The Most Technologically Progressive Decade of the Century

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Because of the Depression's place in both the popular and academic imagination, and the repeated and justifiable emphasis on output that was not produced, income that was not earned, and expenditure that did not take place, it will seem startling to propose the following hypothesis: *the years 1929–1941 were, in the aggregate, the most technologically progressive of any comparable period in U.S. economic history.*[1] The hypothesis entails two primary claims: that during this period businesses and government contractors implemented or adopted on a more widespread basis a wide range of new technologies and practices, resulting in the highest rate of measured peacetime peak-to-peak multifactor productivity growth in the century, and secondly, that the Depression years produced advances that replenished and expanded the larder of unexploited or only partially exploited techniques, thus providing the basis for much of the labor and multifactor productivity improvement of the 1950's and 1960's.

The hypothesis does not imply that all of the effects of the advances registered in the decade were immediately felt in the productivity data, nor, on the other hand, does it dismiss the significance of larder-stocking during the 1920's and earlier, upon which measured advance built. Rather, it draws our attention to the probability that progress in invention and innovation in the 1930's was significant, in ways not well appreciated, both in facilitating the remarkable U.S. economic performance before and during World War II, and in establishing foundations for the prosperity of the 1950's and 1960's.

I. Output Growth, Input Growth, and the Productivity Data

The starting point for this exploration is macroeconomic data on real output growth, labor force growth, and the growth of the real capital stock, series that underlie our conclusions about trends in labor productivity and multifactor productivity growth. Major contributors to the construction, adjustment, and interpretation of these data have included Edward Denison, John Kendrick, Dale Jorgenson, Zvi Griliches, Robert Solow, Moses Abramovitz, Paul David, and Robert J. Gordon. Of these, only the last three have attempted systematic historically informed overviews of the twentieth century as a whole. There is now an emerging consensus that, looking back over the course of U.S. history, the period between roughly 1905 and 1966 experienced exceptionally high rates of multifactor productivity growth, substantially higher than those evidenced in the decades preceding and following, when a much higher fraction of labor productivity growth is to be attributed simply to capital deepening (Abramovitz and David, 1999, 2000; Gordon, 1999, 2000a, b, c).

Within that plateau, the highest rates of MFP growth appear to have occurred in the second quarter of the century. Although the question of *when* within the 1905–1966 period peak MFP growth took place was not central to their research agenda, Abramovitz and David did conclude that it happened in advance of mid-century: "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" (2000, p. 29).[2] Gordon

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[1] The reference in the title to a decade reflects poetic license: my interest here is in a 12-year period. See Broadus Mitchell (1947) for precedent.

[2] See Table 1. Abramovitz and David's principal interpretive emphasis was on the contrast between economic growth based on the accumulation of physical capital in the nineteenth century and the knowledge based growth of the twentieth century. The terms total factor productivity (TFP)

TABLE 1—COMPOUND ANNUAL AVERAGE GROWTH RATES OF PRIVATE NONFARM MFP, UNITED STATES, 1870–1996

Abramovitz/David, 1999		Gordon, 2000b	
		1870–1891	0.39
1890–1905	1.28	1891–1913	1.14
1905–1927	1.38	1913–1928	1.42
1929–1948	1.54	1928–1950	1.90
1948–1966	1.31	1950–1964	1.47
		1964–1972	0.89
1966–1989	0.04	1972–1979	0.16
		1979–1988	0.59
		1988–1996	0.79

Notes: The Abramovitz-David capital input estimates include an adjustment for vintage effects, based on the presumption that more recently installed capital embodies unmeasured quality improvements (see text). Their output series includes housing services and their input series includes the housing capital stock, in contrast to Gordon's, which exclude housing in both numerator and denominator. Gordon's data are before his adjustments for the composition and quantity of labor and capital; for discussion of these adjustments, see text.
Sources: Abramovitz/David: 1999, Table 1:IVA; Gordon: 2000b, Table 1, p. 28.

has zeroed in more intensively on the mid-century chronology, but his interpretations pose challenges because his narrative (and numbers) have changed somewhat in his most recent publications.[3] In his latest work, however, he continues to emphasize, consonant with the Abramovitz/David view, that "In the United States, in comparison to Japan and Europe, a substantial part of the great leap in the level of multifactor productivity had already occurred by the end of World War II" (Gordon, 2000b, p. 22).

Both the Abramovitz/David and the Gordon analyses draw our attention to high and accelerating MFP growth in the second quarter of the century (see Table 1). It was the data underlying what was then recent economic history that so surprised Robert Solow in his 1957 analysis for which, in part, he received the Nobel prize. Solow's work contributed to the development of the concept of the residual and its interpretation: since real output was growing much faster than could be explained by the growth of inputs conventionally measured, he (as did Abramovitz and others) suggested that the unexplained growth should be identified statistically with the contribution of a number of factors, the most important of which was technical change. Solow's seminal article was, however, published more than forty years ago.

Between 1972 and 1995 Solow's residual and, indeed, the multifactor productivity growth to which it gives rise, all but vanished. It is true that labor productivity continued to grow, albeit at a markedly slower rate, but a very high percentage of this can be attributed to capital deepening, which continued at a slower rate than was true in the 1950's and 1960's in part because of an upward trend in hours per worker. Still, to the degree that labor productivity has advanced in recent years, it has, with the exception of a few years at the end of the 1990's, done so the old-fashioned way—through sacrifice of current consumption so that physical capital goods (mostly structures and equipment) could be piled up at a faster rate than the growth of labor hours. Thus the economic history of the last three decades of the twentieth century has recapitulated in the United States a pattern evident in the late nineteenth century, but quite markedly absent during the second quarter of the twentieth century, and more generally over the five-to-six decade period prior to the mid-1960's.

