising not only the capital-labor input ratio, but the capital output ratio as well.

The effect of technological change may of course be to increase the absolute level of the demand for inputs, notwithstanding the possibility of the innovations in question being "capital-saving" and/or "labor-saving" in the senses defined above. Changes in the absolute level of demand reflect three distinct sets of forces: (a) the effects of technological innovation (and scale economies) impinging upon the desired amounts of inputs per unit of output, (b) the effects on the desired input proportions (given output scale) of changes in relative input prices stemming from shifts in relative input supplies, and (c) changes in the demand for the output in question. In the case of particular goods, or a particular industry, the income effects of technological progress may be weak and, consequently, whether or not a bias towards "labor-saving innovation" causes reduced demands for labor services in the industry depends upon the strength of the associated unit cost-savings, and the impact on the quantity of output demanded by consumers (if and when those cost-savings are translated into price reductions). Thus, the outcome in the case of a particular industry depends upon the price elasticity of demand for its product, as well as the impact of the technological change upon unit costs. At the aggregate level, in our one-sector parable of the economy, only the real income effects of technological change operate to offset the factor-saving effects of innovation. To a first-order approximation, the magnitude of those real income effects is what is measured as an increase in total factor productivity.

2. Although the minerals-based, resource-intensive technology proved to be the dominant path of technical progress in all the presently advanced countries, America gained substantial first-mover advantages in whole-heartedly embarking upon that path by undertaking infrastructural investments to explore, develop and reduce the costs of access to her mineral resource deposits. As David and Wright (1997: Tables 1, 2, and Figure 2) have shown, Europe as a whole possessed known reserves of a number of the key minerals, such as iron ore, that in 1910 were as large as those identified in North America at the time, and the current rates of production of iron ore, coal and bauxite in Europe as a whole exceeded that of the U.S. in 1913. But when it came to petroleum, copper, phosphate, gold and other minerals, America was out-producing the whole of Europe – even with Russia included, and there was no nation in Europe, to say nothing of Japan, which approached the U.S. in the variety and richness of the mineral resources that actually had been developed, rather than remaining in "reserve" status. Out of 14 important industrial minerals, America in 1913 accounted for the largest shares of world output in the cases of all but two – and for those two it was the runner-up. Domestic industrial users of these inputs consequently benefitted from the greater dependability of supply sources, freedom from exposure to foreign exchange risks, and lower transport costs. The foregoing statements are based on David and Wright (1997: Figures 3-5), and Wright (1990: Chart 5).

3. For these and the following statistics, see the underlying data in U.S. Department of Commerce, *Historical Statistics of the U.S.* (1975), v. I: Series H-689, 696, 751,755, 756, 759, 764, 765. In 1930 recipients of doctorates represented 3.3 percent of the number who had received a Bachelor’s degree nine years previously (a relevant lag for purposes of comparison, since the average period elapsed since receipt of the undergraduate in 1930 was 8.7 years). In 1948 the lag was 10.8 years, presumably due to the intervention of World War II, and the encouragement of graduate education among returning war veterans under the provisions of the G.I. Bill, but the doctorates of 1948 represented only 2.5 percent of the number of Bachelor’s degree recipients from the class of 1937. The corresponding figure had risen to 6.6 percent by 1969, however, at which time the lag between degrees was back down to 8.0 years. The level of these percentages tends to overstate the actual continuation rate from baccalaureate to doctorate, because the distribution of completion times for the higher degree is left-skewed, and the median and mode are therefore less than the mean. Since the population of college graduates was rising throughout the period, this means that considering the mean lag for the purposes of calculating the proportions results in denominators that are in each case too small.

4.“History,” said Voltaire, “is a fable agreed upon.” The truth of this oft-quoted aphorism impresses itself particularly upon economic historians seeking an interpretation of the quantitative record of long-run macroeconomic performance, especially one set in very aggregate terms. Supply-side approaches to all but the most short-run dynamics have been embraced almost universally in recent decades; most of the economics profession appears to have been thoroughly persuaded by Paul Samuelson’s (1962) contention that the idea of a well-behaved production function leads to the most coherent and analytically attractive “parables” that can be told about aggregate supply relationships in the economy. This approach appears to hold even more strongly today, following the revival of neoclassical supply-side macroeconomics during the 1980s. Thus, as we remarked when first essaying the present approach, any history of an economy’s growth composed in keeping with reigning theoretical macroeconomic fashion can be no more than “a *parable* agreed upon.” Although the concept of an aggregate production function still draws some detractors, it has no want of tacit as well as explicit endorsements. Plainly it underlies the now-standard procedures of modern “growth accounting,” even where, as in our exposition in Part One, it has been pushed into the background; for it remains implicit in the suppositions that there are well-defined elasticities of aggregate real output with respect to each of the classes of aggregated productive inputs; that these elasticities are legitimately treated as parameters (within trend periods at least); and that the latter correspond directly in magnitude to the respective shares of the real gross product paid to the factors of production.

To accept the notion of an aggregate production function for the purposes of organizing and examining the data in this way, however, does not require turning a wholly blind eye to the dangers of reifying the concept. On the contrary, it is quite possible to envisage stable relationships among aggregate output and inputs, and the appearance at the macro-level of regularities in the time trends of relative factor proportions, as emergent system properties arising directly from market interactions occurring at the microeconomic level. One such approach has been explored in the "evolutionary economics" literature, from Nelson and Winter (1977) to Metcalfe (1997). That approach eschews the notion of optimization subject to production function constraints at the micro-level as well as at the macroeconomic level, and seeks to account for statistical regularities at the macro-level as emergent properties of the interplay of underlying dynamic processes. It envisages innovations being generated, and new products and processes being selectively retained in commercial applications, by "boundedly rational" agents who operate in imperfect markets, under conditions of ineluctable uncertainty. While we accept the usefulness of such an approach in interpreting the historical experience of growth at the microeconomic level, we have not found it necessary for the present interpretive task.

Instead, the language of production function analysis may be employed descriptively at the aggregate level, as it is used here, without suggesting that this notional construction had a literal correspondence with some pre-existing set of constraints that were determining the historical growth path of the U.S. economy. Our usage of the concept, therefore, should be read as metaphorical references to hypothesized aggregate supply-side relationships of a persisting or gradually changing kind, which provide an historical summation of myriad dynamic processes that were being played out in reality on the microeconomic level. Quantitative macroeconomic stories related in such terms may be expected to direct attention to potentially important issues, and to highlight promising specific hypotheses that deserve more detailed historical investigation.

In sum, we view our "parables" about the historical behavior of the aggregate production function to have an allegorical value: if they are not taken literally, they can perform the useful heuristic role of indicating in a short-hand way the character of underlying economic tendencies that were manifesting themselves at the level of sectors, industries, firms and households. There is an inevitable tension, nonetheless, between the values of simplicity and clarity of exposition that can be achieved in presenting rather broad-brush parables on the one hand, and on the other hand, the realization of the aim of such heuristic story-telling – which is to indicate the salient points at which the resulting tale makes contact with the specific complexities of the historical experience of growth. Readers therefore should be prepared to encounter a form of "histoire raisonnée" in which the discussion shifts back and forth between the two levels of aggregation, and their corresponding two poles of explanatory attraction.

5. It is of course not unreasonable to approach the matter with some initial skepticism regarding the refined total factor productivity estimates that appear in Part One's Table 1: IV for the earlier epoch. Undoubtedly there are some margins of inaccuracy in the underlying data which could have worked to exaggerate the contribution to output growth made by tangible reproducible capital, and so led to underestimation of the size of the (TFP) residual calculated for the epoch ending in 1890. Yet, the contrast between the average annual estimate of 0.27 percentage points during 1800-90, and the corresponding TFP growth rate estimate of 1.05 percentage points over the whole interval 1890-1989 (from Table 1: IV, Frame II) is too large to be dismissed as simply an artifact of measurement errors.

Indeed, since the latter period includes the 1966-89 period of the TFP "slowdown," there is room for suspicion that the difference between the pre- and post-1890 rates might be *understated* at 0.78 percentage points; some part of the post-1966 "slowdown," perhaps as much as 0.2-0.3 percentage points per annum might reasonably be attributed to the more pronounced underestimation of output growth. Were we to raise the TFP estimate for the 1966-89 interval by 0.25 percentage points on that account, the average annual rate for the whole interval would rise to 1.10 percentage points, and the gap between it and the average for the 1800-90 interval would therefore stand at 0.83 percentage points.

To get a sense of how implausible it is to suppose that measurement errors in the growth account for the nineteenth century would be responsible for an apparent TFP acceleration of that magnitude, we can perform the following simple calculation. Since the average share of capital in gross output is estimated at 0.38 over the 1800-90 interval, we can ask by how much the annual growth rate of the total capital stock during that epoch would have had to be overstated in order for the latter form of measurement error to be responsible for just *one-half* of the apparent gap, that is, for an understatement of the pre-1890 (corrected) TFP growth rate amounting to 0.415 percentage points.

The answer obtained (from 0.415/0.382) is large in both absolute and relative dimension: at 1.1 percentage points, it says that the rate of growth of the total capital input would really have been only 3.15 percentage points, rather than the 4.24 percentage points per annum, an overstatement of approximately 25 percent. [The latter average growth rate is found for 1800-90 from the measure C* entries in the upper panel of Table 2: I.] To account for the other half of the gap, one would need to believe, in addition, that the average gross share of capital in GPDP also was overstated by as much as 25 percent: it would have had to be 0.284, rather than the 0.382 estimate found for 1800-90 from Table 2: I., a difference of 0.097 (= 0.415/4.24).

From the results of the augmented growth accounting shown below, in Table 2: IV, it will be noticed that insofar as we believe there to have been little or no significant contribution from the growth of intangible capital in the nineteenth century, the contrast in measured multifactor productivity growth rates between the pre- and post-1890 epochs would be smaller than the 0.83 percentage point difference just discussed: taking account of intangible capital inputs during 1890-1989, the refined residual averages 0.77 percentage points per annum. But, that still leaves a gap of 0.5 percentage points (0.77-0.27), which has been seen to be difficult to discount without conjecturing rather large measurement biases.

6. For a general discussion of the trend towards roundaboutness and increasing capital intensity in late-nineteenth-century industrial technology, the interested reader might begin with Abramovitz and David (1973a), Rosenberg (1976), and Hounshell (1984). See Cain and Patterson (1981) on the bias of technological change in U.S. manufacturing industries during the nineteenth century, and for comparisons with Britain, consult the careful quantitative work of James and Skinner (1985), and Broadberry (1993). See Abramovitz and David (1973b), David (1975, Chapters 1, 4), David (1977). Cain and Paterson (1981) report consistent econometric results on the bias of technical change in U.S. nineteenth-century manufacturing industries, based on the more general translog production function specification.

For quantitative evidence on the elasticity of substitution and the bias of “factor-augmenting” technical change at the aggregate and industry levels in the U.S., see David and van de Klundert (1965); they find 0.32 for the estimated long-run elasticity of substitution parameter in the private domestic (business) economy during 1900-60. Estimates placing the elasticity parameter closer to unity, but still significantly below it, were obtained in earlier studies by Irving Kravis, John Kendrick, R. Sato, along with the seminal study of Arrow, Chenery, Minhas and Solow (1961), all of which had implicitly or explicitly imposed an assumption of “Hicks neutrality,” which David and van de Klundert (1965) relaxed. The latter found significant non-neutrality, with the trend in the relative efficiency of manhours rising at 0.7 percentage points per annum faster than that in the efficiency of capital. For the nineteenth century, similar allowance for the possibility of Hicksian labor-saving bias has been found to yield estimates indicating a still lower elasticity of substitution and a much more marked rate of increase in the relative efficiency of manhours vis-à-vis that of conventional tangible capital services.

7. This may be seen for the Private Domestic Economy from the entries in Table 2: I (Panel B): the growth rates of total tangible and intangible real stocks of capital (unadjusted for “quality of the tangible stock”) can be weighted using the corresponding shares from Table 2: III (Frame II) to form $C^* = \theta_{KT} K_T^* + \theta_H H^*$; the growth rate of C/Y_A is then found as $(1 + C^*)/(1 + Y_A{}^*)$.

Alternatively, for the Domestic Economy, an increase of approximately 31 percent in the level of this overall capital-output ratio is implied by the growth rates for the tangible and intangible components of the capital stock and the corresponding gross share data in Table 2: III, on the one hand, and the augmented output growth rates for the periods 1929-66 and 1966-89 combined, with an increase of 27 percent occurring in the latter period alone. The entries in Table 2: II-Part A pertain to the domestic economy, rather than the private domestic economy, and imply a smaller proportional rise in the ratio of total capital to augmented real GDP, from a level of 8.4 in 1929 to 9.6 in 1990 (measured in constant 1987 dollar terms); but the movement between 1929 and 1973 is slightly downward – continuing the much more dramatic 1905-29 downward trend evident in both the private sector and the whole of the domestic economy. Hence, both sets of estimates concur in presenting a picture of quite pronounced aggregate capital-shallowing during the century's opening third, and a resumption of capital-deepening in its closing third.

