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Total Factor Productivity Growth in Historical Perspective

Robert Shackleton
Congressional Budget Office
Bob.Shackleton@cbo.gov

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Abstract

This paper reviews the broad contours of total factor productivity (TFP) growth in the U.S. economy since 1870, highlighting the contribution of various technological innovations to the growth of different sectors of the economy. The paper also notes the correlation between TFP growth and improvements in general health and well-being as reflected in changes in life expectancy. Finally, the paper discusses the potential for continued growth in TFP in the future.

Introduction

Economists have long found that they can explain only a portion of economic growth by the growth of inputs to production, such as the number of hours worked or the amount of capital used. The unexplained (or residual) portion, which presumably reflects advances in production technologies and processes, is conventionally attributed to all of the production factors together and is referred to as total factor productivity (TFP) growth.[1] Over the past century or more, gains in TFP have accounted for well over half the growth in measured U.S. labor productivity (output per hour of work)—that is, they have contributed more to the measured growth of labor productivity than has growth in the amount of capital per worker—and they are likely to be critical for future economic growth as well.

To provide a sense of the importance of TFP to long-term economic growth, this paper summarizes current understanding of historical TFP growth in the United States. It describes how trends in both industry-specific TFP growth and overall TFP growth have varied over time, and discusses some of the important technological and institutional sources of TFP growth. It also touches on ways in which estimates of TFP growth ignore other important innovations that have contributed to improvements in well-being during the same period. Finally, the paper discusses how TFP growth might evolve over the 21st century.

Researchers in growth accounting vary in their approaches, in the data they use and the periods of time they analyze, and in the extent of economic activity they analyze and the factors they try

[1] Some experts prefer the term "multifactor productivity (MFP) growth" on the argument that studies do not really measure all factors that may contribute to economic growth, as implied by the concept of TFP.

to take into account.[2] This paper focuses on estimates of TFP that draw on the National Income and Product Accounts (NIPAs) published by the Bureau of Economic Analysis and that measure the residual share of gross domestic product (GDP) as reported in the NIPAs. As a consequence, such estimates of TFP are only as comprehensive a measure of economic improvement as is GDP itself. Because the NIPAs focus overwhelmingly on the value of goods and services exchanged in markets, they (and the TFP measures developed from them) do not explicitly measure improvements in well-being—for example, more leisure time, or improvements in health and life expectancy that result from technological innovations or from policies such as environmental regulations—that are not measured in market transactions. (However, medical advances, by improving labor productivity and extending working lives, may indirectly contribute to growth in measured GDP.)

This paper focuses on a rather broad measure of TFP that includes factors that some other studies account for separately. For example, researchers who explicitly account for improvements in the quality of the labor force attributable to educational attainment find that, over the past half-century or so, those improvements have accounted for roughly one-third of the growth that this paper attributes to TFP.

[2] Most statistics presented here draw from research by Field (2012) or by Gordon (1992, 1996, 2000, 2010, and 2012) but draw from other studies as well. The productivity statistics generally apply to the private nonfarm sector or the nonfarm business sector (which excludes housing). Statistics for life expectancy draw from Carter et al. (2006), vol. 1, pp. 440–441.

Sources of Growth

Productivity growth is often popularly associated with the invention of new products, tools, and technical processes that not only reduce the cost of extracting or producing raw materials and energy but also reduce the cost of transforming those inputs into finished products. Moreover, quantities of inputs and outputs are easier to measure in manufacturing than in complex service industries, such as health care. Researchers therefore tend to concentrate on the production of goods—and on manufacturing, in particular—in seeking sources of productivity growth.

Manufacturing has indeed tended to register significant growth in TFP, and, in some periods—the 1920s, in particular—has accounted for the bulk of aggregate TFP growth. Nevertheless, with the exception of a few years during World War II, manufacturing has never employed much more than a third of the labor force or produced more than a third of nominal output. As discussed below, at various times rapid productivity growth has occurred in other sectors of the economy as well.

Outside of manufacturing and a few other industries whose inputs and output are easily measured, such as electricity generation, serious data problems hinder the ability to estimate historical (and even current) TFP growth. Growth is particularly difficult to measure in many service sectors. The health sector is perhaps the most notable and important case: The data show little improvement in TFP in health care despite dramatic and continuous improvements in health and despite an average increase in life expectancy at birth of about two and a half years per decade over the past century and a half. Although estimates of TFP provide a measure of many

elements of economic progress, they fail to capture large and important historical improvements in well-being.