The 1929–1948 period (I discuss the choice of beginning and end points below) is critical in understanding the long-term trajectory of technical change in the United States, both because of its direct effect on growth during the period and because of its lagged effect on MFP advance in the 1950's which, when coupled with renewed capital deepening, produced a golden age of labor productivity growth and living standard improvement. If we are to put in perspective U.S. accomplishments over the past half century, we need to understand what happened prior to mid-century to place the American economy in the position of world dominance it enjoyed after the war. Partly, of course, this involved wartime devastation in Europe and Japan. But partly, it must have reflected the extraordinarily high rates of MFP growth over the second quarter of the century in the United States, and the question on this account comes down to how much of this was the direct result of wartime experience, and how

and multifactor productivity (MFP) are used interchangeably in this paper.

[3] See below for discussion of the implications of this evolving narrative for the thesis of this paper.

much is to be attributed to prior peacetime advances, particularly those achieved through 1941, both in measured productivity advance and in larder stocking.

A. *Two Stories*

This paper is concerned specifically with what happened between 1929 and 1948, and when, and more particularly, with whether the bulk of multifactor productivity advance over the period had already been achieved *before* full scale U.S. mobilization in 1942. Two competing hypotheses may be suggested with respect to this record. Either the growth in MFP is primarily attributable to an exceptional concatenation of technical advances across a broad frontier of the American economy during the 1930's, building on unexploited opportunities at the end of the 1920's, or it is principally the consequence of the production experience of World War II: a persisting benefit of the enormous cumulated output as well perhaps of spinoffs from war related R&D. For the latter hypothesis, the explanation of how we got where we were by the end of the 1940's, to make reference to a classic article by Arrow, is principally that the economy was one large C-47 factory, permanently reaping the gains from wartime learning by doing (Kenneth Arrow, 1962; Armen Alchian, 1963).

Certainly, the war experience left us with advances in such areas as radar, metal working and materials science, microwave technology, aeronautics, and atomic energy, as well as additional experience in producing large quantities of aircraft, ships, aviation fuel, synthetic rubber, aluminum, and ordnance. Most of the growth accounting studies deal with non-farm output, but we might add that the expansion of munitions plants led to a permanent decline in the real price of fertilizer in the postwar period, benefiting agriculture (Alan Olmstead and Paul Rhode, 2000, p. 710).

Whether these advances were, in the aggregate, more significant in accounting for the level of output and productivity achieved by 1948 than those already attained by 1941, or whose foundations were in place by that point, is a question that has not heretofore been asked. The alternative hypothesis is that the preponderance of gains, both in the achievement of higher measured productivity levels and in the expansion of the larder, had already been attained by the outbreak of war, and indeed helped make possible its successful prosecution. This then implies that throughout the Depression, behind the dramatic backdrop of continued high unemployment, technological and organizational innovations were occurring across the American economy, especially but not exclusively in chemical engineering (including petrochemicals and synthetic rubber), aeronautics, electrical machinery and equipment, electric power generation and distribution, transportation, communication, and civil/structural engineering, that these trends have something to do with the rising real wages during this period of those who managed to stay employed, and that the sum total of these changes had, by the onset of World War II, increased the natural or potential output of the U.S. economy far beyond what contemporary observers and economists at the time believed possible. Some of these developments involved entirely new products, not just process improvements in the production of goods already in the market.

II. The U.S. Achievement During the Second World War

There are several related reasons why economists have been inclined to attribute achieved productivity levels in 1948 to the experience of the war.[4] First, the sheer volume of military and total output produced between 1942 and 1945 was indeed remarkable. Second, there were extraordinary achievements in particular sectors, most notably airframes and shipbuilding. Between the first quarter of 1942 and the last quarter of 1944, for example, airframe production increased by a factor of six, and labor productivity grew by 160 percent. Similarly in shipbuilding: in one ten-month period alone, the number of hours required to build a Victory ship fell by half (U.S. Bureau of Labor Statistics, 1946, pp. 897–98).

[4] William J. Baumol wrote in 1986 that "... except in wartime, *for the better part of a century,* U.S. productivity growth rates have been low ..." (Baumol, 1986, p. 1073). His comment, although within the context of an international comparison, reflects a widespread belief that twentieth century wars, and particularly the Second World War, have been relatively favorable influences on U.S. productivity growth.

These successes, however, need to be kept in perspective. The War Production Board estimated that the overall increase in output per hour in the munitions industries was about 25 percent for the 1939–1944 period: certainly respectable, but far below the increases registered in standout sectors. Looking back on the war from the perspective of 1949, Jules Backman and M. R. Gainsbrugh concluded that the overall experience in the military sector "again reveals the extreme difficulties of securing 'miraculous' gains in productivity in any short term period" (1949, pp. 179–80).

And the period was relatively short. The United States declared war on Japan and Germany in December of 1941, but it took time to formulate and agree on war production plans, pass budgets, and cut contracts. It was well into 1942 before the economy was on anything like a full scale war footing (Michael Edelstein, 2000). So we are talking about a period of a little more than three years for the putative effects of learning by doing to have established the foundations for postwar prosperity.

As far as spillovers, there is at least as much evidence of transfer from civilian experience to military production during the war as there is for feedback in the other direction afterwards. The successes in planes and ships, for example, for the most part represented, in conjunction with massive government funded infusions of plant and equipment, the application to the production of military hardware of organizational techniques that had been pioneered in the manufacture of radios, vacuum cleaners, and automobiles (W. D. Evans, 1947, p. 217). Aside from advances in welding techniques, technologies for working with light metals such as aluminum, and radar (U.S. Bureau of Labor Statistics, 1946), which benefited the commercial aircraft industry after the war, as well as the aforementioned drop in fertilizer prices, there is relatively limited evidence of beneficial feedback from wartime production to civilian activity in the postwar period.[5]

[5] The influence of atomic power on productivity in the electric power generating sector proved eventually a mixed blessing, although a full discussion of the case is beyond the scope of this paper. The crash program for the development of techniques for the mass production of penicillin obviously had persisting benefits from the standpoint of public health (David Mowery and Nathan Rosenberg, 2000, p. 819).