8. Making use of the expression for E^* in equation (5), one may solve for $E_{KT}^* = E^* - (\theta_L)\mathbf{B^*}$, where we implicitly define the “bias parameter” $\mathbf{B^*} = E_L^* - E_{KT}^*$. The joint estimates of the elasticity of substitution and the parameter $\mathbf{B^*}$ reported by David (1975: Chapter 1) for the nineteenth-century U.S. economy put the elasticity of substitution significantly below unity, as noted in the text, and yield $B^* = .017$ (i.e., 1.7 percentage points per annum). Applying this to the interval 1835-90, during which the rise in the capital-output ratio was concentrated, and over the course of which the average share of labor was $\theta_L = .573$, and $E^* = 0.00294$ (according to the data underlying Table 1: IVA), we obtain the pair of estimates: $E_{KT}^* = -\ 0.0068$ and $E_L^* = 0.0109$.

9. This argument has been elaborated quantitatively, and implemented by P. A. David ("The Changing Morphology of American Macroeconomic Growth – A Course of Lectures Delivered in the Faculty of Economics of the University of Ancona," March 1998: Lecture No. 2.) This involves estimating a "Cambridge"-type equation for the gross savings rate as a function of the property income share, based upon decadal estimates for the period 1800-1900; the latter relationship can then be combined with the relationship derived from the aggregate (CES) production function, in which the gross

property income share in output is a function of the real rate of return and the shift effects due to changes in the efficiency index of the tangible capital stock.

10. Based upon the changing shares of structures and equipment in the real value of business fixed investment, and constant (Treasury Bulletin F) service lives of 39.5 and 14.4 years, respectively, the average service life of newly installed business capital declined from 27.8 in 1927-9 to 20.7 by 1962. Our estimates of the composition of the real stock of fixed reproducible tangible assets, in 1964 prices at benchmark dates, shows that the compositional shift effect – which is the main source of the rise in the average rate of depreciation on the gross tangible stock – was negligible during the first quarter of the present century – leaving aside the stock of consumer durables as is customary in the national accounts. This may be contrasted with developments in the period following 1929, as shown by the following percentages:

	Percentages of All Types of Tangible Reproducible Capital Shown in:						
Asset Type		**1912**	**1922**	**1929**	**1949**	**1957**	**1961**
Farm Residential Structures		4.6	4.5	3.5	3.0	2.5	
Non-Farm Residential Structures	42.2	41.2	44.7	45.6	43.9	45.3	
Non-residential Structures	33.3	32.6	31.4	26.8	24.6	24.9	
Business Equipment		13.5	14.1	13.5	17.1	21.1	21.7
Business Inventories		6.3	7.6	6.8	7.5	7.8	8.0

Source: The underlying constant dollar estimates were based upon U.S. Commerce Department, Survey of Current Business (Jazi, Wasson and Gross, 1962), for 1961 with special adjustments to derive the farm residential stock) in 1954 prices, which were then extrapolated to earlier dates. Extrapolators were derived from the work of Goldsmith (1958) on National Wealth stocks, and Denison (1962), following methods described fully in Abramovitz and David, “Statistical Appendix on the Growth of the U.S. Capital Stock,” Sources and Notes to Table V-A-1. (Stanford Department of Economics, 1965: Unpublished mss.).

From Technical Appendix Note 2 (on vintage effects), it is seen that holding constant the composition of the tangible stock by asset-category, the average service life decline for the tangible stock as a whole was proceeding at the average rate of -.25 percentage points per annum during 1948-66, and - 0.124 percentage points per annum over the whole of the period 1929-89. This implied a decrease in the average within-category service life of approximately 5 percent, over each of those two intervals. The absence of any pronounced trends in the make-up of the tangible stock by service life-class in the 1912-29 interval is the main reason for the assumption in that Appendix of no change in the index of (reproducible) capital quality during the 1905-27 interval.

11. Two points should be noted which bear upon both the forces underlying the rise of investment in human capital and the sources of our estimates of the total intangible stock's growth over the period 1905-29. (The details of the estimation procedures are provided in the statistical appendix cited in the Notes and Sources to Table II.4.1A.) The figures for the benchmark dates from 1929 forward are drawn from the work of John Kendrick (1994). To obtain the estimates for 1900-10 (centered c. 1905) the 1929 figures for the components of the stock of intangible human capital have been extrapolated backwards on the basis of the real stock of capital formed by investment in formal education. This involves two suppositions: first, as separate estimates for the real stock of capital formed by training, as distinguished from formal schooling, are not available for this period, it was assumed that the two components were rising *pari passu*. Second, it was assumed that the growth of the stock of education and training capital could be taken as a proxy for that of the whole of the "human" component of the intangible stock. We should consider briefly the plausibility of each assumption, taking each of them in turn.

The first of these conjectures appears not unreasonable, in light of the numerous studies by Jacob Mincer (1967) and others, which have concluded on the basis of data for the post World War II era that there is a strong degree of complementarity between the formal educational attainments of workers and the amount of investments made (mainly through deferred earnings) in their subsequent on-the-job training.

It is possible that future research will be able to establish the point in time at which such complementaries first began to emerge, and to relate them to the evolution of worker recruitment and internal labor market developments affecting major public and private sector employers in the pre-1914 period. Should it turn out that on-the-job training was to a greater degree a substitute for formal education during the early part of the century, the implication would be that we have overstated the growth rate of the combined stock in the pre-1929 era. But, inasmuch as the rate of growth of intangible capital inputs per manhour was relatively slow, and the gross income share imputed for all intangibles was comparatively low during the 1890-1927 period, it will be seen from Table 2-IV (below) that the relative contribution to labor productivity growth from this source prior to 1929 was only one-third to one-half as large as that which characterized the post-1929 era. Consequently, any tendency towards *overestimation* of the growth rate of the real stock of intangibles during the earlier era – for the reasons entertained above – should not be thought capable of having materially distorted the main line of the story related here – viz., the greater impact of intangible capital-deepening in the 1929-89 period.

The second supposition to be considered in this connection arises because our estimate for the total intangible stock of human wealth c.1905 is based upon the estimated movements of the educational (and training) stock between that point and 1929, which implicitly assumes that the other components of human wealth – particularly, cumulated real value of investments in health, as that is especially prominent among the latter – were growing at a pace matching that of the educational and training component. In support of this supposition we may point out that the entries for the two relevant items in Table 2: II, drawn from John Kendrick (1994), have maintained a roughly constant ratio over the years from 1929 to 1990. Moreover, considering the complementarities between investment in health and in education, one finds good economic reasons to expect that such, indeed, should have been the case.

12. The retention of corporate earnings, rather than their distribution to stockholders in the form of dividends, tends to reduce the value of the corporation's equity issues. Rising interest rates have the same effect (given an expected dividend stream) and so will raise the cost of internal financing of capital formation of all kinds. But the incidence of this falls especially strongly upon R&D investment because the alternative of significant resort to debt financing is not available. This creates a potential for the capital market consequences of government deficits to adversely impact the rate of company financed innovative activity. The relevance of this to public debates about the long-term effects of the decline in the national savings rate during the 1980s is noted below.

13. See David and Scadding (1974: p. 237) for further evidence supporting the view of Vatter and Thompson (1966) and Vatter (1967) that the high spending on durables in the years immediately following World War II reflected backlogged demand, rather than a continuing structural shift. Indeed, the share of consumer durables in total personal consumption expenditures has remained remarkably stable in the range between 0.135 and 0.145 from year to year throughout the whole of the ensuing period 1959-89. See The Economic Report of the President (February 1997), Table B-14, based upon NIPA from U.S. Department of Commerce, Bureau of Economic Analysis.

14. Olney (1992) points out that the growth of consumer durables installment purchasing during the 1920s was greatly encouraged by changes in legal and institutional practices that reduced the risk of loss to the buyer from automatic uncompensated repossession when payments were missed. There may be something to the argument that the increased share of personal savings that has continued to take the form of acquisition of consumer durables after 1929 might owe something to the heavier taxation of market incomes and excise taxes on non-durable goods and services, whereas income represented by the flow of services produced within the household (using the stock of appliances and transport vehicles) remains untaxed. See David and Scadding (1974), p.237. But this cannot apply as an explanation for the shift that occurred between pre- and post-World War I consumption patterns, since the relevant tax rates did not change very significantly prior to 1929.

15.The figures presented in Table II.4.2B (upper panel) for the pre-World War I period are based upon estimates of total educational resource costs derived from the work of Fishlow (1966), but incorporating the higher allowances for the costs of foregone earnings which Solmon (1970) has shown to be appropriate. The resulting estimates for this component of educational costs are consequently much larger than those which Schultz (1961) suggests for 1900-10. On the other hand, the underlying estimates for the census years from 1920 through 1940 (in lower panel of the same table) incorporate procedures differing from those of Schultz (1961), which result in the downward revisions of his foregone earnings, to allow for the fact that not all youths enrolled beyond the elementary grade would have been in the labor market.

16. To do so, however, would in effect count the societal costs of the juvenile labor foregone by the legislative restriction of employment and the extension of compulsory schooling. But, as such a standard could not take account of the possible countervailing social costs of child labor, we adhere to the practice of evaluating the opportunity costs of schooling for the individuals involved – taking the current legal framework and the prevailing social norms as given, and allowing changes in the latter over time to affect the level of the estimates. For the time span of the estimates in Table II.4.2B, therefore, no foregone earnings allowance is made for elementary school attendees. In the estimates for the 1920s, 1940 and the post-World War II era, however, we do make adjustment to reflect changing probabilities that youngsters enrolled in high school and college at various ages would not be employed – even when and where such work would have been legal.

17. The 1981 estimate is from Abramovitz (1993: n.21). The underlying estimates (in constant 1929 dollars) for the 1939-59 period are those developed in M. Abramovitz and P. A. David, Appendix 8-B to "Economic Bases of the Rise in Labor Quality," (unpublished MS., Stanford University) on the basis of data in the Biennial Survey of Education in the U.S., and U.S. Department of Health, Education and Welfare, Digest of Educational Statistics and other sources.

18. These percentages are derived from the average ratio of DPI/GNP in Table 2: V-Parts A and B, and the ratio [FE/Y(fully augmented)] in Table 2: VI, col.4. Denoting the former ratio by D and the latter by F, one can obtain the ratio denoted as $\boldsymbol{f}$ = [FE/DPI]= $[F/(1-F)]/D$. The desired magnitude then follows immediately: FE/(DPI + FE) = $\boldsymbol{f}$ / (1 + $\boldsymbol{f}$). There is some offset to the argument for regarding the latter as an underestimate of the private educational cost claim on available household income: while total private costs are roughly 20 to 30 percent above foregone earnings, the estimate of foregone earnings in the numerator and the denominator of the ratio is made gross of income tax. From the private vantage point it should be reckoned net of taxes. Taking the average ratio of DPI to Personal Income to be approximately .88 in the post-World War II period, the estimate given in the text for 1981, FE/(DPI + FE) = .20, should be adjusted downwards to 18.3 on an after tax basis. Since the ratio of direct private (after tax) costs to foregone earnings in the post-World War II period can be approximated as .25, another 5 percentage points (.23 x .20 x 100) must be added to the numerator to get the total educational burden (net of taxes) as a percentage of available household income. The resulting adjusted figure is thus 23.3 percent c. 1981.

19. However, it might well be the case that were they properly measured in real (constant price) terms, the disparity between the growth of these two main components of intangible capital formation would be less marked than appears. Both these measures of expenditures on intangibles suffer for being just the direct and indirect costs of the inputs, rather than independent measures of investment goods production to which there would correspond unit product prices. One might argue that the relative price of additions to the stock of R&D-produced scientific and technological knowledge has fallen dramatically in relation to tangible goods prices, and also declined very significantly in comparison with the relative price of increments of education-produced human capital. An important source of support for this view is the observation that the technology of scientific and engineering research itself has been subject to very rapid progress of a labor-saving and time-saving kind through the use of sophisticated instrumentation and computing, especially during the past quarter century (David 1993). That is a development that is generally conceded not to have been paralleled in the education sector.

20. The trend holds within each subperiod (1895-1926, and 1926-39) in the case of males. See Claudia Goldin and Lawrence Katz, "The Decline of Non-Competing Groups: Changes in the Premium to Education, 1890 to 1940," National Bureau of Economic Research Working Paper, 5202, August, 1995: Tables 5, 6 especially. The education-skill premium for female clerks declined while that for female book-keepers rose (vis-à-vis production workers) over the 1895-1926 interval. The pattern of movement reversed subsequently, but the net change over the whole period 1895-1939 was downward. In the case of female typists and stenographers, the premium declined between 1895 and 1926, but was stable during 1926-39. See also Abramovitz and David (1996: OECD) for further evidence on U.S. education-associated earnings premia pre-WWII.

21. Between 1984 and 1994 the ratio of the earnings of the top decile to the upper half of the earnings distribution (the so-called "90/50 ratio") rose by roughly 12 percent among all male high school graduates, and by 14 percent among 255 34-year-old male full-time, year-round workers. See The Economic Report of the President (February) 1997, pp.170-175, for further discussion.

