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DO YOU BELIEVE IN MAGIC?
THE IMPACT ON PRODUCTIVITY OF U.S. MOBILIZATION FOR WAR: 1941-1948

by

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ABSTRACT

Claims that the experience of economic mobilization between 1942 and 1945 laid the supply foundations for output and productivity growth in the United States after the war have formed the basis of the conventional wisdom for decades. In fact, between 1941 and 1948, total factor productivity within manufacturing declined, and fell even more sharply during the war. The war forced a radical shift towards goods in which manufacturers had little experience, where initial productivity levels were low. The learning that subsequently took place in the mass production of ships, aircraft, and other munitions had little relevance for the postwar period because the wartime output mix and implicit factor prices were unique to that period. Although mobilization achieved huge temporary increases in military product, the longer term impact of the conflict on the level and trajectory of US potential output was, on balance, almost certainly negative. (O47, O51, N12)

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Introduction

Whatever the objectives for which it is fought, and whatever their merits, war is always and everywhere an enormous waste of human and physical resources. Faced with horrendous carnage and destruction, we may be predisposed to search for silver linings. Perhaps that is why economists, historians, and much of the general public have often been so sanguine about the economic benefits of war, emphasizing its role not only in closing output gaps, but also in accelerating the growth of potential output. This has been particularly true for the United States.

More than three quarters of a century ago, Louis M. Hacker, speaking of the effects of the Napoleonic Wars on England and the Civil War on the United States, opined that "As far as capitalism has been concerned, modern war (while it lasts) has been an unmixed blessing" (1940, p. 250). He waxed particularly enthusiastically about the propulsive impact of the conflict over slavery in the United States: "Under the leadership of the new and vital force released by the Civil War and Reconstruction measures, American industry strode ahead on seven-league boots" (p. 401), and "…railroading, like industrial production, was … transformed in the fires of the Civil War" (p. 227). If one digs into the subsequent literature, one finds that these supply side claims have in fact been vigorously disputed (e.g., Kuznets, 1952, p. 116; Goldin and Lewis, 1975; Lindert and Williamson, 2016). But Hacker's appealing sentiments about the longer run positive effects of war continue to resonate, especially as they apply to the conflict the United States was poised to enter as he published.

William Baumol, based on his reading of Angus Maddison's data, took World War II's contribution to higher (labor) productivity growth during and after the war to be established fact: "It is noteworthy that the great leap above historical US productivity growth in the war and early postwar years were just about as great as the previous shortfalls during the Great Depression"

(1986, pp. 1081-82). Vernon Ruttan posed a provocative question in the title of his 2006 book, "Is War Necessary for Economic Growth?" He answered the question affirmatively: "It is difficult to overemphasize the importance of the historical role that military procurement has played in the process of technology development…" (2006, p. 3).[1] Without war, he suggested the R and D spending necessary to develop new technologies would simply not be forthcoming. Alan Milward (1977, p. 2), and Tyler Cowen (2014) argued along similar lines.

Recent treatments by historians are similar. Arthur Herman in "Freedom's Forge: How American Business Produced Victory in World War II" emphasized how wartime spending laid the foundations for postwar prosperity on the supply as well as the demand side (2012, p. x). Maury Klein focuses less on the standard learning by doing narratives, and instead on new products, enumerating a range of innovations he argued originated in the war and benefitted the postwar economy: "…jet planes, radar, magnetic tape recording, early computers, and a host of electronic innovations" (2013, pp. 1-2).

Robert Gordon (2016) provides the most recent statement of the argument insofar as it applies to the Second World War. His language is forceful and clear, and he uses macroeconomic data on total factor productivity growth to bolster his narrative. Evaluating the evidence in support of these views is important not only for our understanding of mid-twentieth century U.S. economic history, but also because of its relevance to broader debates about the impact of war and military spending on technological and economic progress.

The analysis in this paper builds on arguments advanced in Field (2008). That earlier work (see also Field, 2011) explored the contrast between aggregate (private non-farm) TFP

[1] Ruttan went on to argue that "military and defense related R&D and procurement has been a major source of technology development across a broad spectrum of industries that account for an important share of U.S. industrial production" (p. 5), emphasizing computers and the internet, but passing lightly over the histories of electricity and the internal combustion engine.

growth during the periods 1929-41 and 1941-48, and provided a detailed analysis of the wrenching changes associated with industrial mobilization for war (1941-43) and demobilization (1943-48) by identifying sectors acquiring FTEs and releasing FTEs during these two periods, and the magnitudes of the manpower flows involved. This paper focuses not only on aggregate and sectoral evidence *that* the longer term contribution of war mobilization to the growth of total factor productivity and potential output was negative, but also more extensively on the question of *why* that was so.