On balance, the war was detrimental to productivity growth in the civilian sector. It drained skilled workers, managers, and plant and equipment investment from these industries, creating a productivity shortfall that had to be made up afterwards. A 1946 Bureau of Labor Statistics study demonstrates that while output per hour in nonmunitions industries continued to grow through 1939, 1940, and 1941, it declined in 1942 and 1943 before leveling off in 1944 and increasing in 1945 (U.S. Bureau of Labor Statistics, 1946, p. 899). There was thus little net gain over the war years. This should be contrasted with a trajectory of rapid gains that might otherwise have persisted through the first half of the 1940's.

Finally, even setting aside the well known difficulties in valuing wartime output (Robert Higgs, 1992), part of the apparent increase in output per hour was the consequence of the shift of output towards sectors which had traditionally experienced higher value added per worker. Labor productivity for the economy as a whole would have increased as a consequence of this reallocation alone even if there had been no improvement in productive efficiency in any individual sector (see Evans, 1947). This effect, however, could not persist: it had to reverse itself with demobilization, and the return to a less goods-intensive more consumer-oriented production set (U.S. War Production Board, 1945).

For all of these reasons there are grounds for doubting that the production experience of the Second World War was principally responsible for achieved productivity levels in 1948.

III. Why 1941? Why 1948? Kendrick's Data and the Importance of Peak-to-Peak Comparisons

Perhaps the most critical imperative in analyses of productivity trends is that comparisons be made between years in which the economy is at similar stages of the business cycle. In the expansion phase of a cycle, as output increases, input hours go up, but often only with a lag. Cyclical recovery, in and of itself, will commonly lead to an acceleration in productivity growth rates that slows as the expansion nears its end, and a measurement from trough to peak, for example, may tell us little about long-term trends.[6] The most straightforward way to avoid the contamination of cyclical effects is to choose business-cycle peaks for both beginning and end points of a comparison.

Putting the rule into practice, however, is not always a simple matter. The emphasis in this paper on the technological progressivity of the Depression years would appear to conflict with Kendrick's well-known conclusion that although private domestic economy MFP grew at a rate of 2 percent per year between 1919 and 1929, it did so at only 1.6 percent per year between 1929 and 1937 (Kendrick, 1961, p. 72). Given the conventional emphasis on the boom of the 1920's and its contrast with the disastrous macroeconomic performance in the 1930's, we might be inclined to accept this differential and move on to more interesting matters.

The problem is that Kendrick compared a fully employed economy in 1929 (3.2 percent unemployment) with a 1937 economy in which 14.3 percent of the labor force (9.2 percent according to Michael Darby, 1976) was still out of work. Although large firms were doing well, thousands of medium and smaller ones were not. If we seek a peacetime peak-to-peak comparison, we are better served by choosing as an endpoint 1941, when unemployment, although still averaging 9.9 percent (6 percent according to Darby), was closer to what it was in 1929, but before war spending or production could seriously have influenced the economy.

The choice of 1941 warrants further discussion given the two hypotheses developed above. It is true that a military buildup in anticipation of the Second World War had begun by 1941, a year in which federal military spending for rearmament, expansion of uniformed personnel, Lend Lease and other programs totaled $6.3 billion. This represented about 5 percent of 1941 U.S. GNP, and both total military spending and active duty military (1.8 million) were more than triple what they had been in 1940 (Stanley Lebergott, 1964, Table A-3, pp. 512–13; U.S. Bureau of the Census, 1975).

This increased government spending undoubtedly contributed to higher employment and output levels before the war, through standard multiplier mechanisms (J. R. Vernon, 1994). But cumulated military procurement was still minor compared to what would follow. Total federal military spending reached $22.9 billion in 1942, $63.4 billion in 1943, $76.0 billion in 1944, and $80.5 billion in 1945, when active duty military peaked at 12.1 million (Lebergott, 1964; U.S. Bureau of the Census, 1975). By the end of 1941, only a small fraction (2.5 percent) of the $249.1 billion total military spending occurring between 1941 and 1945 inclusive had already been undertaken.

There would have had to have been extremely rapid spillovers from public to private production for the war build up to have affected private sector productivity by this date through any mechanism other than bringing the economy closer to full employment. It seems difficult, therefore, to credit achieved productivity levels in 1941 to the effect of new management techniques learned, or new technologies discovered, as the result of cumulated war production. 1940, on the other hand, is a poor candidate for a peacetime peak, since unemployment (14.6 percent) was actually higher than it had been in 1937. 1941 is therefore our best bet if we wish to differentiate between the two hypotheses set forth above.

In contrast to the work of recent students of productivity change, Kendrick's 1961 book includes detailed appendices providing annual measures, in levels, of inputs, outputs, and productivity indexes.[7] It is thus particularly useful in addressing the issues of timing raised in this paper. Using his data (Commerce version), I calculate a compound annual average growth rate of private domestic economy MFP of 2.27 percent per year between 1929 and 1941. In contrast, MFP grows at 1.51 percent per year between 1941 and 1948. The differential is even more striking for the private nonfarm economy (see Table 2). (Kendrick, 1961, Tables A-XXII, A-XXIII, pp. 334–35; 339–40).[8]

[6] The argument is usually made for labor input, but one can make a similar claim for capital during the 1930's; this effect (very slow capital input growth) is one reason for the remarkable surge in the output-capital ratio, and thus capital productivity, during these years.