Another significant problem is that modern methods of national accounting were not widely adopted until after World War II, and the quality of historical economic data declines dramatically as one looks further into the past, especially into the 19th century. As a consequence, estimates of growth (and of contributions to growth) for that period are considerably less reliable than are estimates for the postwar era.

Nevertheless, the broad pattern that emerges from the current literature is that, in the nearly 150 years since the Civil War, measured private-sector nonfarm TFP in the United States has grown at an average rate of roughly 1.6 percent to 1.8 percent annually, but has experienced several surges occurring in varying parts of the economy (by no means limited to the manufacturing sector), followed by periods of comparatively low TFP growth. [3] As shown in Table 1, the pattern includes a period of substantial growth during the last third of the 19th century, a major wave that peaked during the Great Depression and reached a trough during the 1970s, and a moderate resurgence during the 1990s and early 2000s. Growth in TFP was paralleled by a similar, contemporaneous wave of improvement in life expectancy at birth, such that a child born in 2010 could expect to live nearly 35 years longer than a child born in 1870. That improvement suggests that the conditions that made the wave in measured productivity possible involved sweeping advances that contributed to progress across many different types of economic activity.

[3] The expansion of the nonfarm sector, of course, was underlain by rapid labor productivity growth in agriculture—initially the result mainly of capital investment but later, increasingly, of TFP growth. That growth in productivity made possible a long secular decline in agriculture's share of the U.S. labor force, from more than 80 percent in the early 19th century to just over half in 1870, about 40 percent by 1900, and less than 20 percent by the beginning of World War II, releasing workers to fuel the growth of other industries.

Table 1: Improvements in Living Standards, 1870 to 2010

Period	Total Factor Productivity (Average Annual Growth Rate)	Main Sources of Growth	Change in Life Expectancy at Birth (Years per Decade)
1870 to 1900	~ 1.5% to 2%	Transportation, communications, trade, business organization	1.3
1900 to 1920	~ 1%		3.2
1920s	~ 2%	Electricity, internal combustion engines, chemicals, telecommunications	5.6
1930s	~ 3%		3.2
1940s	~ 2.5%		5.3
1950 to 1973	~ 2%	Widespread	1.4
1973 to 1990	< 1%		2.4
1990s	> 1%	Information technology	1.7
2000s	~ 1.5%		1.4
1870 to 2010	~ 1.6% to 1.8%		2.3
1950 to 2010	~ 1.2% to 1.5%		1.8

Sources: Field (2012), Gordon (2010), Carter et al. (2006), Center for Disease Control and Prevention (http://www.cdc.gov/nchs/data/dvs/deaths_2010_release.pdf).

Growth in the 19th Century

Early 19th-century economic growth resulted mainly from rapid increases in population, land, and capital, rather than from growth in TFP, with improvements in labor productivity stemming primarily from capital deepening—that is, more capital per worker. Significant growth in productivity is believed to have occurred mainly in transportation and communications prior to the Civil War, driven by two important innovations: the steam locomotive and the telegraph. For about a 15-year period bracketing the Civil War, however, the data suggest an overall decline in TFP because of disruptions from hostilities surrounding the war.

For the period from 1870 to 1900, recent research suggests that growth in private nonfarm TFP averaged near 2 percent per year, considerably higher than previously believed.

- The evidence indicates that railroads and telegraphs laid the groundwork for dramatic increases in labor productivity in distribution and trade even before 1870. Those increases were so large that labor productivity in those sectors substantially exceeded that in manufacturing until the 1920s, even as productivity grew more rapidly in manufacturing than in those sectors throughout the late 19th and early 20th centuries.
- The period also saw the initial application of key mid-19th century scientific advances in thermodynamics, physical chemistry, and electromagnetism, leading to the introduction of electricity generation and internal-combustion engines.
- The transportation and trade sectors nursed much of the initial development of the modern business enterprise, using innovations in legal structure and management to coordinate the movement of goods and the turnover of inventory on a national scale. Consistent with the view that institutional developments contributed to TFP growth by rationalizing the use of factor inputs, rapid TFP growth spread to other sectors such as mining and manufacturing in the late 19th and early 20th centuries as companies in those sectors began to adopt modern business structures and practices.