Long Run Productivity Trends in the US Economy

Studies of long run productivity growth in the United States began with the work of Moses Abramovitz (1956), Robert Solow (1957), and John Kendrick (1961). Solow's memorable conclusion (based on Kendrick's then unpublished data) was that a remarkably small fraction of real output growth between 1909 and 1949 could be accounted for by the growth of inputs conventionally measured. Subsequent studies with access to longer runs of data agreed that the second and third quarters of the twentieth century experienced particularly strong TFP growth, but there remain important differences about when within those decades the most rapid advance occurred (Abramovitz and David, 2000; Field, 2003, 2011; Gordon, 2016). Field situated it in the 1930s (specifically, measuring between 1929 and 1941), but (in his most recent work) Gordon located it in the 1940s.[2] Whereas Gordon accepted Field's revisionism regarding (at

[2] Gordon originally settled on One Big Wave as his way of calling attention to the strong TFP growth that characterized the half century between roughly 1920 and 1970. In The Rise and Fall of American Growth he abandoned this catchphrase and adopted instead that of a Great Leap Forward. The idea of applying this language to TFP growth in the 1930s originated with Field (2011). As justification for his partial appropriation of the phrase, Gordon cited Baumol (the quote referenced above) as evidence that the idea of a 'great leap' was current in the literature a quarter century before Field published (Gordon, 2016, pp. 706-07). But Baumol used the words to apply to a period after 1941, accepting the then conventional wisdom that productivity advance was below trend between 1929 and 1941. His view, roughly the opposite of what Field argued, epitomized what had for decades been the conventional view of the Depression and the war.

least moderate) productivity advance between 1929 and 1941, he retained (but repackaged as new) the “economic miracle” interpretation of the supply side effects of the war, arguing that TFP growth across the war years greatly exceeded that during the Depression.[3]

There is little dispute that World War II confirmed the fundamental Keynesian prediction that massive fiscal stimulus combined with expansionary monetary policy could bring a depressed economy to full employment and beyond within a very short time. But for decades, it has also been argued, as did Baumol, that the war was associated with a permanent boost on the supply side, particularly due to its effect on the growth of total factor productivity (TFP).[4] Gordon developed his version of this view in chapter 16, claiming that its “most novel aspect” was “its assertion that World War II itself was perhaps the most important contributor to the Great Leap.” As he developed his argument, he abandoned the hedging reflected in his initial inclusion of the word ‘perhaps’: “In fact this chapter will argue that the case is “overwhelming for the “economic miracle” interpretation of World War II along *every conceivable dimension*…” (p. 537, my italics).

In 1945, in a short book criticizing Alvin Hansen’s theory of secular stagnation, George Terborgh included this aside:

> Incidentally, the march of invention has probably been stepped up on balance by the impact of the war, which has in many cases telescoped into a few years what would otherwise be the product of decades. We face the postwar era with an unprecedented accumulation of new materials, new techniques, and new products, that will create

[3] Bakker, Crafts and Woltjer (2017) are of little help in adjudicating these differences, since they don’t explore growth across the war years. They argue that the postwar period (1948-73) was the locus of the most rapid TFP growth, a position that Gordon endorsed beginning around 2000 but subsequently abandoned. Most recently, Gordon has stepped back from discussion of individual subperiods and instead focused broadly on the half century 1920-70 (Gordon 2018). But calculations over shorter intervals remain of considerable interest They can powerfully color our understanding of different subperiods, directing our attention in one direction or another towards other evidence, and influencing how we interpret it.

[4] Baumol speculated that “Perhaps the accumulated innovative ideas, unused because of the depression, as well as frustrated savings goals, fueled an outburst of innovation and investment when business conditions permitted.”

> hundreds of new industries and revolutionize scores of old ones. Never in history have we had so huge a backlog of invention awaiting practical application (1945, p. 90).

We see in this passage the same transition from qualified speculation ("probably") in the first sentence to the unqualified certainty reflected in the final declarative sentence that we observe in Gordon's exposition. Those transitions represent leaps of faith – and a key question is whether they are justified.