[7] Annual BLS data on multifactor productivity is available beginning only in 1948; see www.bls.gov. Neither Abramovitz/David nor Gordon includes the type of detailed annual data available in Kendrick, although both acknowledge their debt to him.

[8] One of the differences between the Gordon and the Abramovitz/David chronology is that Gordon uses 1950 as a reference peak, as opposed to 1948. It is not clear why.

TABLE 2—COMPOUND ANNUAL AVERAGE GROWTH RATES OF MFP, UNITED STATES, 1919–1948

	Solow (Private nonfarm economy)	Kendrick (Private domestic economy)	Kendrick (Private nonfarm economy)
1919–1929	0.78	1.97	2.02
1929–1941	2.36	2.27	2.31
1941–1948	0.89	1.51	1.29

Sources: Solow, 1957, Table 1, p. 315; Kendrick, 1961, Tables A-22, A-24, pp. 334–35, 339–40.

It is interesting in this light to reread Solow's 1957 article, which examined annual data for the years 1909 through 1949. The interpretation of his work has generally focused on the small fraction of improvements in output per hour that can be attributed to capital deepening over this period. To my knowledge, his numbers have rarely been examined with an eye to comparative MFP growth rates within the four decades he looked at. It is striking, in this regard, and not entirely coincidental, to observe that the pattern evident in Kendrick's data for the entire private domestic economy was also apparent, in more extreme form, in Solow's original article. Solow intended his analysis (much of it based on Kendrick's preliminary data) as only a first cut. But he did note that with respect to total factor productivity, "there does seem to be a break at about 1930. There is some evidence that the average rate of progress in the years 1909–29 was smaller than that from 1930–49" (Solow, 1957, p. 316). Although he did not use his data to examine growth within the latter period, they suggest (see Table 2) that MFP growth was much higher between 1929 and 1941 as compared with 1941–1948.

Unemployment in 1948 was 3.8 percent, vs. 5.2 percent in 1950. Output peaked in 1948: Q4; and the year remains a peak in labor productivity, even after series are cyclically adjusted (Peter Clark, 1978). On a variety of dimensions 1948 appears to be a superior year for a peacetime peak-to-peak comparison, and I follow Abramovitz and David in using it. Gordon's reasons for preferring 1928 to 1929 are similarly unclear: both the output peak and the unemployment trough occur in the latter year, although 1928 unemployment, at 4.2 percent, was closer to the 3.8 percent of 1948 than was the 3.2 percent of 1929.

IV. Adjustments to the Capital Input Series

Although Gordon, in contrast to Abramovitz/David, has repeatedly drawn attention to the extraordinary midcentury productivity record, his work poses special interpretive challenges because of the evolving character of his narrative. In his original emphasis on "one big wave," Gordon identified the 1928–1950 period as evidencing peak MFP growth, and it is this chronology that he featured in three editions of his macroeconomics textbook, beginning in 1993 and extending through the eighth edition published in 2000 (Gordon, 2000a, Table 10-1, p. 323). More recently he has made adjustments to both capital and labor input that tip the balance in favor of his 1950–1964 period (in Gordon, 2000b, adjusted MFP growth is 1.13 percent per year for the latter years and 1.05 for 1928–1950; see Table 7, p. 51).

It is important to understand what drives this switch in the top two MFP growth periods. Gordon's adjustments to labor input are straightforward and similar to those made by others: they create an "augmented" input series that takes into account the changing educational and demographic characteristics of the workforce. These changes have almost no impact on comparative MFP growth, however, because they boost "effective" labor input growth by almost the same amount (0.5 vs. 0.4 percentage points per year) during the two periods.

Nor is the switch in peak MFP growth periods due to the adjustment to capital input for the increasing importance of equipment. Following Jorgenson, Gordon argues that the service flow from equipment tends to be higher because of its higher annual depreciation rates. Thus using net capital stock data to proxy for service flow will understate capital input growth if the equipment share is rising. This adjustment, however, operates in favor of the 1928–1950 period, since it increases capital input growth 0.85 percentage points per year between 1950 and 1964 as opposed to only 0.68 percentage points per year between 1928 and 1950.

The toppling of 1928–1950 as the highest MFP growth period in Gordon's latest chronology is in fact entirely driven by the "Gordon quantity adjustment"—unique to the author—which boosts the compound annual average growth rate of capital input by 0.96 percentage points between 1928 and 1950, while *reducing* it 0.45 percentage points between 1950 and 1964.[9] It is scarcely surprising that such a large difference in the adjustment to input growth rates during the two periods reverses their relative dominance in terms of MFP growth.

The adjustment has three components. The first is the inclusion of street and highway capital. As argued below, there is good reason to believe that such capital is complementary to private sector capital in industries such as trucking, housing, and wholesale and retail distribution. Including it works, nevertheless, in favor of 1928–1950, because street and highway capital grew faster between 1950–1964 than it did over the earlier period (compound annual average growth rate of 4.61 percent vs. 2.99 percent; see U.S. Bureau of Economic Analysis, Fixed Asset Table 7.2, line 10).[10]

The second adjustment, which does favor 1950–1964, is for government owned, privately operated (GOPO) capital, which grew rapidly between 1940 and 1945. During the war Washington funded the construction of large plants for the atomic bomb project (government owned, government operated). But it also used billions of dollars of taxpayer money to build structures and pay for equipment (especially machine tools) in a number of other industries critical to the war effort, including synthetic rubber, airframes and engines, aviation fuel refining, and aluminum production (U.S. Reconstruction Finance Corporation, 1946). These plants were owned by the government, operated by private firms during the war, and sold off to the private sector in its aftermath.