Innovations in the late 19th century were not confined to production, transportation, and trade: Improvements in nutrition and public sanitation resulted in a 6-year increase in life expectancy in the United States between 1850 and 1870, in spite of the Civil War, and a further 4-year increase

between 1870 and 1900. All told, life expectancy at birth rose from about 38 years to 48 years over the half-century. That improvement contributed to higher output by increasing the labor force in any given year and by increasing the returns to educating children who were more likely to survive to adulthood. However, the improvement does not appear in the data explicitly as an increase in productivity.

The "Big Wave" of the Early 20th Century

After averaging somewhat more than 1 percent annually from 1900 to 1920, measured TFP growth accelerated to nearly 2 percent on average during the 1920s and around 3 percent during the 1930s. Researchers attribute that "big wave" primarily to four clusters of critical innovations—electricity generation, internal-combustion engines, chemicals, and telecommunications—with nearly all of the important innovations in those clusters already in place well before World War II.[4] Although the capital equipment associated with those innovations was produced in the manufacturing sector, much of the productivity growth occurred elsewhere, particularly during the 1930s.

- Electricity transformed American energy use by dramatically improving the distribution of power in manufacturing and by making possible the widespread introduction of consumer appliances.[5]

[4] A complementary hypothesis proposes that the dramatic reduction in immigration from the 1920s through the 1970s tended to raise domestic real wages and encourage greater investment and more labor-saving innovation than would have been the case otherwise.

[5] Despite the spread of electricity and automobiles, energy use per unit of real output has steadily declined by about 75 percent over the past 90 years, even as total energy use has increased more than fourfold.

- Internal-combustion engines revolutionized motor and air transport and laid the basis for a suburban society.
- Innovations in chemistry produced petrochemicals (including fertilizers for agriculture), plastics, and pharmaceuticals (including antibiotics).
- Advances in telecommunications yielded telephones, radios, and televisions, and provided unprecedented access to mass entertainment and information.

Again, note that the narrative focusing on growth in measured TFP ignores the rapid improvement in life expectancy of about 12 years—from 48 years to nearly 60 years—between 1900 and 1930. That 25-percent increase in life expectancy constitutes an extraordinary improvement in human welfare that does not appear in the productivity statistics.

The 1920s. The initial spurt in measured TFP growth occurred during the investment boom of the 1920s, as electric utilities and the proliferation of automobiles cleared the way for the electrification of industrial activity, the development of assembly lines, and the first rapid expansion of suburban neighborhoods. The investment boom was dominated by structures, with residential construction exceeding 8 percent of GDP from 1924 to 1927 (helping to expand the real housing stock, which grew by about 50 percent from 1922 to 1929). Nonresidential construction also expanded as factories were built to exploit electricity distribution and assembly-line processes. Nevertheless, structures contributed almost entirely to capital deepening rather than to TFP growth during the 1920s: An estimated 84 percent of aggregate TFP growth took place in the manufacturing sector, which saw about 5 percent TFP growth per year on average.

The 1930s. Although the construction boom ended in a financial crisis at the close of the 1920s and was followed by a long depression, the decade of the 1930s appears to have experienced the most rapid TFP growth of any comparable period in American history, with average annual growth rates of 3 percent or more. In contrast with the experience of the 1920s, that growth was widely diffused throughout the economy: TFP growth in manufacturing fell to half its rate of the preceding decade, persisting most notably in electrical machinery and equipment, aircraft, and chemical engineering, and accounted for only about half the growth in aggregate TFP. However, the decade also saw strong growth in private investment in research and development throughout industry, and other sectors, including electric-power generation and distribution, transportation, communication, and civil and structural engineering, experienced unusually rapid TFP growth. Important developments in civil and structural engineering included construction techniques for bridges, tunnels, dams, and highways, as well as the development of appropriate designs for suburban infrastructure. Moreover, the decade saw a political consensus emerge in favor of increased regulation of housing and land use in the suburbs, which had begun to expand dramatically during the 1920s but which had suffered from design flaws that dramatically limited the growth of real housing services. Following the creation of the Federal Housing Administration in 1934, jurisdictions increasingly adopted newly developed principles of subdivision design with complementary infrastructure—utilities, parks, schools, roads, and the efficient layout (or platting) of blocks—appropriate to automobile-based transportation. Principles laid down in the 1930s thus guided the rapid growth of suburbs after real housing investment finally returned to its 1926 peak in 1950.