Gordon went on to argue that the 'economic miracle' propelled total factor productivity to a permanently higher level, and was largely responsible for setting the stage for the golden age (1948-73). This was his explanation: "The most obvious reasons why productivity remained high after the war was that *technological progress does not regress.* People do not forget. Once progress is made… it is permanent". After the war, "As they struggled to fill orders that seemed almost infinite, they adopted all that they had learned about efficient production in the high-pressure economy of World War II" (p. 550). He repeated the oft-cited examples of learning by doing building airframes and Liberty ships, and then argued that "the shipyard example can be generalized to the entire manufacturing sector" (p. 549), and that "Every part of the postwar manufacturing sector had been deeply involved in making military equipment or its components, and the lessons learned from the war translated into permanent efficiency gains after the war" (p. 550).

No other combatant began mobilization with as large a gap between actual and potential output as did the United States. And in the case of no other major combatant is it common to argue that economic mobilization contributed positively to levels and rate of growth of productivity in the postwar period. There is likely a connection between these observations, a connection due to an improper conflation of the record with respect to output and productivity. The output gap is crucial in understanding U.S. success in producing huge increases in military (and total) product. The record with respect to productivity (output *per unit of input*) is much less impressive, whether we look at the total economy or the manufacturing sector alone.

I argue, in contrast to the optimism and enthusiasm of Baumol, Ruttan, Terborgh, Herman, Gordon, and many others, that the war retarded the growth of potential. It did so not just by slowing the growth of total factor productivity, but also by destroying human capital and distorting the accumulation of physical capital. It was associated with a decline in the level of total factor productivity in manufacturing and a reduction in its growth rate in the private domestic economy.[5]

Productivity Within the Manufacturing Sector

If the "war benefits aggregate supply" view is correct, we should most likely see evidence of spillovers from war mobilization in the manufacturing sector. Table 1 reports growth rates of TFP within the sector over intervals from 1919 through 2016. These data are central to the argument of this paper. The focus is on the estimation of the rates of advance over the period 1941-48 as compared with 1929-41.[6] Kendrick has TFP growth in manufacturing at 5.12 percent year between 1919 and 1929, a figure accepted by Abramovitz/David, Field, and Gordon. Although Kendrick provides annual data on output and hours inputted, his capital input series, based on Creamer et al (1960), has a level for 1937 and then again for 1948 but not the

[5] In 1969, Gordon himself expressed concern that the U.S. "Wirtchaftswonder" (wartime productivity advance) was overstated because of the failure to include government provided physical capital in the official fixed asset data (1969, p. 226).

[6]1941 is the closest we can come to potential before the effects of full scale war mobilization kick in. Although Lend-Lease and some rearmament had begun, less than five percent of cumulative real military spending between 1940 and 1945 inclusive had taken place at the time of Pearl Harbor (Field, 2011, p. 85). By 1948 demobilization was largely complete and the economy, now on a civilian footing, was close to potential, as evidenced by the low 3.8 percent unemployment rate.

intervening years. To calculate a growth rate of total factor productivity to and from 1941, one needs series on output growth, labor input growth, and capital input growth, as well as labor and capital shares that can be used to weight growth rates of the latter two series.

Nominal income in the durables and nondurables subsectors of manufacturing (U.S. Department of Commerce, 1966, table 1.12, lines 13 and 24) are converted to real value-added using deflators for each subsector (table 8.6, lines 2 and 14; 1958=100) and then summed. This yields an estimate of the growth of manufacturing output of 4.43 percent per year between 1929 and 1941, and 1.98 percent per year between 1941 and 1948.

Table 1
Total Factor Productivity Growth in U.S. Manufacturing, 1919-2016

	(percent per year)	\Source
1919-1929	5.12	Kendrick (1961), table D-1, p. 464.
1929-1941	3.06	See Appendix table A1, text.
1941-1948	-1.57	See Appendix table A1, text.
1949-1973	1.49	U.S. Bureau of Labor Statistics (2004), table 2
973-1995	.68	U.S. Bureau of Labor Statistics (2004), table 2
1995-2005	1.78	www.bls.gov, accessed 10/4/2018
2005-2016	-.37	www.bls.gov, accessed 10/4/2018

FTEs in the sector are drawn from BEA NIPA Table 6.5a (These numbers are identical to those in Department of Commerce 1966, table 6.4 line 11, except for a small difference for 1948). Data in HSUS (2006, series Ba4580) show average weekly hours in manufacturing declining from 44.2 in 1929 to 40.6 in 1941 to 40.2 in 1948. The growth rate of hours across particular intervals is proxied by adding the growth rate of weekly hours to the growth rate of FTEs. Based on these calculations, hourly labor input in U.S. manufacturing grew between 1929 and 1941 at 1.22 percent per year, and between 1941 and 1948 at 2.18 percent.[7] Combining data on the growth of sectoral output and hours, we can estimate labor productivity growth (their difference) as 3.22 percent per year between 1929 and 1941, and .04 percent per year between 1941 and 1948.