22. The more refined figures obtain real output by deflating output in current prices by a price index in which prices of individual goods and services are combined by weights that change as the composition of output changes. By contrast, the official figures of the NIPA combine prices with the fixed weights of a base year (1992 in the latest revision; 1987 in the formal tables of this chapter). Indexes with changing weights ("chained superlative" or "Fisher ideal" indexes) are now accepted as superior, and NIPA itself is widely expected to switch to such indexes soon. The differences between productivity growth rates based on the two concepts are shown below:

The Effects of Shifting from Fixed-Weights to Chain-Weighted Indexes of Real Output

Private nonfarm sector	**1950-72**	**1972-87**	**1987-94**
Labor productivity, official	2.24	0.99	1.21
Labor productivity, chain weight	2.57	1.19	0.92
Crude TFP, official	1.30	0.34	1.22
Crude TFP, chain weight	1.60	0.54	0.93
Private business sector			
Labor productivity, chain weight	3.67	1.69	1.22
Refined TFP, chain weight	2.39	0.72	0.30

Sources.
Private nonfarm sector: Calculated from the figures in R.J. Gordon (1996), Table 6. The official figures are on the 1987 base. The terminal dates of the periods in the table above are the annual dates closest to the quarterly terminal dates of the Gordon figures.
Private business sector: Calculated from the Bureau of Labor Statistics estimates in U.S. Department of Labor, News Release, USDL 95-518, Jan. 17, 1996.

23. To make the point concretely we can follow Griliches ("Productivity, R&D and the Data Constraint,"1994) in dividing the industries that produce the total output of the private sector between the "measurable" and the "hard-to-measure." The first consists of agriculture, mining, manufacturing and transport and other public utilities. These industries produce commodities such as bushels of wheat, tons of coal, and yards of cloth or countable services, such as ton-miles of freight and kilowatts of electric power. The second group consists of construction, trade, finance, insurance and real estate (FIRE) and miscellaneous other services whose products differ so much in content and quality that they are quite difficult to measure in countable units. The hard-to-measure group has been growing in relative importance, and rising, indeed, with especial rapidity in recent decades. Its average percentage share of output was about 49 percent over the interval 1948-66 but over 58 percent from 1966 to 1989 – a rise of nearly 20 percent. For this calculation, the average levels for the intervals were obtained roughly as simple averages of the levels in the terminal years. 1948 and 1966 are from NIPA 1986, Table 6.1; 1989 from NIPA figures in Survey of Current Business, Aug. 1986, Table 10. The figures cited by Griliches (1994) for the periods 1947-69 and 1969-1990 tell virtually the same story – a rise in the hard-to-measure group's share from 49.6 to 59.7.

From Griliches (1994: Fig. 1) it is found that the difference between the trend rates of output per manhour (over the whole period 1947-1990) for these two sectors amounted to about 1.4 percentage points, in favor of the better-measured group. Therefore, a simple re-weighting of those trend growth rates would lower the aggregate labor productivity trend by 0.13 points between 1947-9 and 1969-90. But this represents less than 12 percent of the observed slowdown that Griliches was seeking to explain.

An alternative approach to the question would allow for the fact that the decline of the labor productivity growth rate for the "hard-to-measure" group of sectors was far more severe than that of the "measurable" group. The "measurable" productivity growth rate declined by about 1 percentage point between 1948-66 and 1966-89, whereas the decrease recorded for the hard-to-measure sector was about 2.5 percentage points. (These rates are based on measures of industry real gross product originating per person engaged drawn from NIPA figures.) Consider, next, the following hypothetical calculation which allows explicitly for the possibility that the hard-to-measure group of sectors is especially subject to underestimation of its productivity growth as a result of an "over-deflation" bias.

According to the findings of the Report of the Advisory Commission to Study the Consumer Price Index (the Boskin Commission, 1997), the CPI overstates the rate or rise in the true cost of living – currently and "looking forward"– by 1.1 percentage points a year, with a plausible range from 0.8 to 1.6 points. Suppose, then, that: (a) the overall bias in the past was at the high end of this range, at 1.6 points a year, (b) this bias applied to the entire private GDP deflator, (c) it was concentrated exclusively in the hard-to-measure sector, (and, therefore, was much higher in that sector than 1.6 points) but (d)t it had remained unchanged since the end of the War. A simple calculation can then be made of the weighted bias – which takes account of the increase in the importance of the hard-to-measure sector. This suggests that the overall bias would have risen between the rapid-growth period, 1948-66 and the slowdown period, 1966-89, by 0.22 percentage points. That amounts to 11.7 percent of our figure for total decrease in the trend rate of labor productivity growth (1.88 points), which coincides remarkably closely with the (12 percent) figure obtained above, from the alternative calculation based data in Griliches (1994). The assumptions behind our second calculation are extreme, and the result, therefore, may be regarded as an upper-bound estimate of the possible contribution of the increased weight in the US economy of sectors belonging in the hard-to-measure category.

Closely related to the foregoing is the frequent observation in the literature that the pace of total factor productivity growth in the US economy's Service sectors has historically been slower than that experienced in the commodity-producing sectors. Whether or not this reflected a downward bias in the measurement of the growth of some (but surely not all industries) within the Services sector, or for other, real causes, the suggestion is made that the growing relative importance of Services in the US economy has been a significant contributory factor in the diminished pace of TFP growth. Now, inasmuch as the rise in the relative weight of the Service sector has been a continuous process, rather than a development peculiar to the last three decades of the twentieth century, this lacks a priori plausibility as serious candidate explanation for the sudden slowdown. Moreover, when directly assessed, it too fails to stands up to the data. The best estimates on this question are those of Dale Jorgenson. ("Productivity and Economic Growth", in Fifty Years of Economic Measurement, Ernst R. Berndt and Jack E. Triplett, Eds., Chicago, Chicago University Press, 1990, Table 3.1.) Proceeding from a growth accounting of 51 industrial sectors comprising the national economy, Jorgenson was able to decompose the (refined) growth rate of aggregate total factor productivity into two major elements. One is the weighted average growth rate of productivity "within sectors". It is a measure of the growth that would have been achieved, given the actual growth rates of the 51 sectors, had there been no changes in the relative importance of the individual sectors. The other, which is the difference between the growth rate of aggregate productivity and that of "within sector growth," is the amount attributable to reallocation. It is also the sum of the independently calculated amounts attributable to the reallocation among industries of Value Added, Labor "Input" (Hours and Quality Change) and Capital "Input (Stock and Quality Change)". This calculation yielded the following figures for the change in productivity growth between the slowdown period, 1966-85 and the preceding period, 1947-66:

	Percentage points	
Output per manhour		-1.82
Aggregate refined TFP	-1.14	
Within-sector refined TFP	-1.0	
Reallocation		-0.09

Once again, the effects of structural or compositional change is found to be a whole order of magnitude smaller than the observed contraction in the productivity growth rate.

24. See Paul A. David and W. E. Steinmueller, “Understanding the Paradoxes and Payoffs of the Computer Revolution: Information Technology and the Productivity Slowdown Revisited,” (April 1999), forthcoming as Ch.1 in Information Technology and Productivity – From Paradoxes to Payoffs, P. A. David and W. E. Steinmueller, Eds., Harwood Academic Publishers, forthcoming in 1999; also, Paul A. David, “Digital technology and the productivity paradox: after ten years, what has been learned?” Paper presented to the White House Conference Understanding the Digital Economy: Data, Tools and Research, (Washington D.C., 25-26 May, 1999), forthcoming from MIT Press in the conference volume, edited by E. Brynolffson and B. Kahin.

A central defect in the official output measures, and the main source of the persisting underestimation of real product growth, is their failure to capture improvements in output quality that arises from the introduction and diffusion of new goods and services, and their continuing enhancement. The problem arises in obtaining quality adjusted unit price indexes, because the practise of “splicing in”, or “chaining” a price series for a new commodity to the price index for a mature substitute commodity is prone to result in “over-deflation” of the value of goods and services produced. Typically, the early history of a new product is marked by its most rapid phase of price decline, because it is then that scale economies are achieved and elements of monopoly power (whether from patent protection or product differentiation) tend to weaken, thereby shrinking the initial profit margins that product innovations can often command. Consequently, the linked price series does not fall as fast as it should. This technical defect, however, is not in itself a new problem. Nor is there reason to think that statistical procedures themselves have themselves become more biased. (See Charles B. Hulten, “Quality Change in the CPI: Some Missing Links,” Jan. 1997, a technical paper prepared for the Federal Reserve Bank of St. Louis Fall Policy Conference, Oct. 1996. Forthcoming in Challenge Magazine.). On the contrary; many improvements have been introduced. An increase in the severity of the bias, therefore, could help explain the slowdown only if there were reason to believe that quality change and the spread of new goods or their importance has proceeded more rapidly during the slowdown period than in the immediately preceding decades.

25. There is another proposed explanation, not considered in the text, that for some while commanded attention and which deserves at least passing mention. The steep increases in energy prices that marked the post-1973 years were widely credited with depressing productivity growth. Several reasons were adduced. Energy users were forced to economize their use of power. The higher price of energy made power-using capital goods less valuable. Engineers were led to seek productivity gains along less energy-abundant technological paths unfamiliar to them. The energy-price increases supported a general acceleration of inflation and led public authorities to take contractionary measures that depressed economic activity at large. The plausibility of these arguments weakened, however, when, during the 1980's the real price of energy declined almost as much as it had previously risen; yet there was no commensurate recovery in rates of productivity growth.

26. According to Luc Soete and Bart Verspagen, the total expenditures on the production of technology could amount to anything between 2 and 3 times the officially measured expenditures on R&D activities. (See “Recent Comparative Trends in Technology Indicators in the OECD Area” in Technology and Productivity, Paris: Organization for Economic Cooperation and Development, 1991, 249-74. See also Denison, Trends in American Economic Growth (1985), p. 28.) One need not take these numbers literally to see that the official figures are a serious understatement of total technological effort. The important question, however, is whether the official figures are biased indicators of the trend of such effort. They probably are. Earlier in the century and continuing into the Sixties, the growing importance of science-based research and the growth and spread of large firms tended to move larger fractions of technological effort into specialized departments whose expenditures count in the R&D statistics. In more recent years, the rapid growth of independent computer software firms and the expanding R&D efforts of other service sectors mean that a larger fraction of effort is being missed. The earlier trend meant that the official figures overestimated the growth of total effort. The more recent developments mean that the official figures are understating its growth. The indications, therefore, are that total technological effort, as measured by expenditures, has not declined since the 1960s; it may have grown.

27. The figures for the extent of diffusion of electric motors are from David, “Computer and Dynamo,” 1991: Table 3. David (see “Digital Technology and the Productivity Paradox,” 1999: section 6.1) also presents additional quantitative

indicators, including comparisons of the rate of decline in the real price of computer services with that of purchased electricity and electrical machinery (of a constant kind), to substantiate the parallel between the two cases. While there seems to be considerable heuristic value in this historical analogy, a cautious, even skeptical attitude is warranted regarding the predictions for the future that some commentators have sought to extract from the quantitative resemblance between the two transition experiences. For one thing, statistical coincidences in economic performance are more likely than not to be mere matters of coincidence, rather than indications that the underlying causal mechanisms are really one and the same.

28. See, for further discussion and sources, Steinmueller "The U.S. Software Industry" (1996). Digital Equipment Corporation, the leading minicomputer manufacturer retreated from its vertical marketing strategy of offering computer systems specifically designed for newspapers, manufacturing enterprises, and service companies; it specialized instead in hardware production, leaving the software market to independent software vendors. Similar decisions were made by all of the US computer manufacturers. This process, which had begun in the late 1970s as an effort to focus corporate strategy, greatly accelerated during the 1980s with the advent of the large-scale personal computer platforms united under the IBM PC standard or utilizing the Apple Macintosh's. The "general purpose" software produced for these platforms not only discouraged task-specific software, it also created a new collection of tasks and outputs specifically driven by the new capabilities such as "desk top publishing" (typeset quality documents), "presentation graphics" (graphic artist quality illustrations for speeches and reports), and "advanced word processing" (the incorporation of graphics and tables into reports). All of these changes improved the "look and feel" of information communication, its quality and style, the capability for an individual to express ideas, and the quantity of such communications. But singly and severally they made very little progress in changing the structure of work organization or the collective productivity of the work groups employing these techniques.

III. Endnotes for Part Three

1.The table that follows is a simple decomposition of the growth rates of GDP per capita in Europe and the U.S. It shows the dominant importance of Labor Productivity growth over Labor Input per capita as proximate sources of output per capita in the twentieth century (Panel A). Indeed, after 1913, labor productivity determined the direction of movement of output per capita while the growth of labor input per capita acted only to offset some of the force of labor productivity growth. The same comments apply to a decomposition of the difference between U.S. and European growth rates of output per capita (the "U.S. Advantage") which was negative since 1950 as shown in Panel B.