The 1940s. The rapid productivity improvements of the Depression years laid the groundwork not only for the rapid mobilization for production during World War II but also for the "golden age" of postwar productivity growth in the 1950s and 1960s. This interpretation contrasts with the common view that persistent growth in the postwar period resulted from research and development, investment, and cumulative productivity growth related to the war effort itself, as exemplified by extraordinary improvements in aircraft production and shipbuilding and by the volume of military output. In fact, however, labor productivity in the munitions industries—the result of TFP and capital deepening combined—increased by a total of only about 25 percent from 1939 to 1944, and TFP grew at an estimated annual average of about 2.6 percent from 1941 to 1948, significantly lower than during the preceding decade. The evidence suggests that, if anything, the war effort absorbed resources that might otherwise have been used to improve production for the private sector. However, the war did contribute to improved medical care: Over the 1940s, innovations from modern antibiotics to blood banks helped to increase average life expectancy by over 5 years in a single decade, from 63 to over 68.

The Later 20th Century

The 1950s and 1960s. What is commonly viewed today as the golden age of productivity growth—the postwar period from 1948 to 1973—combined extensive capital deepening with TFP growth that averaged about 1.5 percent to 2.0 percent annually to yield dramatic improvements in living standards. In the context of the big wave, however, the golden age may be more accurately interpreted as the full final exploitation of an earlier burst of innovations through electrification, suburbanization, completion and increasing exploitation of the highway

system, and production of consumer appliances. Interestingly, TFP growth in manufacturing fell to an average annual rate of around 1.5 percent, accounting for only about a quarter of aggregate TFP growth during the period—and accounting for essentially all of the decline in aggregate TFP growth from the Depression-era peak. Substantial shares of TFP growth continued to come from electricity generation, transportation, telecommunications, and housing—all benefiting in no small part from the government's continuing build-out of the transportation network.

The 1970s and 1980s. By about 1970, however, the bulk of the gains in TFP associated with the innovations of earlier periods had been exploited. The productivity slowdown is usually dated to 1973 but, in retrospect, can be traced to the late 1960s. It affected industries throughout the economy except for services, which actually saw substantial improvement in TFP growth in the years leading up to 1973. Beginning around 1973, however, aggregate TFP growth slowed dramatically to well under 1 percent per year on average through the late 1980s, driven by a widespread slowdown in TFP growth in specific industries. In some cases, such as in the electric-utility sector, unsuccessful attempts to extend the ongoing exploitation of economies of scale actually led to significant decrements in productivity.

Researchers still have not reached consensus on a comprehensive explanation for the slowdown. Declining TFP growth in manufacturing accounted for only a modest share of the aggregate slowdown. It appears likely that the exhaustion of gains associated with the expansion of the transportation network played a significant role, and that a decline in private non-military research and development may have contributed to the slowdown as well. Whatever the case, the widespread view that the decline stemmed from the dramatic rise in energy prices after 1973

fails to account for the lack of a similarly strong slowdown in other countries or for the failure of TFP growth to recover after energy prices declined in the 1980s.

The 1990s and 2000s. The resurgence in private nonfarm TFP growth since the early 1990s reflects strong TFP growth concentrated largely in the manufacturing sector and particularly in information technology (IT). However, industries throughout the economy have experienced gains in TFP, even when the benefits of IT capital deepening in non-manufacturing industries are taken into account. Nevertheless, the resurgence has been modest compared with the big wave of the mid-20th century, and some evidence suggests that the resurgence is slowing.

Reflecting the pattern of measured TFP growth—but not contributing to it—improvements in health care continued to contribute to life expectancy throughout the second half of the 20th century, but at only about half the pace of the preceding half-century. Life expectancy rose at a fairly steady rate of nearly 2 years per decade between 1950 and 2010, from 68 years to 79 years.