To estimate TFP growth, we need also to know how fast capital input was growing. The BEA's Fixed Asset Table 4.2, line 9, provides chain type quantity indexes for the net stock of private fixed assets in the sector. This series shows that manufacturing capital grew across the depression years at 1.11 percent per year and 3.90 percent per year between 1941 and 1948. The BEA numbers, however, do not include government owned manufacturing capital (according to the table the net stock of privately owned manufacturing capital *declined* between 1941 and 1943), whereas value added includes a privately earned return to government owned capital provided within GOCO facilities (see Gordon, 1969). We know that there was a huge increase in manufacturing capital during the war, owned by the federal government, and funded largely by the Defense Plant Corporation. To adjust private sector capital upwards, I've cumulated government expenditures on manufacturing plant and equipment (1958 dollars) and subtracted retirements as summarized in Gordon (1969, table 4). I've then converted the current cost net stock of manufacturing capital (BEA FAT 6.1, line 12) into 1958 values by multiplying by the ratio of the implicit GDP deflator for nonresidential fixed investment in 1958 as compared with

[7] These are close to growth rates based on Kendrick's manhours series for manufacturing: 1.23 and 1.96 percent per year for the two periods respectively.

1941 and then 1948 (FRED series A008RD3A086NBEA). I then augment the BEA fixed capital quantity indexes, multiplying by one plus the ratio of government owned to privately owned manufacturing capital. This increases manufacturing capital by about 8 percent in 1941, 41 percent in 1943, 50 percent in 1944, and 32 percent in 1948, and increases the 1941-48 growth rate of manufacturing capital to 6.75 percent per year.[8]

Combining these series in the fundamental growth accounting equation, and weighting capital growth by .3 and labor input growth by .7, yields manufacturing TFP growth of 3.06 percent per year between 1929 and 1941, and -1.57 percent per year between 1941 and 1948 (table 1).[9] These numbers differ slightly from the 2.76 per year between 1929 and 1941 and -.35 percent per year reported by Field (2011).[10] Inclusion of a cyclical adjustment for the level of manufacturing TFP in 1941 would increase an estimated growth rate between 1929 and 1941 and further reduce it for 1941-48 (Field, 2010, 2018), although switching to chained index sectoral output growth in manufacturing, were that available, would likely raise growth rates for both periods.

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[8] The 1948 calculation is likely biased upward, since some of these assets had been sold off and were already included in the private sector totals at their sales prices, which represented a heavy discount from their cost of construction.

[9] If Y is output, K is capital, N is labor, A is total factor productivity, β is capital's share in national income, and lower case letters represent continuously compounded rates of growth, then the fundamental growth accounting equation is $y = a + \beta k + (1- \beta)n$. The measurement of capital and labor shares involves difficult decisions about how proprietors' income is allocated and whether and for what purposes gross as opposed to net (of depreciation) measures are to be preferred (Rognlie, 2015). Capital shares commonly used for this period vary between one quarter and one third. The 1929-41 calculation is insensitive to differences within this range, since labor and capital input growth rates were quite similar. For 1941-48, assuming a capital share of .25 would imply TFP growth within the sector of -1.34 per year, whereas a capital share of .33 would imply TFP growth within the sector of -1.72 percent per year.

[10] The manufacturing output growth rate between 1929 and 1941 used in these calculation (4.43 percent) exceeds that calculatable from Kendrick's table D-II (3.81 percent), which was used in Field (2011). Thus the higher reported TFP growth rate. For 1941-48, the 1.98 percent per year output growth calculated here is slightly less than a rate based on Kendrick's output index, which grows at 2.20 percent per year over that period. The estimates also differ because of the adjustment to capital input described in the text.