For decades Gordon has rightly insisted that we acknowledge the economic importance of these assets (Gordon, 1969). The increase in GOPO capital between 1940 and 1948, however, is too small in relation to overall private sector capital stocks to account for the reversal in peak MFP periods. It is, moreover, counterbalanced almost exactly, in terms of its impact on comparative MFP growth in the two periods, by the effect of including street and highway capital (see Gordon, 2000b, Table 5).[11]

Finally, and most problematically, Gordon adjusts for variable retirement rates. The conventional Kendrick/BEA input series assume constant asset lives for each class. In making this adjustment, Gordon assumes instead that retirement rates varied directly with gross investment (Gordon, 2000b, pp. 42–45), so that during the 1928–1950 period, when there was relatively little investment, structures and equipment were kept in service longer than would otherwise have been the case. As a consequence, adjusted capital input in 1950, he argues, is much higher than the standard series suggest.

There is little dispute that the average age of capital increased over the 1928–1950 period, and declined between 1950 and 1964, and that these changes were quite substantial (see U.S. Bureau of Economic Analysis, Fixed Asset Tables 6.9, 6.10). It is commonly assumed, however, that newer assets are more likely to contain unmeasured or poorly measured quality improvements. If the average age of assets increased over the second quarter of the century, the contribution to capital input growth of unmeasured quality improvements would have declined. This indeed is the rationale for the vintage adjustment made by Abramovitz and David, which in their analysis *reduces* capital input growth by 0.11 percentage points per year between 1929 and 1948, while increasing it by 0.16 percentage points per year between 1948 and 1966 (Abramovitz and David, 1999, Table 1: IVA). Gordon notes, but does not adjust for,

[9] There are some inconsistencies between Tables 5 and 6 in Gordon, 2000b. The numbers reported above are based on the sum of columns 5, 6, and 7 in Table 5 for the two respective time intervals. For 1928–1950, this is very close to what one gets by subtracting column 5 from column 6 in Table 6, although there is a considerable difference (−0.27 vs. −0.45) when one attempts this for 1950–1964. I rely on Table 5 because it presents a more detailed breakdown of the components of the capital quantity adjustment.

[10] This is reflected in Gordon, 2000b, Table 5, column 7.

[11] Gordon's GOPO adjustment is apparently based on the data on line 28 of Table 7.2 of the BEA's Fixed Asset Tables (the source notes in Gordon, 2000b, in this instance are opaque). It is not clear, however, whether the BEA's valuations for the postwar period reflect the cost of replacement for the original use or for the use to which the assets may have been put following demobilization. There remains an unresolved dispute over the usefulness for civilian production of this capital after the war. Some have criticized the transfers to the private sector as sweetheart deals; the valuations reflected in the sales, however, have been defended on the grounds that substantial retrofitting was often required to make them suitable for civilian production. To the degree that defenders of the postwar sales have a point, the adjustment for GOPO capital that Gordon has included may be somewhat too large, and artificially inflate capital input for 1950.

the likelihood of unmeasured improvements in capital quality (Gordon, 2000b, p. 42). There is some irony here, given the emphasis he has given the issue elsewhere.

His adjustment for variable lifetimes also depends on the assumption that annual service flow remains uniform throughout the life of an asset. If structures and equipment were retained in service longer than normal during the Depression and war years, service flow could well have declined as a consequence, with the equivalent of chewing gum and baling wire allowing the continued operation of depreciated assets.[12]

The impact of an older capital stock on service flow has at least three components. In a relatively arbitrary fashion, Gordon has made an imputation for one of them, without attempting to account for the counterbalancing effects of the other two. For this reason we should approach these latest adjusted estimates with caution. Although the dust has not yet settled, my expectation is that we will ultimately accept the broad ranking of peak MFP growth periods emerging from Abramovitz/David, as well as the earlier Gordon work, as the more appropriate one. The 1999 revisions of the National Income and Product Accounts (NIPA), which result in an upward revision of the 1929–1948 output growth rates, reinforce this conclusion.

V. Micro-Level and Sectoral Analysis

The macroeconomic evidence that the fastest rate of multifactor productivity growth over the last century and a half, and probably two centuries, took place in the 1929–1941 period is consistent with a variety of evidence at the micro level. Alfred Kleinknecht's study of product and process innovations from 1850 to 1969 provides a data set on fundamental innovations, divided into product, process, instrumentation, and other. The peak for the total and two of the four components is in the 1930's, and is particularly marked for product innovations (Kleinknecht, 1987, p. 66). Jacob Schmookler's 1966 enumeration of basic and improvement innovations shows a similar peak in the 1930's, particularly its second half, as does the chronology provided by Gerhard Mensch (1979, pp. 132). These studies have often been ignored in macroeconomic inquiry, in part because their results seem so at variance with our impressions of the economic "success" of the Depression years.

These patterns, along with the aggregate data, are also consistent with David Mowery's study of research and development (R&D) expenditures and employment in U.S. manufacturing. National Research Council data show that between 1919 and 1928 inclusive, companies founded an average of 66 R&D labs per year. Between 1929 and 1936 inclusive, a period that brackets the worst years of the Depression, 73 on average were founded per year. During the 1930's, industry R&D expenditures more than doubled in real terms, with acceleration in the last years of the decade (Mowery and Rosenberg, 1989, p. 69; see also Esther Fano, 1987, p. 262). Mowery reports that employment of research scientists and engineers grew 72.9 percent between 1929–1933 while employment totals in other occupational categories collapsed. Between 1933 and 1940, R&D employment in U.S. manufacturing almost *tripled,* from 10,918 to 27,777. In the Second World War, in contrast, research and development employment growth slowed as employment in other categories skyrocketed. Federal spending for nondefense R&D also fell substantially during World War II (Mowery and Rosenberg, 2000, pp. 814, 819).