Future TFP Growth

Although forecasters generally project relatively strong continued growth in TFP over the next decade or so, some researchers express concern about several trends that could constrain productivity improvements over the longer term.[6] They worry that it will become increasingly difficult to increase the educational attainment of a labor force when the great majority of workers already have at least a high-school degree and a large portion have attended college. They also worry that the recent concentration of TFP growth in information and communication

[6] See, for example, Gordon (2012).

technology indicates that widespread improvement in many different areas of technology, as in the past century, may have been a one-time event that cannot be replicated. They are concerned that manufacturing's contribution to overall TFP growth will decline as the sector's nominal share of output continues to shrink, while rising demand for services with little measured TFP growth, such as health care, will exert an additional drag on aggregate TFP. Some observers express further concern that resource constraints (such as rising costs of fossil fuel extraction and changes in climate resulting from the burning of fossil fuels) will require continual innovations and continual increases in expenditures simply to maintain current productivity levels.

Other researchers note factors that could work in the opposite direction, helping to maintain or even increase TFP growth rates. They suggest that, much as the key innovations of the late 19th century were not fully exploited until the big wave of TFP growth occurred several decades later, recent innovations in information technology, communications, medicine, and elsewhere may yield substantial growth well into the future. They also note that, over the long term, TFP growth is limited only by the ability of innovators to develop new technologies, and that a larger population—especially a larger global population—makes possible a larger pool of talent to be devoted to research, and thus opens up more potential for innovation.

Projection of Long-Term Trends. Simple calculations suggest that, as long as historical trends in sectoral labor productivity persist, the gradual decline of manufacturing's share of nominal output, by itself, is not likely to cause a significant decline in aggregate TFP. For example, if one uses available data for the past 60 years to calculate industry-specific trends in hours worked, real value added per hour worked, and relative prices, and projects those average trends 30 years

into the future, the resulting projections of sectoral shares of nominal value added and aggregate real value per hour worked yield a remarkably stable trend.[7] Such results suggest that, as long as long-term historical trends in sectoral labor productivity persist, aggregate labor productivity growth will average somewhat less than 1.7 percent per year between 2010 and 2040, about 0.2 percentage points lower than its 60-year average, even if manufacturing employment declines from its current employment share of about 10 percent to 7 percent (see Figures 1 and 2). Comprehensive multisectoral models that use detailed sector-level productivity growth projections produce relatively constant growth in aggregate TFP as well.[8]

Further Considerations. The themes outlined above provide several reasons why measured TFP growth could continue at a fairly steady rate for some period to come, but also provide several counterarguments pointing to a gradual slowdown over an extended period of time. Whatever the case may be, a few additional observations are worth considering. First, TFP growth is likely to have been considerable—but poorly measured—in many service sectors during at least part of the historical period, and such growth is likely to continue in the future. Researchers are therefore seeking to understand and predict the evolution of economic forces that are at best very imperfectly measured. Statistical offices such as the Bureau of Economic Analysis are making substantial efforts to improve the measurement of prices and output in some of those sectors—health care, in particular—and those improvements can be expected to increase the measured rate of TFP growth. Nevertheless, it is not clear how improvements in accounting

[7] Industry accounts from the Bureau of Economic Analysis include 60-year data series for 8 industries (durable manufacturing, non-durable manufacturing, mining, construction, transportation, finance, government, and other), providing information both on total hours worked and on value added—that is, outputs minus inputs purchased from other industries—measured in real (inflation-adjusted) and nominal (unadjusted) terms. Growth rates for sectoral labor shares are projected forward and are prorated to sum to unity.