Note again that in this calculation we are measuring from premobilization to the first fully employed post-demobilization year. By 1948 the economy was once again on a largely civilian footing. We are not primarily interested in measuring from 1941 to 1943 (the peak of wartime industrial production), or to 1944 or 1945, because the principal question is whether wartime manufacturing experience positively influenced sector wide rates of productivity growth between 1941 and 1948 and then in subsequent years. That said, both labor productivity and TFP within the sector fell very sharply across the war years.[11]

Between 1941 and 1943, real output rose 15.4 percent a year, and hours by 19.2 percent a year; labor productivity fell at a rate of 3.8 percent per year. Using BEA manufacturing capital augmented by Gordon's estimates of government owned manufacturing capital, TFP declined at a rate of -2.18 percent per year between 1941 and 1943, -3.66 percent per year between 1941 and 1944, and -5.05 percent per year between 1941 and 1945 (see table A1). This contrasts with the two years prior to mobilization (1939-41), during which manufacturing TFP grew at 10.9 percent per year, reflecting strong secular TFP growth across the depression years along with the predictable effects of a cyclical recovery. Between 1945 and 1948 TFP recovered at 3.1 percent a year, but this was from the very low levels of 1945 and 1946 and still left the 1948 level substantially below where it had been in 1941.[12]

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[11] V.R. Cardozier, echoing many other authors, described wartime manufacture as "An astonishing feat of productivity, accomplished in a short period." (1995, p. 134). That is not quite right. If *production* appeared astounding, it was because, prior to Kuznets' calculations, the full extent of that growth in potential had not been realized or appreciated. But, as the above data indicate, wartime manufacture was not a *productivity* miracle.

[12] One caveat about capital inputs during the war for the metal working industries (these industries were devoted almost exclusively to making military goods between 1942 and 1944). The BEA numbers likely include the automobile and appliance maker equipment mothballed for the duration of the conflict. We have added in the government provided machine tools for making the war goods, so capital input may be slightly overestimated during the period of economic mobilization. The effect of this on calculated TFP is counterbalanced, however, by the fact that the intensity of machine use was much higher during the war than before or after, due to adoption of double and

Sectoral Productivity Estimates

The data underlying the calculation of TFP growth rates over the intervals 1929-41 and 1941-48 for manufacturing and eight other sectors are detailed in Appendix tables A1-8. Table A9 combines these with data on sectoral shares in the private domestic economy to calculate percentage point contributions to aggregate TFP growth. It is not possible to do this decomposition using chained index measures of output growth, the metric of choice when calculating TFP growth rates for broad aggregates such as the PNE or the PDE, because such measures of output are not available at the sectoral level. Still, the decomposition illuminates the relative importance of different sectors in the economy in contributing to such growth. Between 1941 and 1948, the manufacturing sector contributed -.54 percentage points per year to private domestic economy (PDE) TFP growth.

Productivity advance in the PDE between 1941 and 1948 was, overall, positive. But the main contributors were sectors other than manufacturing or construction, in particular wholesale and retail distribution, railroad transportation, and electric and gas utilities (Appendix table A9). These were sectors, in contrast to manufacturing, that, on balance, were starved of both capital and labor during the war. War did inspire process innovations. But these apparently had more persisting benefits in sectors disadvantaged by war mobilization, not those favored with government funded plant and equipment, and featured in stories about production miracles. Partly that is because these sectors were forced to make do during the war with less on the input

sometimes triple shifts, and thus the service flow per dollar of the fixed asset stock increased during the war compared with peacetime. The chair of the War Production Board reported that "the average utilization of facilities in the metal products industries late in 1944 was about two thirds above the prewar level, after having reached nearly twice the prewar level in the spring of 1943" (1945b, p. 7). My speculation is that the second effect is somewhat larger than the first, meaning that table A1 probably underestimates the declines in manufacturing TFP during the war.

side, and partly because they were less likely to face the wrenching changes in output mix associated with mobilization and demobilization. If war mobilization did have longer term positive effects on total factor productivity growth, it appears to have been in areas such as logistics, and not in the learning by doing narratives in manufacturing so frequently referenced.

Manufacturing TFP declined between 1941 and 1948 because the government funded expansion of war related plant and equipment had much weaker spillover effects on TFP than did the streets and highways, bridge, tunnel, and hydroelectric dam construction of the 1929-41 period (Field, 2003, 2011). Value added grew on average about 2 percent a year between 1941 and 1948, but the sharp rise in manufacturing capital, along with growth in hours, left no space for a positive residual.