Growth Rates of GDP per Capita and its Components
U.S. and Europe, 1870-1992

Panel A: Growth Rates

	1870-1913			**1913-1950**			**1950-1973**			**1973-1992**		
Europe	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH
10 countries	1.31	-0.35	1.66	1.40	-0.30	1.70	3.95	-1.03	5.03	1.84	-0.55	2.39
11 countries	1.28	-0.37	1.65	1.40	-0.30	1.70	3.82	-0.98	4.85	1.80	-0.57	2.37
U.S.	1.80	-0.12	1.92	1.60	-0.90	2.50	2.40	-0.31	2.72	1.4	0.26	1.14

Panel B: The U.S. Advantage in Growth Rates
U.S. minus Europe

Europe	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH	Y/P	MH/P	Y/MH
10 countries	0.49	0.23	0.26	0.20	-0.60	0.80	-1.55	0.72	-2.31	-0.44	0.81	-1.25
11 countries	0.52	0.25	0.27	0.20	-0.60	0.80	-1.42	0.67	-2.13	-0.40	0.83	-1.23

Definitions:
10 European countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden.
11 European countries: 10 countries plus U.K.
Symbols: *Y/P* = GDP per capita; *MH/P*: Manhours per capita; *Y/MH*: GDP per Manhour, All italicized symbols represent growth rates.
Sources: Angus Maddison, Monitoring the World Economy, Paris: OECD, 1995: for *Y/P*: Table 3-2; *MH/P = Y/P - Y/MH*; for *Y/MH*: Maddison, 1995, Table -J-4.

Between 1870 and 1913, however, things were different. In this period, the U.S. grew more rapidly than Europe and enlarged an existing lead. Then, the U.S. growth of labor input per capita (input measured in manhours) worked together with labor productivity to account for the American advantage over Europe in per capita output growth. This difference with later decades appears to stem in large part from the importance of the massive population migration from Europe to the U.S. This added substantially to the growth of the American population, but it increased the growth of labor input in America still more. The immigrant population stream was skewed towards men of working age and away from dependent women, children and the elderly. And, of course, it had the opposite effect on European labor input and population growth. All this stands in sharp contrast to the far more limited European migrant flow to America after restrictions on immigration came into force in the early 1920s.

We owe our awareness of the importance of per capita labor input in accounting for the superior growth of American per capita output in the period between 1870 and 1913 to the quite recent work of Jeffery Williamson, Alan Taylor and their collaborators. (See references in the International Section of the General Bibliography to Taylor and Williamson, 1997; Williamson, 1997, and the publications cited in their papers.) Their calculations serve to show that America's superior growth in manhours per capita then stemmed from the faster growth of its economically active population (EAP), which they measure by the people aged 15 to 64, the people of working age. It was not due to differences in the growth of the ratio of manhours per employed worker. Thus from 1870 to 1913, the American advantage in per capita output growth can be decomposed, as follows:

	GDP/P	EAP/P	MH/EAP	MH/P	Y/MH
10 European countries	0.49	0.29	-0.06	0.23	0.26
11 European countries	0.52	0.27	-0.02	0.25	0.27

<u>Sources</u>: GDP/P and Y/MH from Maddison, 1995, Tables 3.2 and J-4. EAP/P from Williamson 1997, Table 2. MH/P = GDP/P - Y/MH. MH/EAP = MH/P - EAP/P (all figures are growth rates of the ratios)

Williamson and Taylor, however, carry the matter further. They contend that besides its direct effect on output per capita, the growth of labor input per capita has an additional effect because it helps to determine labor productivity growth. They provide two analyses of this effect, with contradictory results. In the first (Taylor and Williamson, 1997, Working Paper, 1994), they calculate counterfactual estimates of productivity growth from 1870 to 1910, estimating that growth as it might have been if migration had been zero. They find that productivity growth in the U.S. would have been slower than it actually was and the opposite in Europe. And similarly with output per capita. This implies that the forces other than migration that supported a U.S. productivity growth advantage were even stronger than the actual measures suggest. And they remain to be explained.

The counterfactual calculation was carried out subject to certain restrictive assumptions: that the growth of the supplies of reproducible capital and land were independent of labor supply and that there were constant returns to scale. Moreover, in the counterfactual calculation itself, the equalizing effect of international trade on the relative wages and productivities in trading countries was neglected. (It was treated separately by Taylor and Williamson and served to support the results of the counterfactual calculation). These restrictive assumptions presumably are taken into account implicitly in a second experiment carried out by Jeffery Williamson alone and reported in a draft circulated in 1997 ("Growth, Inequality, Demography and History," Harvard Economics Department Working Paper). There Williamson carried through a cross-country regression of the growth of output per capita between 1870 and 1913 on the difference between the growth of the Economically Active Population (people aged 15-64) and the growth of the Dependent Population. This measure – Williamson calls it DIFF – is itself only an alternative measure of the growth of the Economically Active Population per head of the total population. In Williamson's regression some half-dozen characteristics of countries entered as additional variables. None proved to be of substantial importance. The influence of DIFF, however, was both statistically significant and powerful. Applying Williamson's results, it appears that the American advantage in per capita growth over an average of European countries in the "age of mass migration" was entirely attributable to the greater rapidity of America's growth of DIFF and thus to the American advantage in the per capita growth of the economically active population, a superior growth owing in good part to transatlantic migration.

Since the simple decomposition of per capita output growth (see Table above) suggests that only about half the American growth advantage finds its "proximate" source in the growth of labor input per capita, the Williamson regression suggests that the remainder must be attributable to a close <u>positive</u> relation between labor input and productivity growth. It is important to notice, however, that the positive relation revealed by regression stands in sharp contrast to the negative relation that emerged from the earlier counterfactual calculation. There is a presumption, therefore, that the difference arises because the regression implicitly takes account, among other possibilities, of forces set aside in the counterfactual calculation: returns to scale, the interactions between labor supply and the supplies of reproducible capital and land, and international trade, the last working perhaps in ways not contemplated by the factor-price equalization theorem.

The Williamson studies, with their emphasis on demography, are a valuable contribution to studies of the relative growth of nations. Readers of this chapter will find that the questions that Williamson's analysis suggests, concerning scale and the interaction of factor supplies with one another, and with technological changes affecting productivity, are pursued in our own analysis.

2. "Social capability" is a subject that has drawn the attention of historians and economists for many years. De Tocqueville (Part 2, 1840) and Veblen (1915) are notable examples of older writings. Economic historians added considerably to this literature in the years following World War II, and the pages that follow reflect their contributions; especially, the essays by Arthur H. Cole, Thomas C. Cochran and others in the collective volume prepared by the Harvard Entrepreneurial Research Center (1949), the series of biographies of businessmen edited by Miller (1952), the essays on France by Sawyer (1951, 1954), studies of entrepreneurship in France and Germany by Landes (1949, 1951, 1954) and Gerschenkron (1953, 1954, 1955); also Wiener's (1962) controversial work on the role of culture and class in Britain's relative decline. In the following decades the subject was largely neglected by economic historians, and only lately is being taken up again, as in Parker (1982, 1991) and Lazonick (1994). An even fuller view of social capability would include the literature of public choice, economic organization and institutions, not only in economics but also in political science and sociology.

TECHNICAL AND STATISTICAL APPENDICES

Technical Appendix Note 1:
A General Production Function with Factor-Augmenting Technical Change

The relationships in equations (1-5) of the text, in Parts One and Two, may be thought of as being "nested" within the more general one-sector, closed economy model of production. The latter is described by the "well-behaved"[1] aggregate product function that takes the following general form:

(6) $$Y_A(t) = Y\{\, L(t), K(t), R(t), H(t) \,\} \quad .$$

Here $Y_A(t)$ is an appropriately defined measure of real gross output at time t, which reflects the production and utilization of both conventional and unconventional (intangible) inputs. Correspondingly, the dated inputs are measures of the services of "raw labor" (L), reproducible capital (K), non-reproducible capital (R) – such as land and depletable natural resources, and intangible capital (H). We use italics in this notation to indicate variables that are *measured in efficiency units*, that is to say, in which the input service flows are adjusted in each case by an index of the current average efficiency of the constituent elements with that input class.

For the purposes of implementing this framework quantitatively we place two additional restrictions on this function. The first is that $Y\{\bullet\}$ exhibits constant returns to scale, so that doubling all the input measures would result in the doubling of output. This is tantamount to specifying that the elasticities of output with respect to the inputs, denoted by ϵ_i always sum to unity:

(6a). . . . . $\epsilon_L(t) + \epsilon_K(t) + \epsilon_R(t) + \epsilon_H(t) = 1$, for every t.

The second restriction is that the input services enter the production function measured in their respective *efficiency units*, which is to say that the input of labor services at time t, as measured as the number of full time equivalent manhours (of basic quality level) $L(t)$, adjusted by an index $E_L(t)$ that indicates the currently prevailing level of productive efficiency of those "raw" labor services relative to their efficiency level at some fixed reference date (t=0). The choice of the reference date is arbitrary and simply serves to fix the scaling of the function $Y\{\ \}$.

Thus, the production function can be written :

(6b). . . . . $Y(t) = Y\{\, L(t)\cdot E_L(t),\ K(t)\cdot E_K(t),\ R(t)\cdot E_R(t),\ H(t)\cdot E_H(t) \,\}$,

[1] Formally, the "well-behavedness" of the function consists in it being continuous and continuously differentiable in all of its arguments. Further, we assume that the partial first derivatives with respect to each of the arguments are all positive, and the second derivatives are negative – i.e. marginal products of the inputs are positive, but there are diminishing marginal returns in all directions.

which is referred to as the form with “generalized factor-augmenting technological change.[2] The latter designation refers to the assumption that technological and organizational innovations, and other unobserved temporal changes affect production by altering one or more of the input-specific indexes of average efficiency.

For expositional purposes, especially when considering twentieth century trends, it is sufficient to work with the (Divisia) aggregate K_T in which the components of the total tangible capital stock – reproducible and non-reproducible – are combined, and to emphasize the contrast between the growth profiles of the total tangible capital stock and the stock of non-conventional and intangible capital, denoted by H. Notice that a proper (Divisia) measure of the growth rate of tangible capital services *in natural units* includes the kind of "quality corrections" for compositional change that are introduced in the standard growth accounting framework for Table 1.IV. We therefore suppress separate notice of the non-reproducible capital inputs, *R,* that appears above, in equation (6), and, by total differentiation of the latter with respect to time, obtain the following relationship for labor productivity growth in the “augmented Solow model”:[3]

$$(7)\ldots\ldots\ldots\ldots\ldots (Y^*_A - L^*) = E^* + (\theta'_{KT})[K_T^* - L^*] + (\theta_H)[H^* - L^*],$$

where

$$E_A^* \equiv \theta'_L[E_L^*] + \theta'_{KT}[E_{KT}^*] + \theta_H[E_H^*],$$

and the respective average factor-shares in gross output (Y_A) over the time interval are taken as approximating the respective input elasticities during the time interval:

$$\theta'_L = \epsilon_L \quad , \ \theta'_{KT} = \epsilon_K \ , \ \theta_H = \epsilon_H .$$

When a particular index increases with the passage of time, the effect is a proportional “augmentation” of the productive services of the input in question, when the latter is considered in its natural units. In other words, in this model the impact upon aggregate output of a 10 percent increase in the average efficiency index of our labor input measure would be equivalent to that of augmenting the physical number of manhours worked by 10 percent. It should be noted that these input efficiency indexes may decline over time, rather showing only positive changes; it is quite possible for biased technological change to *lower* the efficiency index of one of the inputs while raising that of another. Such a skewing of the production isoquant field may be referred to as an “input-using” innovation in the case of the former, whilst it is “input augmenting” in the case of the latter. An innovation that is, say, reproducible capital-using in this sense is one that (with everything else held constant) will raise the capital-output ratio that corresponds to a given real rate of return on capital, supposing that the latter is equal to the marginal physical product of the capital goods.

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[2] For further discussion, see David and van de Klundert’s (1965) introduction of this general formulation in a constant elasticity of substitution (CES) model of production.

[3] The descriptive term “Augmented Solow model” has become popular in the recent growth theory literature, following the work of Mankiw, Romer and Weil (1991) and Barro and Sala-i-Martin (1992), and we use it here with the caution that the “augmentation” to which it refers is simply the explicit inclusion among the arguments of the production function of “factors” additional to conventional labor and capital. The usage here should not lead to confusion with the specification of the aggregate production function as subject to factor-augmenting innovations reflected by changes in factor-specific efficiency indexes, such as E_L and E_K.

The flexibility of the model of production with factor-augmenting technological change permits the relaxing of assumptions that usually are made, sometimes implicitly, as to the effects of such innovations on the relative productivities of the inputs. Thus, the condition of general Hicks-neutrality (discussed in Endnote 1 to Part Two) corresponds to: $E^*_A \equiv E_L^* = E_{KT}^* = E_H^*$. Under the assumption that the elasticity of substitution between labor and (tangible) capital inputs is less than unitary, $(E_L^* - E_{KT}^*) > 0$ corresponds to the condition of a Hicksian (relative) labor-saving bias in technological change.