Within manufacturing, advance took place across a variety of fronts (Michael Bernstein, 1987, especially Ch. 4). There were, to be sure, older industries such as textiles, leather goods, and apparel, where productivity growth was slow or nonexistent. But there were also a remarkable number of dynamic sectors, generating new process and product innovations, with varying levels of commercial exploitation before the war. Petrochemicals is an obvious example. At companies such as Dupont, advances in chemical engineering generated a host of new products, including Lucite (sold as Plexiglas by a rival manufacturer), Teflon, and Nylon (Peter H. Spitz, 1988; Stephen Fenichel, 1996). Even in an older industry such as automobiles, innovation and product quality improvement during the decade proceeded at a rapid rate. Indeed, Daniel M. G. Raff and Manuel Trajtenberg (1997) view the decade as the last

[12] There are still 1959 Chevrolets operating on the streets of Havana, but most would agree that the equipment is not providing the same service flow it did four decades ago.

TABLE 3—COMPOUND ANNUAL AVERAGE GROWTH RATES OF MFP IN THE TELEPHONE, ELECTRIC UTILITIES, AND RAILROAD INDUSTRIES, UNITED STATES, 1919–1948

	Telephone	Electric utilities	Railroads
1919–1929	1.60	2.51	1.63
1929–1941	2.01	5.55	2.91
1941–1948	0.53	5.87	2.56

Source: Kendrick, 1961, Tables G-III, H-IV, H-VI; pp. 544–45, 586–87, 590–91.

one in which there were truly revolutionary improvements in internal combustion engine powered vehicles.

But progress was not limited to manufacturing: communications services, electric utilities, and transportation were also standouts. MFP growth in the telephone industry accelerated significantly after 1929 before falling precipitously during the war years. In electric utilities, MFP growth more than doubled comparing 1929–1941 with 1919–1929; in contrast to the telephone case, high rates persisted after 1941 (see Table 3).

The railroad sector, which dominated the economy at the end of the nineteenth century in a way no single sector has before or since, continued to figure prominently in the second quarter of the twentieth. In 1941 railroad fixed capital still comprised more than one out of every four dollars (26.9 percent) of U.S. private fixed nonresidential assets (U.S. Bureau of Economic Analysis, Fixed Asset Table 2.1). Labor productivity in railroads grew much more dramatically during the 1930's than it had in the 1920's, and as Spurgeon Bell wrote in 1940, "In the twenties, the increase was largely due to new capital investment, in the thirties to organizational economies" (Bell, 1940, p. 64). Bell's analysis is consistent with Kendrick's data (see Table 3). The strong MFP growth between 1929 and 1941 takes place in the context of a capital input series in railroads that declines after 1931. We see here at the sectoral level a major contributor to the unusual rise in the aggregate output-capital ratio during the Depression years (Kendrick, Table G-III, pp. 544–45; on manufacturing, see Bernstein, 1987, pp. 112–20).

The 1930's also witnessed advances in structural engineering, particularly improved techniques for utilizing concrete in conjunction with steel in bridge, tunnel, dam, and highway design.[13] Perhaps of even greater importance, the decade saw the working out of a paradigm for building infrastructure suitable for an age of automobiles and trucks, with implications for the spatial configuration as well as design and construction of roads, highways, bridges, wholesale and retail distribution facilities, and residential subdivisions. Much of the development work on these principles was done during the 1930's under the aegis of the newly formed Federal Housing Authority and diffused throughout the United States after the Second World War through the efforts of this agency in conjunction with local zoning authorities.

A large portion of the infrastructure required for economically successful postwar housing construction was put in place during the 1930's, as the consequence of the use of public funds to improve the road transport system. During the 1920's, infrastructure, particularly streets and highways, did not keep up with the burgeoning sales of private vehicles. Public expenditures during the 1930's substantially remedied this, in a manner that impacted the productivity of the housing sector as well as that of the economy as a whole.

Due to network effects, the design improvements in conjunction with infrastructural investment generated a boost in output in housing beyond what can be swept back to the value of the physical capital formation itself. Edward F. Denison's data show a surge in the real value of the service flow from the housing sector beginning in 1940 (Denison, 1974, Figure 3.1, p. 20). This may be partially attributable to a reduction in the vacancy rate, as Denison suggests, but it also coincides with the sharp increase in the streets and highways capital stock during the Depression (see Table 4). After the war the increase in the real service flow from the housing stock continued apace, reflecting not only

[13] The Hoover Dam, George Washington, Golden Gate, and Oakland Bay Bridges, Lincoln Tunnel, Pennsylvania Turnpike, Merritt Parkway and Pasadena Freeway are notable achievements in civil engineering in the 1929–1941 period. Exhibits highlighting these achievements, in particular the General Motors exhibit and Democracity, were the standout attractions at the 1939–1940 New York World's Fair. See David Gelertner (1995). The last major suspension bridge built in the United States was the Verrazano Narrows, completed in 1964.

TABLE 4—COMPOUND ANNUAL AVERAGE GROWTH RATES OF NET STOCK OF STREETS AND HIGHWAYS, SEWER, AND WATER SUPPLY CAPITAL, UNITED STATES, 1925–2000

	Street/highway growth	Sewer capital growth	Water supply capital growth
1925–1929	6.00	6.88	4.91
1929–1941	4.32	3.69	2.66
1941–1948	0.08	0.43	0.66
1948–1973	4.15	3.85	3.29
1973–2000	1.63	2.76	2.36

Source: U.S. Bureau of Economic Analysis, Fixed Asset Table 7.2 (http://www.bea.doc.gov).