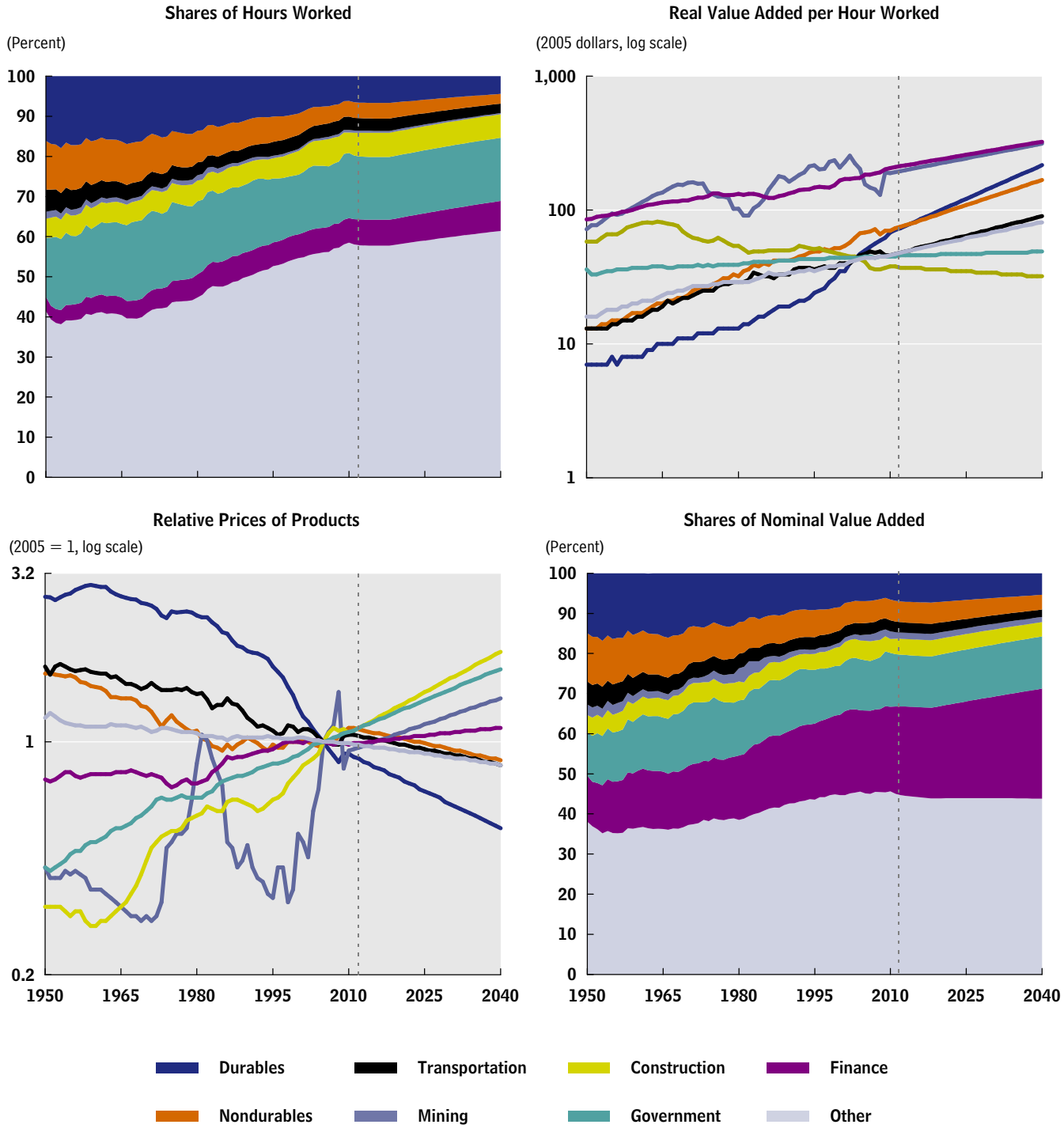
[8] Peter Wilcoxen (Syracuse University), personal communication, and Jeffrey Werling (University of Maryland, College Park), personal communication.

of such growth, incorporated into both the historical data and the projections, would affect the comparative optimism of projections. Furthermore, extending such improvements back into the long-term historical data would be extremely difficult.

It bears emphasis that measured TFP growth applies only to the growth of measured output, which is at best a poor proxy measure of improvements in well-being resulting from economic progress. Indeed, innovations could continue to provide significant growth in human welfare—for example, further decreases in mortality—without enhancing conventional measures of TFP. Conversely, it would be possible for innovations to contribute to measured TFP growth but to be offset by other developments, such as environmental deterioration, that are not measured in the NIPAs.

Finally, the sweep of the 20th century underlines the extent to which long-term TFP growth and economic growth in general have been influenced by the development of energy and transportation infrastructure suited to the expansion of suburbs. To the extent that policies to address the potential problems associated with climate change will require adjustments to patterns of land use, energy production and consumption, and transportation, those policies could have substantial but highly uncertain effects on the growth of TFP.

Figure 1.
Historical and Projected Measures of Labor Productivity, by Sector



Sources: Bureau of Economic Analysis (historical data) and author's calculations (projections).

Note: As used here, finance includes finance, insurance, and real estate services.

Figure 2.
Historical and Projected Annual Growth in Real Value Added per Hour Worked
(Smoothed percentage of annual growth)

Sources: Bureau of Economic Analysis (historical data) and author's calculations (projections).

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