Technical Appendix Note 2:
On the Vintage Effect and Efficiency Improvements Embodied in Capital

The method of assessing the contribution made to measured total factor productivity growth by "vintage effects" – on which lines 7 and 8 of Tables 1.IV and 1.IVA (in Part One) are based – is based on the approach introduced and applied by Richard Nelson (1964). The following is adapted from Nelson's approximating formula, which partitions the TFP residual into three components:

$$E^* = \gamma + \theta_K \gamma_K + [-\Delta\mathbf{a}]\theta_K \gamma_K \quad ,$$

where, using our notation, E* is the refined measure of the TFP growth rate (corresponding to the crude TFP measure, A* , after adjustments for labor- and capital-quality changes. The rate of disembodied technological advance is here denoted by γ, and for purposes of implementation we take it to be a fixed proportion, $(1 - \alpha)$, of the refined TFP rate: $\gamma = (1 - \alpha)E^*$. Since λ_K represents the average annual growth rate of technological change that is embodied in the latest tangible capital goods, and θ_K is the gross factor share estimate of the elasticity of output with respect to tangible capital services, the second term on the right-hand-side of the equation ($\theta_K\gamma_K$) represents the contribution of capital-embodied technical change to the refined TFP rate. Were there to be no alteration in the age structure of the tangible stock, this term would constitute the whole contribution of embodied technical progress.

The third term on the right-hand-side of the equation is the contribution made by the so-called "vintage effect", denoted hereinafter as V*. It is the effect on the TFP rate of the average yearly change (over the indicated period) in the mean age (**a**) of the tangible capital stock, measured in years of age change per year: $[-\Delta\mathbf{a}]\gamma_K$ is the percentage improvement in embodied capital efficiency due to the *reduction* of the tangible capital stock's age, which increases the weight of the more recent vintages in the aggregate. Obviously, the vintage effect is negative when $\Delta\mathbf{a}$ is positive.

By substituting our specification for γ we obtain the decomposition formula:

$$\overset{*}{E} = (1-\alpha)\overset{*}{E} + \alpha\left(\frac{\overset{*}{E}}{1-\Delta a}\right) + \overset{*}{V} \quad .$$

The vintage effect $V^* = (\alpha E^*)\{[-\Delta\mathbf{a}]/[1-\Delta\mathbf{a}]\}$ may be calculated directly, or obtained as a residual, by subtracting the first two terms on the right-hand side from E*. The sum of the first two terms is referred to as "total age-neutral" technological progress in Table 1.IV and the accompanying text in Part One.

To apply this formula, three data are needed to obtain the figures that appear in the Addendum to Tables 1.IV and 1.IVA:

1. E* we identify with Refined TFP as this emerges in line 6 of Tables 1.IV and I.IVA.

2. The " total capital-embodiment fraction" (α), and its complement (1- α). We assume conservatively that the latter number is 0.5, but readers can easily substitute higher numbers for α, thereby raising the absolute and relative dimension of the portion of the total age-neutral TFP rate that is assumed to be embodied, and, likewise, of the vintage effect. It is noted below that the division of E* between the vintage effect and the total age-neutral effect is not affected by the choice of α.

3. The new data required are the average changes per year in the age of the capital stock: $\Delta \mathbf{a}$. The Bureau of Economic Analysis[4] presents figures on average age for total gross private, fixed, reproducible capital in constant prices and also for Equipment and Structures separately. These figures are derived from the sums of annual gross investments cumulated over the estimated service lives of detailed categories of Equipment and Structures. The categories and service lives are shown in the same source, Table B. For our purposes, however, the average ages of the total stock, as presented by BEA, are inappropriate. They reflect changes in age due not only to changes in the age of particular types of assets but also to changes in the composition of total capital by assets of different lengths of service life. The main change in composition is the rise in the importance of relatively short-lived equipment compared with longer-lived structures. We therefore used the BEA data to construct an alternative set of estimates for the average age of total capital by calculating a weighted average of the ages of equipment and structures for the terminal years of each period. Our weights (constant for the terminal years of each period) were the average fractions of total capital made up of equipment and structures.

The following Table shows the calculations that underlie the entries in Table 1.IV:

[4]See US Department of Commerce, Bureau of Economic Analysis, Fixed Reproducible Tangible Wealth in the United States, 1925-89. Washington, DC: US Government Printing Office, Jan. 1993, Table A-6.

Calculation of Age-neutral TFP Rate and Vintage Effect:
U.S. Private Domestic Economy, 1929-1989
(Growth rates in Percentage points per Annum)

	1929-48	**1948-66**	**1929-66**	**1966-89**
1. Refined TFP rate: E*	1.43	1.47 (1.68)	1.45 (1.55)	0.04 (0.19)
2. Non-Embodiment fraction:	0.5	0.5	0.5	0.5
3. Embodied TFP, with α = 0.5:	0.71	0.73 (0.84)	0.72 (0.77)	0.02 (0.09)
4. Rate of change in capital's age (in yrs. per yr.): $\Delta\mathbf{a}$	0.14	-0.25	-0.05	-0.025
5. [1- $\Delta\mathbf{a}$]	0.86	1.25	1.05	1.025
6. *Age-neutral Refined TFP rate*	*1.54*	*1.31 (1.51)*	*1.41 (1.50)*	*0.04 (0.18)*
a) Embodied: (α E*)/ [1-$\Delta\mathbf{a}$]	0.83	0.58 (0.67)	0.69 (0.73)	0.02 (0.09)
b) Disembodied: (1-α)E*	0.71	0.73 (0.84)	0.72 (0.77)	0.02 (0.09)
7. Vintage effect (line 1-6)	-0.11	0.16 (0.17)	0.04 (0.05)	0.00 (0.01)
8. Total Efficiency Growth Embodied in Tangible Capital (lines 6a + 7)	0.72	0.74 (1.01)	0.73 (0.78)	0.02 (0.09)

The figures we reach are, of course, only the roughest of estimates. They rest on rather arbitrary assumptions whose accuracy is difficult to assess. The Refined TFP from which the calculation starts is not a pure measure of technological progress and economies of scale, although we believe it to be a useful approximation. The embodiment fraction is a guess, set on the lowish side, in order to produce figures that are a lower bound to the estimated Vintage Effect. Further, for lack of evidence, we assume that the embodiment fraction remains unchanged from period to period, but it may not. We think it likely that the proper fraction may be larger, but possibly not very much larger, at least for the period 1929-66.

One way to indirectly assess the plausibility of the guess we made for the parameter α is to consider the plausibility of the estimates it yields for the total rates of efficiency change that are embodied in the tangible capital stock, which is found in Line 8 of the Table, as the sum of Lines 6a and 7. For this purpose we propose a comparison with an alternative estimate of the rate of technological changes reflected in a dated index of the average productivity efficiency of quality-adjusted tangible capital inputs, $E_{KT}(t)$. This index itself may be thought of as entering the aggregate production function as a multiplier of the quality-adjusted capital inputs.The growth rate of the latter we denote by (K_T* + q_K*), the second term in the brackets being the "capital quality growth rate"; the embodied capital efficiency growth rate itself is E_{KT}*.

Having defined this magnitude, the question now is how we might obtain an independent estimate for it. We propose to do so by building upon the hypothesis that aggregate production relationships (metaphorically summarized by an aggregate production function) in the twentieth century have been characterized by strong "skill-technology complementarity." For the period since 1929, with which we are here especially concerned, this hypothesis certainly finds considerable support. A large body of econometric research pertaining to the post-World War II U.S. economy points to the existence of strong tangible capital-skill and technology-skill complementarities at the plant and industry level.[5] Furthermore, in recent reseach combining census statistics for U.S. manufacturing industries at the 2-digit SIC level with corresponding micro-level samples of workers' characteristics (including formal educational attaintments), Goldin and Katz (1998) have shown that "capital-skill" and "technology-skill" complementarities already had emerged at least in that sector during the first quarter of the twentieth century.

A strong interpretation of "the skill-technology, capital-technology" hypothesis in the present context is that (within any trend period) strict proportionality will be maintained between the average quality adjusted stock of intangible capital per manhour, on the one hand, and the input of total "quality-adjusted" tangible capital *measured in efficiency units* per manhour. The U.S. real intangible capital stock, as will be seen below from Part Two: Table 2.II, is preponderantly made up of human – education and training – capital and is measured in constant dollar terms; we denote it by H(t), and dropping the time index (t), we write the intangible stock per manhour as h = H/L. Correspondingly, the quality adjusted tangible stock measured in efficiency units per manhour is $k = (K_T \cdot q_K \cdot E_{KT})/L$.

The strict complementarity hypothesis implies that the relationship $h^* = k^*$ must hold over the course of each trend interval. From that we obtain a simple expression for the growth rate of tangible capital-embodied efficiency: $(E_{KT}{}^*) = [H^* - (K_T{}^* + q_K{}^*)]$. All the data required to implement this formula are readily at hand for the periods 1929-66 and 1966-89: the growth rates $K_T{}^*$ and H^* appear as entries in Part Two: Table 2.IA. The underlying estimates of the capital quality growth rate, $q_K{}^*$, may be found, simply by dividing the entries for the "Capital quality" contribution to growth that appear in Part One: Table 1.I – which correspond to $\theta_{KT}(q_K{}^*)$, by the estimates of the gross tangible capital share, θ_{KT}, shown in Part Two: Table 2. IB.

The following Table displays the results:

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[5] See the survey of early econometric work on this subject in Hammermesh (1993). Bartel and Lichtenberg (1987) conclude, from their examination of a panel of manufacturing industries over the 1960-80 period, that the share of highly-educated labor in total costs was significantly greater where the capital-stock was younger (taking the latter as a proxy for greater use of recent embodied technology). Berman, Bound and Griliches (1994) find that *across* U.S. manufacturing industries, skill-upgrading during the past 30 years was positively associated with the level of investment in R&D and computer equipment, as well as with high capital-output ratios. For studies that find positive correlations between utilization of formal company training on the one hand, and technological change and sectoral capital intensity, see also Bartel and Sicherman (1995), Mincer (1989). The latter is as pertinent in the present context as is the evidence for the complementarity of formal educational attainments with greater use of the latest embodied technologies, because in implementing the hypothesis at the aggregate, we use measures of total intangible capital stock per manhour input per labor. While education *and* training capital have remained the preponderant components of the total intangible stock H from the opening of the century onwards, it is true that the R&D component of the latter more than doubled in relative importance between 1948 and 1990, as can be seen from Part Two: Table 2. II - Parts A, B.

Speculative Estimates of the Growth Rate of Total Tangible Capital-Embodied Efficiency: U.S. PDE
(Average growth rates in percent per annum)

	1929-1966	**1966-1989**
1. [H^* - K_T^*]	1.48	0.90
2. q_K^*	0.67	0.89
3. E_{KT}^* (line 1 minus line 2)	0.81	0.01

The rough concilience of the speculative estimates of E_{KT}^* for these two periods with the independently derived figures in Line 8 of the preceding Table – .81 versus 0.73 (.78) percent, and .01 versus .02 (.09) percent, respectively – is quite striking, both as to the magnitudes and their temporal movement. It suggests our partitioning of the refined TFP growth rate may not be so wide of the mark, however arbitrary the underlying assumptions might seem.

Our judgment, therefore, is that the estimates of the Vintage Effect presented above, and in Table 1.IV, should be regarded as realistically illustrating the possible importance of changes in the rate of gross tangible capital formation as it affects both the growth of the flow of physical capital services and the concomitant average efficiency effect of changes in capital's average age. The main lesson to be drawn from those estimates, and the point underscored by the text in Part One, is that "vintage effects" may well exert important influences on the comparative growth rates of TFP in successive intervals of perhaps 20 years' duration, and then probably only in exceptional circumstances – as in a comparison between a period of severe depression or war, and the rebounding growth enjoyed when peace returns. But, over longer periods which embrace episodes of depressed capital formation and an ensuing rebound, such as is the case for 1929-66, the accompanying transient vintage effects are seen to be offsetting, so the overall effect fades out. This provides a further, and concrete point supporting our focus upon the trends manifested over such extended periods in the nineteenth century (where we have combined 1855-71 with 1871-90), as well as the extended twentieth century period 1929-66.

Technical Appendix Note 3:
Estimates of Trend Growth Rates of Efficiency of Intangible Capital Inputs

The interpretation of twentieth century macroeconomic trends as having been shaped in significant part by the emergence of a bias towards technological and organizational innovations that were intangible capital-using can be supported by numerical estimates of the growth rate E^*_H. The latter designates that rate of "intangible capital augmenting" innovation, and should carry a negative sign when the changes in efficiency are such as to raise the desired ratio (H/Y), given the same rate of return on the real intangible stock, H. Therefore, finding the sign condition ($E^*_H < 0$) to be fulfilled for the U.S. private domestic economy from 1929 onwards is an important point of quantitative substantiation for the argument we advance.

For the reasons given by the text of Part 2, Section 2.3, it is not possible to infer the sign of E^*_H immediately from the behavior of the input ratios and their shares in total product. Hence, a direct computation is required. This requires solving the whole system of relationships describing the input specific rates of efficiency change.

These are: E^*_L, E^*_{HL}, E^*_L for the inputs of pure tangible manhours, intangible human capital, and tangible and intangible labor, respectively;
E^*_{KT}, E^*_{HK} and E^*_K, for inputs of tangible capital, intangible, non-human capital and tangible and non-human, intangible capital combined;
and E^*_H itself.