TABLE 5—STREET AND HIGHWAY CAPITAL AS A PERCENT OF THE NET FIXED PRIVATE CAPITAL STOCK, UNITED STATES, 1929–2000

	Street/highway capital	Private fixed capital stock	As a percent of private capital stock
1929	$16,415	$253,987	6.46
1941	$30,861	$289,487	10.66
1948	$47,892	$582,248	8.22
1973	$290,389	$2,698,194	10.76
2000	$1,423,833	$21,464,786	6.63

Source: See Table 4.

new investment, but the full exploitation of new blueprints for organizing residential subdivisions and associated infrastructure tailored to the automobile (Field, 1992, Table 2, p. 796).

The 1930's witnessed qualitative and quantitative changes in the nation's infrastructure, as well as its sources of funding. Ever since E. Cary Brown's 1956 article, it has been commonplace to downplay the significance of public investment during the Depression as too small in relation to GDP to have "made much of a difference" in returning us to natural output.[14] What this point of view obscures is the likelihood that although insufficient in terms of its influence on aggregate demand to compensate for the drop in autonomous private spending, public investment nevertheless had significant impacts on the supply side.

A first step in reckoning the relative impact of public sector capital on productivity growth in different time periods is to consider the impact on the residual growth rate of including in the overall capital input series a portion of public sector capital designated as complementary to private sector production. If we follow Gordon and adjust capital input to include both streets and highway and GOPO investment, this further widens the MFP gap between 1929–1941 and 1941–1948 in favor of the earlier time period, because the increase in GOPO investment between 1941 and 1945 is significantly larger than the drop off in street and highway building over the same period (see U.S. Bureau of Economic Analysis, Fixed Asset Table 7.5; lines 10, 28). Although both types of government investment were complementary to private sector production, network effects and improved principles of street layout contributed to MFP growth in the 1929–1941 period in a way GOPO investment between 1941 and 1948 did not.

The BEA fixed asset stock data, which begin in 1925, show very rapid rates of public investment in automobile-related infrastructure in the second half of the 1920's that *continued largely unabated through 1941.* The real net stock of streets and highway capital in the United States increased by more than ⅔ between 1929 and 1948, with virtually all of this increase occurring before U.S. entry into the war. Streets and highways capital surged in value from 6.5 percent of the net private fixed capital stock in 1929 to 10.7 percent in 1941, roughly the same percentage recorded in 1973 (see Table 5). Somewhat less dramatic patterns are seen for public investment in water and sewer systems. While spending on publicly owned capital has figured heavily in debates about the significance of declining infrastructure investment in the fall off in productivity growth in the last quarter of the century (David A. Aschauer, 1989; Edward M. Gramlich, 1994), virtually no attention has been paid to its role on the supply side in the earlier period.

What is striking in retrospect about Depression-era technological progressivity is its broad base, both within and outside of manufacturing. In contrast, the most recent period of MFP acceleration in the United States (1995–2003) has seen advance narrowly concentrated within manufacturing, within manufacturing within durables, and within durables, within computers, software, and telecommunication (Gordon,

[14] Thus the famous quote: "Fiscal policy ... seems to have been an unsuccessful recovery device in the 'thirties—not because it did not work, but because it was not tried" (Brown, 1956, pp. 863–66).

2000c; Steven D. Oliner and Daniel E. Sichel, 2000). Some additional MFP growth in IT-using sectors such as wholesale/retail distribution and securities trading has also been realized, but the magnitude of these effects remains uncertain. It is striking that the estimates we have for aggregate MFP growth during the "New Economy" boom remain significantly below those evidenced during the Depression.

TABLE 6—COMPOUND ANNUAL AVERAGE GROWTH RATES OF OUTPUT PER HOUR, PRIVATE DOMESTIC AND PRIVATE NONFARM ECONOMY, UNITED STATES, 1919–1948

	Private domestic economy	Private nonfarm economy
1919–1929	2.36	2.27
1929–1941	2.48	2.35
1941–1948	2.17	1.71

Source: Kendrick, 1961, Table A-XXII, A-XXIII, pp. 334–35, 339–40.

VI. Alternate Interpretations of Rising Labor Productivity in the 1930's

The disastrous record of capacity and labor force utilization in the Depression has overshadowed the comparatively high rate of MFP growth over the same period. Many authors, however, while failing to appreciate the record of MFP advance, have nonetheless found it difficult to overlook evidence of rapidly rising output per hour in the context of low rates of capital formation during the Depression. In developing idiosyncratic explanations for this, however, they have overlooked one that is more straightforward.

In a recent survey, for example, Claudia Goldin noted that nonfarm hourly labor productivity "grew during the 1930's at a rate greater than that for the 1920's" (2000, pp. 566–67).[15] She attributes this trend to Depression-era cuts in hours per worker and the probability that those unemployed were less educated and "probably less skilled" than those retained. Goldin's interpretation, however, is emblematic of an ambiguity in the labor economics literature involving whether labor productivity is pro- or countercyclical. Supporters of the view that it is countercyclical, such as Goldin, adduce the hypothesis of selective retention, whereas supporters of the procyclical view emphasize labor hoarding. The unresolved character of this debate reinforces the importance in calculating growth rates of labor productivity of making comparisons between peaks in business cycles. Goldin is not entirely clear what intervals she has in mind, but interpreting her statement literally implies looking at the years 1920–1930 in relation to 1930–1940.