We thus have seven unknowns, and the following directly measurable magnitudes:
K^*_T, H^*, E^*_A, θ_L, θ_K (= $1-\theta_L$), θ'_L(= $\theta_L - \alpha_L$), θ'_{KT} (= $\theta_K - \alpha_K$), $\theta_H = \alpha_L + \alpha_K$ and q^*_K, from Appendix Note 2.

Given seven equations in these magnitudes, the system can be solved from the seven unknowns. Beginning with the residual, from Appendix Note 1, equation (7), we first write the definitional identities:

(i) $E^*_A \equiv \theta'_L E^*_{L'} + \theta'_K E^*_{KT} + \theta_H E^*_H$;

(ii) $E^*_H \equiv (\alpha_L / \theta_H) E^*_{HL} + (\alpha_K / \theta_H) E^*_{HK}$;

(iii) $E^*_L \equiv (\theta'_L / \theta_L) E^*_{L'} + (\alpha_L / \theta_L) E^*_{HL}$;

(iv) $E^*_K \equiv (\theta'_{KT} / \theta_K) (E^*_{KT} + q^*_K) + (\alpha_K / \theta_K) E^*_{HK}$.

Then, from the specification that the bias of innovation is a time invariant parameter, we have

(v) $\lambda = (E^*_L - E^*_K)_t$, for all t.

which, under suitable separability conditions, can be obtained by regression estimation for the constant elasticity of substitution production function:

$$(\theta^*_{L'} - \theta^*_K)_t = [(1-\sigma) / \sigma] [K^* - L^*]_t - [(1-\sigma) / \sigma] \lambda .$$

From the specification based on the strict skill-technology complementarity hypothesis, in Appendix Note 2, we have:

(vi) $E^*_{KT} = H^* - (K^*_T + q^*_K)$.

Finally, we specify a proportionality constant $\beta \geq 0$ in the relationship

(vii) $E^*_{HK} = \beta E^*_H$.

A little algebra is needed to solve for E^*_H in terms of the known magnitudes and the parameter β. One may first substitute from definitions (iii) and (iv) into equation (v) and solve for $E^*_{L'}$; next substituting (vi) in (i), we can solve for E^*_H in terms of $E^*_{L'}$ and the other known magnitudes, whence we can eliminate $E^*_{L'}$ and obtain:

(viii) $E^*_H = \{\lambda - (E^*_A / \theta_L) - 2(\theta'_{KT} / \theta_H) [H^* - K^*_T - q^*_{KT}]\} / [1 - (\theta_H / \theta_L) - \beta\delta]$,

where $\delta \equiv [(\alpha_K / \theta_H) + (\alpha_K / \theta_{KT})]$.

Referring back to equation (vi), we directly obtain E^*_{KT}. Using (ii) and (iii) to eliminate E^*_{HL}, and (iv) and (v) to eliminate E^*_L, one obtains:

(ix) $E^*_{L'} = \{(\lambda + E^*_{KT})\, \theta_L + E^*_H [\theta_H - \alpha_K \beta]\} / \theta'_L$.

Substitution of the values of $E^*_{L'}$ from (ix) back into (ii) and (iii) provides us with E^*_{HL}, and thence E^*_L, whence using (v) we obtain E^*_K; and using (iv) we can find E^*_{HK}, to complete the solution.

The following Table shows the solutions for E^*_H obtained from equation (viii) using the indicated values for q^*_K, E^*_{KT} and β, as well as the E^*_A estimates from Part Two, Table 2.IV-Part A, and applying the invariant parameter estimate $\lambda = .007$ obtained by David and van der Klundert (1965) for the whole period 1899-1960. The magnitude of the shares, θ_i, are those shown for the relevant intervals in Table 2.III, with the 1890-1927 interval value found as the weighted average of the sub-periods 1890-1905 and 1905-27.

Given the heroic specification assumptions, and the use of "speculative" magnitudes obtained in Appendix Note 2, we can do no less than caution the reader by labelling the results frankly as "speculative".

Table A3:1
Speculative Input Specific Efficiency Rates (Per Annum): PDE, 1890-1989

	E^*_A / θ_L	q^*_K	E^*_{KT}	$[1 - (\theta_H / \theta_L) - \delta\beta]$		E^*_H	$E^*_{L'}$
Periods				**Assuming: $\beta = 1$**			
1890-1927	.0223	.0026	.0120	0.744	(0.742)*	.0116	.0293
1890-1905	.0221	0	.0079	0.834	(0.833)*	.0008	.0179
1905-1927	.0228	.0046	.0146	0.682	(0.679)*	.0193	.0400
				Assuming: $\beta = 2$			
1929-1966	.0155	.0067	.0081	- 0.491		- .0079	.0212
1966-1989	- .0021	.0089	.0010	- 0.492		- .0215	.0027

***Note:** Values in parentheses are found with $\beta = 2$, essentially identical to those for $\beta = 1$ in these sub-periods.

The computed rates in Table A3.1 for E^*_H and E^*_L' are *conditional* on the specification used in Appendix Note 2 to find E^*_{KT}, and consequently the share-weighted sum of these two rates is not constrained to yield the same value as will be found by subtracting $[\theta'_{KT} (E^*_{KT})]$ from the residual estimates shown for E^*_A in Table 2.IV-Part A. To insure consistency of the full set of input specific efficiency growth rates, we normalize the computed values of E^*_H and $E^*_{L'}$ by multiplying each by the normalizing ratio $n = [E^*_A - \theta'_{KT} E^*_{KT}] / [\boldsymbol{E}^*_A - \theta'_{KT} E^*_{KT}] = n$, where $\boldsymbol{E}^*_A = \theta'_L E^*_{L'} + \theta'_{KT} E^*_{KT} + \theta_H E^*_H$, using the values entered in Table A3.1. The final estimates are shown in Table A3.2.

Table A3:2
Normalized Speculative Efficiency Growth Rates

Periods	n	$nE^*_{L'}$	nE^*_H	E^*_{KT}
1890-1929	0.534	0.156	.0062	.0120
1929-1966	0.307	.0277	- .0103	.0081
1966-1989	0.273	.0007	- .0059	.0010

4. Appendix Tables and Statistical Notes and Sources

4.1 Statistical Appendix for Part One

This Appendix is arranged as follows. Section 1 contains Part One Tables IA through IVA, the Tables of "Measures Over Long-Swing Intervals". Section 2 is a description of the Sources and Procedures that lie back of the figures for the nineteenth century. These are the figures in Frame I of each table, including Tables I-IV, the tables of "Measures Over Long Periods" which appear in the text itself. Section 3 contains the descriptions of Sources and Procedures that lie back of the twentieth-century figures, those in Frame II of each table, including Table V.

Section l: Appendix Tables to Part One

(We follow the numbering convention in the text, in which each (roman) numbered table is preceded by the (Arabic) "Part" number.)

Table 1: IA. The Growth Rates of the National Economy and the Private Domestic Economy, 1800-1989
Measures Over Long-Swing Intervals

	GNP	GPDP	Population	Per capita rates		Intensive growth fractions (%)	
Frame I The Nineteenth Century							
				GNP	GPDP	GNP	GPDP
1800-1855	3.99	3.93	3.03	0.93	0.87	23	22
1855-1871	2.92	2.69	2.55	0.36	0.14	12	5
1871-1890	4.92	4.97	2.30	2.56	2.61	52	53
1890-1905	3.80	3.80	1.91	1.85	1.85	49	49
1905-1927	3.40	3.30	1.61	1.76	1.66	52	50
FRAME II THE TWENTIETH CENTURY							
1890-1905	4.29	4.25	1.91	2.34	2.34	55	55
1905-1927	3.42	3.31	1.61	1.78	1.67	50	50
1929-1948	2.44	2.21	0.98	1.44	1.21	59	55
1948-1966	3.97	3.95	1.64	2.31	2.29	58	58
1966-1989	2.69	2.86	1.00	1.67	1.84	62	64

Note: Here and in Tables 1. II-A through IV-A, the dates 1855, 1871, 1890, 1905 and 1927 are the midpoints of five year averages ending with the peak year of a "long swing." Thus the period 1855-71 is properly 1853-57 to 1869-73; 1871-90 stands for 1869-73 to 1888-92, and so on. Other terminal years are single years chosen to represent the peaks of long swings.

Table 1: IIA. The Contributions of Labor Input and Labor Productivity to the Growth of Output per Capita. Private Domestic Economy, 1800-1989 (Compound Growth Rates per Annum)

	Measures Across Long Swing Intervals		
	Output per capita	**Manhours per capita**	**Output per manhour**
Frame I The Nineteenth Century			
1800-1855	0.87	0.48	0.39
1855-1871	0.14	0.00	0.14
1871-1890	2.61	0.75	1.84
1890-1905	1.85	0.49	1.36
1905-1927	1.66	-0.77	2.45
Frame II The Twentieth Century			
1890-1905	2.34	0.36	1.93
1905-1927	1.67	-0.36	2.05
1929-1948	1.21	-0.74	1.96
1948-1966	2.29	-0.82	3.11
1966-1989	1.84	0.60	1.23

Table 1: IIIA. Decomposition of the Growth of Manhours per Capita Measures Across Long-Swing Intervals, 1800-1989 (compound growth rates per annum)

	Manhours per capita	Labor Force per capita	Persons Engaged per Member of the Labor Force	Manhours per Persons Engaged
I. The Nineteenth Century				
1800-1855	0.48	0.19	0.14	0.15
1855-1871	0.00	0.15	-0.02	-0.13
1871-1890	0.75	0.48	0.14	0.14
1890-1905	0.49	0.31	0.21	-0.03
1905-1927	-0.77	0.05	-0.43	-0.41
II. The Twentieth Century				
1890-1095	0.36	0.31	0.16	-0.11
1905-1927	-0.36	0.06	-0.09	-0.33
1929-1948	-0.74	0.19	-0.14	-0.80
1948-1966	-0.82	-0.38	-0.35	-0.06
1966-1989	0.60	1.12	-0.11	-0.37

Table 1: IVA. Sources of Labor Productivity Growth, Private Domestic Economy, 1800-1989

	Measures Across Long-Swing Intervals									
	I Nineteenth Century					**II Twentieth Century**				
	1800-1855	**1855-1871**	**1871-1890**	**1890-1905**	**1905-1927**	**1890-1905**	**1905-1927**	**1929-1948**	**1948-1966**	**1966-1989**
1. Output per manhour	0.39	0.14	1.84	1.36	2.45	1.93	2.05	1.96	3.11	1.23
<u>Sources</u>										
2. Capital stock per manhour	0.19	0.53	0.84	0.45	073	0.55	0.48	0.07	0.81	0.57
3. Crude total factor productivity	0.20	-0.39	1.00	0.91	1.72	1.38	1.57	1.89	2.30	0.66
4. Labor quality	-	-	-	0.10	0.19	0.10	0.19	0.38	0.43 (0.22)	0.31 (0.16)
5. Capital quality	-	-	-	-		-	-	0.08	0.40	0.31
6. Refined total factor productivity	0.20	-0.39	1.00	0.81	1.53	1.28	1.38	1.43	1.47 (1.68)	0.04 (0.19)
<u>Addenda</u>										
7. Gross factor share weights	-	-	-	-	-	-	-			
a. Labor	0.65	0.54	0.55	0.54	0.54	0.56	0.60	0.63	0.65	0.65
b. Capital	0.35	0.46	0.45	0.46	0.46	0.44	0.40	0.37	0.35	0.35
8. Vintage effect	-	-	-	-	-	-	-	-0.11	0.16 (0.17)	0.00 (0.01)
9. Age-neutral refined total factor productivity	-	-	-	-	-	-	-	1.54	1.31 (1.51)	0.04 (0.18)

Section 2: Sources and Procedures for Nineteenth-Century Data (in Frame I)

With some minor revision, the following description first appeared as an Appendix to a paper by Abramovitz, "The Search for the Sources of Growth: Areas of Ignorance, Old and New." This was published in the Journal of Economic History, 53, No. 2 (June 1993). A more detailed description of sources and procedures behind the output and labor input data for the period 1800-60 is provided in David, "Real Income and Economic Welfare in the Early Republic,"1996 (see General Bibliography). In Part One, Endnote (1) these estimates are compared with the alternative figures available from Robert Gallman's Chapter in Volume 2 of the Cambridge Economic History of the U.S.

The tables in Frame I include periods (1890-1927 in the long period measures, 1890-1905 and 1905-27 in the long-swing measures) which provide an overlap between Frames I and II.

The estimates presented in Frame I rest on the Abramovitz-David figures first published in 1973 and, after minor revision, in David, "Invention and Accumulation" (1977). 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.