None of these dates is a business-cycle peak. As Table 6 shows, however, a peak to peak comparison of 1941 with 1929 reveals the same remarkable growth in output per hour. Goldin's selective retention mechanism cannot explain the increase in labor productivity over this period, since both 1929 and 1941 were years of relatively full employment. Nor can this increase be attributed to a rise in the capital-to-labor ratio, since the fixed asset data show this to be a period of capital shallowing. If the numbers are right, *the rapid growth in labor productivity must be attributed, at least in an accounting sense, to high MFP growth over these years.*

In contrast to Goldin, who emphasizes a countercyclical tendency of labor productivity, Ben S. Bernanke and Martin L. Parkinson note sharp procyclical movements in manufacturing productivity in ten industries over the 1929–1939 period. But they reject *ab initio* the possibility that supply side shocks might have played some role in producing this result: "we believe that it is quite unlikely that the preponderance of interwar cyclical variation (at least during the 1930's) was due to technological shocks to the production functions of individual manufacturing industries" (Bernanke and Parkinson, 1991, p. 441).

Within manufacturing, there is evidence that the downturn differentially affected high- and low-productivity firms, with a shakeout taking place as the least efficient establishments were culled out (Timothy F. Bresnahan and Daniel M. G. Raff, 1991). This Darwinian mechanism—a version of selective retention applied to firms—may have reinforced the technological trends I identify in contributing to measured

[15] Her series splices data from *Historical Statistics*, Series D-684, with U.S. Bureau of Labor Statistics data for 1947 onwards.

productivity growth between 1929 and 1941. But Bresnahan and Raff limit the source of productivity improvement to a between firm (or plant) effect, much of which would have been reversed with the return to fuller employment before the war. I argue that the productivity outcome, measuring peak to peak, was due to more than temporarily losing the weakly performing tail of the firm or plant productivity distribution.

In a more recent paper, Harold L. Cole and Lee E. Ohanian also note the rapid labor productivity growth during the Depression years (Cole and Ohanian, 2001). Their focus, however, is on the consequences of rising real wages, whose causes they identify as institutional. The National Industrial Recovery Act and the effective continuation of its policies after it was declared unconstitutional represent, in their view, a significant governmentally induced negative supply shock to the economy.[16] Ironically, given that they write within the real-business-cycle tradition, Cole and Ohanian do not emphasize the possibility that a considerable portion of the upward wage movement was in fact warranted by labor productivity improvement as a consequence of *positive* supply shocks.[17]

In each of these instances, the authors' characterizations of the data (as opposed to their explanations) are consistent with a set of powerful supply shocks in the Depression years that laid the groundwork not only for the remarkable Allied victory in the war, but also for postwar expansion. Profits, as well as wages, felt the beneficial impact of this advance. Most of the corporations occupying the commanding heights of the economy, including RCA, AT&T, IBM, Dupont, Alcoa, GM, Kodak, and General Electric—companies that because of a strong commitment to organized privately funded research and development activity (Mowery and Rosenberg, 1989, pp. 74–75) were contributing disproportionately to MFP advance—had returned to profitability well before the onset of World War II (Louis Galambos, 2000, p. 947).

VII. Conclusion

At the time of the Japanese attack on Pearl Harbor, a very substantial fraction of 1948 productivity levels had already been achieved. Moreover, almost all of the foundations for what W. W. Rostow (1960) would later call the age of high mass consumption were already in place. These included a growing public infrastructure geared to automobiles and trucks, the technical foundations and physical capital investments necessary for producing and distributing cheap petrochemicals, gasoline and electric power, and a range of new and improved materials and appliances that could take advantage of these inputs. The high rates of investment in street, highway, water, and sewer capital literally helped paved the way for the postwar suburbanization boom. In commercial aviation, technical advance (the DC-3 was introduced in 1936) as well as government investment in municipal airports during the 1930's had fostered a nascent industry with much room for profitable expansion. The defining new product of the third quarter of the century—television—was on the verge of explosive commercial exploitation. The Second World War had relatively little to do with any of this.

The Depression years experienced exceptionally high MFP growth rates partly as a result of serendipity. Technical advances do not necessarily arrive in a steady stream, and the 1930's were characterized by progressive programs in a remarkably large number of industries and sectors. The advances in chemicals, long distance communication, electrical machinery, structural engineering, and aviation proceeded largely independently of the Depression. Many of these sectors relied upon and benefited from scientific advance in a way nineteenth century industry leaders often did not. This type of economic progress was fostered by a system of privately funded R&D labs that reached maturity during this period, and operated during the 1930's in a fashion relatively undistorted by the subsequent demands of the military. In other sectors, for example railroads, the disruptions of financial intermediation and very low levels of capital formation associated with the downturn fostered

[16] Its labor policies, including encouragement of the right to organize, they see as persisting through the instrumentality of the Wagner Act. Encouragement of firms to cartelize they see persisting, at least through the first Roosevelt administration, through lax antitrust enforcement.

[17] Elsewhere I argue that the main obstacles to recovery lay in construction, not, as they suggest, in the manufacturing sector (Field, 1992).

a search for organizational innovations that enabled firms to get more out of what they had. Finally, government and university researchers played an important role in helping to work out and promulgate design principles for surface transport and residential platting in an automobile age.

The various papers discussed in the previous section aim at reconciling otherwise anomalous labor productivity data with the apparently disastrous economic record of the Depression. But the performance of the economy between 1929 and 1941 was not disastrous from the standpoint of long-term growth. The reverse was true. In spite of his many contributions to our understanding of productivity trends, Kendrick led us astray by choosing 1937 as a reference peak in calculating productivity growth in the 1930's. If we use instead 1941, it is clear that the bulk of the very rapid growth of MFP between 1929 and 1948 took place *before* U.S. entry into the war. Once this is recognized, labor productivity growth during the Depression in the absence of capital deepening ceases to be anomalous, and the conclusion drawn from the aggregate data finds strong support in microeconomic studies of the timing of key innovations, in sectoral studies of productivity change, and in data on private sector employment and expenditures on research and development. This finding will require rethinking our understanding of the broad contours and determinants of U.S. economic growth in the twentieth century.

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