Real Gross Private Domestic Product (RGPDP)

The growth rates were computed from an underlying constant dollar series, expressed alternatively in 1860 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 earlier by the authors 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 manhours 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 Lance E. Davis et al., American Economic Growth, New York: Harper & Row, 1972: Tables 17.1, 17.2. The deflator used for this was the David-Solar Consumer Price Index (From Table 5.A in P.A. David and P. Solar, "A Bicentenary Contribution to the History of the Cost of Living in America" in Research in Economics History, Paul Uselding, Ed., Vol. 2, Greenwich, CT, 1997, pp. 1-80). 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 as a deflator for current dollar estimates from Paul M. Trescott ("The U.S. Government and National Income, 1790-1860," Trends in the American Economy in the Nineteenth Century (Studies in Income and Wealth, Vol. 24), Princeton, NJ: Princeton University Press for the N.B.E.R., 1960: Table 2, p. 339.

Full-Time Equivalent Manhours in Private Domestic Economy

Estimates of FTE manhours of labor input have been derived by subtracting estimated manhour employment estimates for government, military, and education sectors from the FTE manhours estimates underlying the tables in Abramovitz and David, "Reinterpreting"(1973). 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 manhours 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 manhours estimates in Kendrick, Productivity Trends, 1961, 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 (See General Bibliography) 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 interval weights for forestry and fishing, mining, construction, and manufacturing), and noncommodity production. The manhours per gainful worker coefficients for those aggregates in 1840 were applied in extrapolating the estimates backward to 1800. To obtain manhours estimates for the private economy for the pre-1840 period, the difference in the national and private economy manhours 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"(1973): Table 2, p. 31. The growth rate of the resulting aggregate index, C, is equivalent to a Divisia index, as the weights change each subperiod. The entries for C in Table IV were obtained by the following operation: $1 + C = \textit{antiln}[\theta_R\{\ln(1 + R)\} + \theta_K\{\ln(1 + K)\}]$; they differ slightly from those shown for the same variable in Abramovitz and David, "Reinterpreting" (1973), where the percentage growth rates were erroneously directly aggregated using the indicated weights.

Gross Income Share of Tangible Property

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"(1973): 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 IV and IVA.

The estimates for the nineteenth century described here are clearly not the only treatments of the available evidence that deserve consideration. Others are cited in the General Bibliography.

The periods for which measures were originally calculated are those shown in the Measures over Long Swing Intervals. 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 through 1927 (1925 to 1929).

The growth rates over the "long swings" so distinguished in Frame I were then combined to form the Measures over Long Periods. The rationale behind these combinations as they apply to the nineteenth century is set forth in the text.

Section 3: Sources and Procedures for the Twentieth-Century Data (in Frame II)

The twentieth century tables contain periods (1890-1927 in the long-period measures, 1890-1905 and 1905-27 in the measures over long swings) which provide an overlap between Frames I and II.

The terminal dates of periods beginning 1929 are single-year data for the peaks of the business cycles that mark the termini of long-swing expansions and, in the measures over long periods, the termini of long periods.

In the twentieth century, the major decision involved in combining growth rates over long-swings into long-period measures is also set forth in the text. In addition, we view the long period from 1890 to 1927 as 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 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 of potential productivity growth.

The remainder of this Section of the Appendix provides Sources Notes for Frame II table by table.

Tables 1: I and IA

GNP 1890-1927: John Kendrick, 1961, Table A-XIX, Real gross product.

GPDP 1890-1927: John Kendrick, 1961, Table A-XXII, Real gross product.

GNP 1929-1988: National Income and Product Accounts of the U.S., 1929-88, vols. I and II, Washington, D.C., Government Printing Office, 1992, 1993, Table 1.10.

GNP 1989: Economic Report of President, Jan., 1993, Table B-20, deflated by implicit deflator for Gross Domestic Product, ibid., Table B-2.

Population: 1929-1966 Historical Statistics, Colonial Times to 1870, Table A-7.
1966-1989 Economic Report of the President, Jan. 1993, Table B-29.

GPDP: GNP - Government Product
1929, 1948 NIPA 1929-58 Table 1.8
1966, NIPA, 1959-88 Table 1.8.
1989 Economic Report of President, Jan. 1993, Table B-9.

Tables 1: II and IIA

Output and output per capita: from Tables 1: I and IA
Manhours:
1890-1948: Kendrick, 1961, Table A-XXII.
1948-1989: National Income and Product Account (NIPA), 1992 and 1993 and Survey of Current Business, July 1992.

Aggregate manhours in the Private Domestic Economy were estimated from NIPA as the sum of aggregate manhours of full-time and part-time employees (NIPA Table 6.9) and the aggregate manhours of self-employed persons (family helpers not included).

Aggregate manhours of self-employed persons were calculated as the product of the number of self-employed (NIPA Table 6.7) and the average hours of full-time employees. The average annual hours of full-time employees were derived by dividing the aggregate hours of full-time and part-time employees in each sector by the number of Full-time Equivalent Employees (NIPA Table 6.5).

Output per manhour:
1890-1948. Calculated directly from Kendrick 1961, Table XXII.
1948-1989. Calculated from NIPA data for aggregate output and manhours.

Tables 1: III and IIIA

Population: Tables 1: I and IA

Manhours: Table 1: II

Labor Force:
1890-1905. Estimates by authors using Gainful Workers as a proxy.
1905-1927, from Lebergott, 1964, Table A-3.
1929-1989, President's Economic Report, Feb. 1991, Table B-32. Figures for 1929-1948 are for persons 14 and over; thereafter, 16 and over.

Persons Engaged:
1890-1927, Kendrick, 1961, Table A-XXII.
1929-1989, 1929-1988 from NIPA, 1992 and 1993, Table 6.8; 1989 from NIPA tables in Survey of Current Business, Table 6.8.

Manhours per Person Engaged:
Manhours from Table 1: II. Persons Engaged as above.

Tables 1: IV and IVA

For 1890-1927:

Gross output and manhours from Kendrick, 1961, Table A-XXII.

Capital stock per manhour: Net capital stock from Kendrick, 1961, Table A-XV. Manhours from ibid, Table A-XXII.

Labor quality: Based on figures for the contributions of Age, Sex, and Education in the National Economy in 1909-29 from Denison 1962. The figures are adjusted for the difference between Denison's share weights for labor in National Income and the share weights for labor in Gross National Income in the Private Domestic Economy. There are further adjustments to conform to Denison's later procedures and to allow for the slower growth of workers' education between 1890 and 1909.

Factor shares: Capital's gross factor share is capital's net share in Kendrick, 1961, Table A-10 plus an estimated depreciation rate of 9 percentage points. The allowance for depreciation is the difference between capital's gross compensation as a fraction of gross national income and its net compensation as a fraction of net national income as shown in Kendrick, 1973, Table A-V. Labor's share is 1-minus capital's share.

For 1929-66:

Gross output per manhour: From National Income and Product Accounts, of the U.S. (NIPA), as described in the Sources for Tables 1: I and II, above.

Capital stock per manhour: Capital stock growth rates calculated from the sums of fixed private, reproducible, gross non-residential capital stock and private residential capital stock from Bureau of Economic Analysis, 1993, Tables A-6 and A-9. Manhours growth rates. See Table 1: II, Source, above.

Labor quality contribution: Calculated as the product of the growth rate of the labor quality index and the share of labor, from Denison's (1985, Table 7-1) figures for the contributions of Age, Sex and Education in the Non-residential business economy. The figures are adjusted for the difference between Denison's net share weights and the gross "labor's share weights" used in this table.

Capital quality contribution: Calculated from Jorgenson, 1973, Table 15. The growth rate of the average quality index is multiplied by the gross income shares for total capital (i.e. for reproducible capital and rent on non-reproducible captial combined).

Factor shares. Capital's gross income shares were calculated as the quotients of Private Gross Capital Compensation in the Private Domestic Economy divided by the Gross National Income. Private capital compensation was obtained as the sum of total capital consumption plus proprietor's net income (less the imputed labor compensation of self-employed persons) plus net rental income plus net corporate profits plus net interest income. Underlying figures from Bureau of Economic Analysis, NIPA, op.cit. Labor share is 1 minus capital's share.

For 1966-89:

Output per manhour and capital stock per manhour, as in 1929-66.

Labor quality: Estimates are based on figures for the growth rates of "Labor Composition", which represents the effects of Sex, Experience and Education, as given by Bureau of Labor Statistics (BLS) computer printouts underlying BLS Bulletin 2426 (dec. 1993). The resulting growth rates were raised by the ratio of the growth-rate level of the Denison figures to that of the BLS figures in the overlapping period, 1948 to 1966. The original BLS figures are in parentheses.

Capital quality: Estimates are from the BLS figures for "Capital Composition" in the BLS computer printout referred to above. The resulting growth rate was virtually identical with that of the Jorgenson figure used above in the overlapping period, 1948-66; so no adjustment was made.

Factor shares: See the description for 1929-66.

Addendum on the Vintage Effect and Age-neutral refined TFP, 1929-89. See the Appendix Note on the Vintage Effect in Technical and Statistical Appendices, Appendix 1 (above).

Table 1: V

For sources of underlying data:

Left-hand frame: from the figures in Table 1: IV.

Right-hand frame: The bases of the percentage figures are the growth rates of gross private domestic product per capita from Table 1: I.

The formula from which the sources of per capita output growth are calculated can be derived from Equation (1) in the text in Part One, by subtracting the growth rate of population from each side. So derived, A*, the residual in the equation is the growth rate of crude TFP. The contributions of Factor Composition changes (i.e., Labor Quality plus Capital Quality) are then added to the right-hand side, and E*, as the residual in the equation, is then Refined TFP.

The sources of the figures underlying the numerators in the right-hand frame in the table are as follows:

Manhours per capita: Table II.

Capital per capita: The growth rates of the capital stock itself are from the date sources shown for capital in Table IV. Population growth used to calculate the growth of capital stock per capita is from Table I.

Factor composition from Table IV.

Factor shares used to weight manhours per capita and capital per capita from Table IV.

4.2 Statistical Appendix for Part Two: Notes and Sources for Text Tables

Notes and Sources to Table 2: II-Part A:

For 1929-90, Parts A and B: Underlying data from J.W. Kendrick, "Total Capital and Economic Growth," Atlantic Economic Journal 22(1), 1996: Tables 1A, 2B.

For 1900-10, Part A:

Line 1: The conventional tangible total stock was extrapolated to 1905 from the 1929 level, using the estimate of K_T* for 1903/07-1925/29 from Table 2: I.

Lines 2 and 3: The sum of the tangible reproducible stock was found for 1900-10 as the difference of estimates of Lines 1 and 4. The allocation between Line 2 (structures and equipment) and Line 3 (inventories) was determined from the geometric average of two estimates of the share of inventories in the total: Gallman (1986: 204) gives 0.197. For 1900 in 1900 prices, and other sources, see Abramovitz and David, "Statistical Appendix to Chapter 5 – Growth of the U.S. Capital Stock," Table V-A-1 (unpublished memo, August 1964) for full details.
A corresponding estimate of this ratio was obtained for 1912 (in 1954 prices) based on data in Goldsmith National Wealth Table A-46.

Line 4: Natural resource stock estimate was obtained from Line 1 multiplied by the ratio of non-reproducible to total domestic (non-monetary) wealth) in 1900, as given by Gellman (1986: 204, Appendix Table 4.A.1) in current prices.

Line 5: The non-conventional non-tangible total was extrapolated to (1900-10), centered on 1905 from the 1929 level, using the estimate of H* for 1907-27 from Table 2: II.

Line 6: The education and training stock denoted here as H_1 was extrapolated from the 1929 level, using our estimate of the growth rate of H_0*, the stock of educational capital (schooling only) for 1900-29. This assumes that $H_0* = H_1*$. See Appendix: Statistical Notes to Part Two, Table 2: II: The Intangible Capital Stock Growth before 1929.

Line 7: The 1929 ratio of Line 7 to Line 6 was applied to Line 6 in 1905, as it is found to be very constant for later dates in the table.

Line 8: R&D stock in 1905 was found as a residual from Lines 5 minus the sum of lines 6 and 7.
The average annual growth rates for H_0* in the following periods are estimated (in percent per annum) as: 4.05 in 1900-29; 3.27 in 1929-48; 4.17 in 1948-73; and 3.75 in 1973-90.

Notes and Sources for Table 2: III

For Frame I, 1800-90:

Gross Factor Shares in Gross Private Domestic Income are estimated by imputation of the average *net* rental rate on non-reproducible capital (unimproved land), multiplied by the corresponding current capital-output ratio, and average *gross* rental rate on tangible reproducible assets, multipled by the corresponding current dollar capital output ratios. This was done to obtain indexes of the shares at census dates up to 1909, and the level of the respective shares was fixed by reference to Denison's (1962) estimates for the net shares, and an estimate of capital consumption from Kuznets (1955), Table 9.

The averages for the periods shown were obtained by interpolation to the decade mid-points in the cases of 1835 and 1855, and interval averages of the shares were calculated from the terminal year estimates.

For Frame II, 1890-1989:

The Conventional Gross Factor Shares of Labor and Capital described in the Sources to Table 1: IV and 1: IVA were adjusted, respectively, in order to remove the imputed returns to intangible human capital from labor income, and the imputed returns to intangible non-human capital from property income. The adjustment method made use of augmented gross product and comprehensive capital stock estimates in Kendrick (1994). For further description, see Paul A. David, "A Tale of Two Traverses" (1998): Appendix Note on Statistical Sources for Estimates of Gross Product Elasticities with respect to Inputs of Human Intangible and Non-Human Intangible Capital Services.

General Bibliography

I. Statistical sources, trends and fluctuations

The most convenient, authoritative compilation of long-term statistical information is the U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1870, Washington, D.C., Government Printing Office, 1975.

The following sections contain references to outstanding sources of statistics on particular subjects together with discussions by the compilers of the estimates and of the forces governing their trends and fluctuations.

A. National Product

Paul A. David, in "Real Income and Economic Welfare in the Early Republic," Discussion Paper in Economic and Social History No. 5, March 1996, University of Oxford, presents the basic estimates of national product used in this chapter for the period 1800 to 1840. Alternative estimates may be found in Thomas Weiss, "U.S. labor force estimates and economic growth, 1800-1860" in American Economic Growth and Standards of Living Before the Civil War edited by Robert E. Gallman and John Joseph Wallis, Chicago and London: University of Chicago Press, 1992. The figures underlying the estimates used in this chapter for the decades from 1840 to 1890 were made by Robert Gallman, "Gross national product in the United States, 1834-1909" in Output, Employment and Productivity in the United States After 1800 edited by Dorothy S. Brady, National Bureau of Economic-Research, Studies in Income and Wealth, vol. 30, New York: Columbia University Press, 1966. These, however, have now been superseded by his chapter in Vol. II of the Cambridge Economic History of the United States, "Economic Growth and Structural Change in the Long Nineteenth Century."

The basic data for the decades 1890 to 1930 are to be found in John Kendrick, Productivity Trends in the United States, Princeton, N.J.: Princeton University Press for National Bureau of Economic Research, 1961. Beginning 1929, the standard figures are those of the U.S. Bureau of Economic Analysis as presented in Department of Commerce, National Income and Product Accounts of the United States, vol. I, 1929-1958 and vol. II 1959-1988, Washington, D.C.: Government Printing Office, 1992 and 1993. The figures are carried forward in the Department's Survey of Current Business.

B. Population, Immigration and the Foreign Born

A classic publication on the growth of the U.S. population is that of Conrad and Irene B. Taeuber, The Changing Population of the United States, New York: Wiley, 1958. The historical data are reviewed and discussed by Michael R. Haines in "The population of the United States, 1790-1920" in this volume. His chapter has a useful bibliographical note. Another analysis of the forces governing long-term trends and fluctuations is that of Richard A. Easterlin in his chapter in This Volume (CEHUS, vol. 3).

Simon Kuznets and Ernest Rubin, "Immigration and the Foreign Born", National Bureau of Economic Research, Occasional Paper 46, 1954, is a valuable paper of statistics and analysis bearing both on population and the labor force.

C. Labor Force, Employment, Manhours.

Stanley Lebergott's Manpower in Economic Growth: The American Record Since 1800, New York: McGraw Hill, 1964 is a basic source of labor force figures together with an insightful analysis. See also the references above to David and Weiss for the nineteenth century, to Kendrick for the early twentieth century and to the National Income and Product Accounts for the period since 1929. All are cited above in Section I.A of this Bibliography.

D. Capital Stock

The basic estimates for much of the nineteenth century are the work of Robert E. Gallman, "The United States Capital Stock in the Nineteenth Century" in Long-term Factors in American Economic Growth, edited by Stanley L. Engerman and Robert E. Gallman, Chicago and London: University of Chicago Press for National Bureau of Economic Research, Studies in Income and Wealth, vol. 51, 1986. For more recent data from 1890 to 1950 see John W. Kendrick, cited above in Section I.A. Underlying Kendrick's estimates are those of Raymond Goldsmith, A Study of Saving in the United States, vol. III, Princeton, J.J.: Princeton University Press, 1956. The U.S. Department of Commerce, Bureau of Economic Analysis, "Fixed Reproducible Tangible Wealth of the United States, 1925-89. Washington, D.C.: U.S. Government Printing Office, Jan. 1993, contains the basic official estimates of the total and its principal components. The series is continued annually in the Survey of Current Business.

II. Long Swings in Economic Growth

The pioneering studies of this subject were made by Simon Kuznets in Secular Movement in Production and Prices, Boston: Houghton-Mifflin, 1930 and Arthur F. Burns, Production Trends in the United States Since 1870, New York, National Bureau of Economic Research, 1934. Brinley Thomas, Migration and Economic Growth, Cambridge: Cambridge University Press, 1954 is a thorough study of the inverse relations between long swings in British and American growth and their connections with the movements of population and capital.

Simon Kuznets' Capital in the American Economy, London: Oxford University Press for Nat. Bur. Econ. Research, 1961, Ch. 7 is a more mature and rounded statement of his view. Moses Abramovitz in "The Nature and Significance of Kuznets' Cycles", Economic Development and Cultural Change, IX, No. 2 (April, 1961), 225-48, presents a quite different hypothesis about the underlying causes of the long swings. This article also offers a brief survey of the preceding literature and extensive reference to the relevant evidence.

Notable studies of particular aspects of long swings may be found in Kuznets, "Long Swings in the Growth of Population and Related Economic Variables", Proceedings of the American Philosophical Society, February 1958, 25-52; Kuznets and Rubin, "Immigration and the Foreign Born", op.cit in Section I.B, above; Jeffrey G. Williamson, American Growth and the Balance of Payments, Durham, North Carolina: University of North Carolina Press, 1964; Richard Easterlin, Population, Labor Force and Long Swings in Economic Growth, New York: National Bureau of Economic Research, 1968 (distributed by Columbia University Press, N.Y. and London); and Moses Abramovitz, The Monetary Side of Long Swings in U.S. Economic Growth (1973), reissued as Publication No. 471 by the Center for Economic Policy Research of Stanford University, 1997.

III. Growth Accounting and the Sources of Growth

Jan Tinbergen, "Zur Theorie der langfristigen Weltwirschaftsentwicklung", Weltwirtschaftliches Archiv, 55, No. 3 (1942), was the first to present growth accounts leading to an estimate of the growth of crude total factor productivity. Moses Abramovitz, "Resource and Output Trends in the United States since 1870", American Economic Review, May 1956 and Robert Solow, "Technical Change and the Aggregate Production Function," Review of Economic Statistics (August, 1957) were the papers that first captured a wide interest in growth accounting among economists. Solow's paper presents the basic theory of the subject, and both papers revealed the dominant role of total factor productivity in accounting for growth in the twentieth century. John Kendrick's Productivity Trends in the United States, op.cit. in Section I.A above, is a full length quantitative study of economic growth in the growth accounting framework. It presents basic statistics for the United States between the 1870s and the 1950s and is carried forward in his Postwar Productivity Trends in the United States, 1948-1969, New York: National Bureau of Economic Research, 1973.

Major studies that have led to the estimation of the contributions of education and other aspects of labor quality and of capital quality and thus to the refinement of total factor productivity growth are: Edward F. Denison, Accounting for United States Economic Growth, 1929-1969, Washington, D.C.: The Brookings Institution, 1974; Dale W. Jorgenson, Frank Gollop and Barbara Fraumeni, Productivity and U.S. Economic Growth, Cambridge, MA: Harvard University Press, 1987, and U.S. Department of Labor, Bureau of Labor Statistics, Labor Composition and U.S. Productivity Growth, 1948-1990, Bulletin 2426.

IV. Historical Studies of U.S. Technological Progress

There is a very large historical literature dealing with the technological progress of particular industries and processes and another large theoretical literature. Good selections of work bearing on these subjects may be found in Nathan Rosenberg, The Economics of Technological Change, Harmondsworth, England: Penguin Books, 1971, and Exploring the Black Box: Technology, Economics and History, Cambridge: Cambridge University Press, 1994. David Mowery and Nathan Rosenberg, "Technological Change in the United States in the Twentieth Century," in The Cambridge History of The United States, S.L. Engerman and R.E. Gallman (eds.). This volume is an authoritative survey of major twentieth-century developments.

The following are a number of important historical studies of technological progress that have a broad significance for American growth.

H.J. Habakkuk, American and British Technology in the Nineteenth Century, Cambridge: Cambridge University Press, 1962; Nathan Rosenberg, Technology and American Economic Growth, New York: Harper and Row, 1972; Paul A. David, Technical Choice, Innovation and Economic Growth, New York: Cambridge University Press, 1975; Gavin Wright, "The Origin of American Industrial Success 1879-1940," American Economic Review, 80, No. 4 (September 1990), 651-68; Paul A. David and Gavin Wright, "Increasing Returns and the Genesis of American Resource Abundance," Industrial and Corporate Change, 6(2), 1997, pp. 203-45.

V. The Slowdown

The slower growth of productivity during the last quarter-century has generated an outpouring of papers and books. We notice here a few contributions to the subject, following the outline of discussion in the text.

On mismeasurement: Martin Baily and Robert J. Gordon, "Measurement Issues, the Productivity Slowdown, and the Explosion of Computer Power", Brookings Papers on Economic Activity, 18, No. 2, 347-420.

On impediments to investment and innovation, F. Denison (ed.), Accounting for Slower Economic Growth, Washington, D.C.: The Brooking Institution, 1979; Michael L. Dertouzos, Richard K. Lester and Robert M. Solow, and the MIT Commission on Industrial Productivity, Made in America: Regaining the Productive Edge, Cambridge, MA, London: MIT Press, 1989.

On the potential for technological progress and the shift of technological regimes: Zvi Griliches, "Productivity Puzzles and R&D: Another Non-explanation", Journal of Economic Perspectives, 2, No. 4, Fall, 1988, 9-21; "Patent Statistics as Economic Indicators – A Survey," Journal of Economic Literature, S. Gilfillan, The Sociology of Invention, Chicago, 1934; C. Freeman and C. Perez, "Structural Crises of Adjustment, Business Cycles and Investment Behavior," in G. Dosi et al., (eds.), Technical Change and Economic Theory, London: Pinter, 1988; Paul A. David "Computer and Dynamo: The Modern Productivity Paradox in a Not-too-distant Mirror," in Technology and Productivity: The Challenge for Economic Policy, Paris: OECD, 1991; Elhanan Helpman, ed., General Purpose Technologies and Economic Growth, Cambridge, MA: MIT Press, 1998.

VI. The International Perspective

Angus Maddison's Monitoring the World Economy, 1820-1992, Paris: OECD, 1995 is the most important general survey of data bearing on economic growth over a long period of time. It is the culmination of work stretching back over a quarter of a century which yielded a rich series of books and papers. Maddison's work follows on that of Simon Kuznets who was the pioneer of such international comparative studies. Kuznets' work led up to his classic book, Modern Economic Growth: Rate, Structure and Spread, New Haven and London: Yale University Press, 1966.

For more recent years, readers should also consult the Penn World Tables, prepared under the direction of Robert Summers and Alan Heston. The Tables, Mark V, appeared in the Quarterly Journal of Economics, 1991. These and later versions of the Tables are available on computer diskettes from the authors at the Department of Economics, University of Pennsylvania.

All these data render the current price accounts of national income and product expressed in national currencies into a common monetary unit based on the relative purchasing powers of the national currencies. This procedure is carefully explained in the series of volumes written by Sidney Kravis, Robert Summers and Alan Heston for the United Nations

International Comparison Project. Important work on purchasing power parity ratios is now carried on by the OECD and Eurostat.

Analytical studies in recent years have been heavily concerned with the theory and empirical foundations of the hypothesis that the levels of GDP per capita and GDP per manhour of countries tend to converge and that laggard countries tend to catch up with a leading country or countries. Thorstein Veblen, Imperial Germany and the Industrial Revolution, New York, 1915, and Alexander Gerschenkron, "Economic Backwardness in Historical Perspective" in The Progress of Underdeveloped Countries, B. Hoselitz (ed.), Chicago: Chicago University Press, 1952, were early anticipations of contemporary work. Edward Denison, Why Growth Rates Differ, Washington, D.C.: The Brookings Institution, 1967, was a notable empirical study of postwar experience in Europe and the U.S.A.

Contemporary interest in the subject begins with papers by Moses Abramovitz, "Catching Up, Forging Ahead and Falling Behind", Journal of Economic History, 466, No. 2 (June 1986) and William J. Baumol, "Productivity Growth, Convergence and Welfare," American Economic Review, 766, No. 5 (December 1996). Among the studies that followed, there has been an effort to identify the limits of the simple, or unconditional, hypothesis and the conditions prerequisite to strong convergence and catch-up. See Robert J. Barro, "Economic Growth in a Cross-Section of Countries," Quarterly Journal of Economics, 106, No. 2 (1991), William Baumol, Sue Anne Batey Blackman and Edward Wolff, Productivity and American Leadership: The Long View, Cambridge, MA: The MIT Press, 1989 and Moses Abramovitz and Paul A. David, "Convergence and Deferred Catchup," in The Mosaic of Economic Growth, edited by Ralph Landau, Timothy Taylor and Gavin Wright, Stanford, CA: Stanford University Press, 1996.

VII. References to Works Cited in Endnotes

(The works referenced here are not cited in text footnotes.)

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