Whether they occurred during this interval in favored or unfavored sectors, innovations were often in response to and especially suited to a highly unusual set of input availabilities and implicit factor prices, conditions that would disappear with the end of the war. Construction firms, for example, faced with shortages of structural steel, developed kiln dried wood forms called, due to their shape, thunderbirds. These served as effective roof bearing substitutes in many of the one-story factory buildings hastily erected by the federal government (Walton, 1956, p. 214; Klein, 2013, p. 532). This innovation, however, was a response to a materials shortage that would not persist. It was of little relevance in the postwar period.

One might argue that 1948 is too soon to see the putative beneficial effects of learning by doing. Sectoral TFP did increase after 1948, but much more slowly than during the interwar years, and, in contrast to the prewar period, its rate of advance was generally below the economy wide average. Exceptions were briefly (and barely) during the 1995-2005 IT boom and, less consequentially, during the doldrums of the dark ages (1973-95). Between 1949 and 1973 TFP growth in the sector was less than half what it was between 1929 and 1941, and less than a third what it had been between 1919 and 1929.[13] The key takeaways are these: the level of manufacturing TFP in the United States was lower in 1948 than it had been in 1941, and grew much more slowly in the postwar years than had been true in the interwar period. Those defending the view that war benefitted aggregate supply because of learning by doing in manufacturing need to claim that without wartime economic mobilization the downward trend in sectoral productivity growth would have been even more pronounced.

Learning by Doing

Learning by doing is central to the claim that World War II production experience had positive persisting effects on aggregate supply. References almost always begin with the Liberty ships and go on to cite examples of the inverse relationship between cumulated output and unit labor requirements for B-24s, C-47s, or Oerlikon antiaircraft guns.[14] To the extent these oft-reported gains were real (they do require some qualification), they were nevertheless associated with striking declines in overall manufacturing productivity during the war (see table A1). The learning that did take place did little to boost either military or civilian production capability after the war. With respect to the former, the manufacture of most of these products ceased by V-J day. In contrast to what was true during the war, postwar military hardware had limited production runs and much higher costs per unit.

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[13] If you believe that the 1949 official capital data should be higher, because the government owned capital had been sold (and then added to BEA capital) at prices that were too low, then the TFP growth rate over this interval will be even lower.

[14] Roosevelt's "Must List" of January 6, 1942 announced unit production targets for 1942 and 1943 in four categories: Planes, Ships, Anti-Aircraft Guns, and Merchant Ships (Edelstein, 2001, p. 60, citing Smith, 1959, p. 141). Planes and (military) ships were the biggest ticket hardware items in the US war effort (Smith, 1959, p. 7).

With respect to civilian production capability, there were very limited spillovers to the consumer sector. Independently of this, the wartime diversion of resources to military production disrupted the peacetime trajectory of learning in the production of consumer durables. Then, as now, the most important of these was automobiles. In 1939, the car industry consumed 18 percent of the steel, 75 percent of the plate glass, 80 percent of the rubber, 34 percent of the lead, and 10-14 percent of the copper, tin, and aluminum in the US economy. Largely because of the industry's customary annual model change, it was, prior to mobilization, the machine tool industry's largest customer (Klein, 2013, p. 64). Output and sales of passenger vehicles rose rapidly in 1940 and 1941, as growing defense spending along with foreign orders primed the pump of an economy finally emerging from a decade of depression. As monthly production between September of 1940 and July of 1941 pressed against peak 1937 (but not 1929) levels, "all-outers" became concerned that, if war came, rising demands for consumer durables and military hardware could not both be accommodated without exacerbating developing shortages in steel, machine tools, and other key inputs.

Those who believed war inevitable concluded that in order to maximize production of aircraft, tanks, and ships, the United States needed to terminate, or at least dramatically curtail the production of metals-intensive consumer durables, particularly automobiles and white goods (refrigerators, washing machines, metal office furniture, and other appliances). Prior to Pearl Harbor industry leaders resisted curtailment, arguing that only a small part of its plant and equipment could be converted to military production. They were joined by officials in the Office of Production Management, who echoed industry fears. After a decade of depression, their concern was that factories and workers might sit idle during an interval between curtailment and a stream of military orders whose size and timing remained uncertain, and they had unpleasant memories of what had happened after World War I. They also feared an overhang of excess capacity after the war. The President, economists such as Leon Henderson, and other New Dealers, meanwhile, pushed for speedier reductions in civilian metals-intensive production (Koistinen, 2004, pp. 130-132).

In October 1940, the automobile industry agreed to suspend subsequent annual model changes (Herman, 2012, p. 115), although, since one had just been completed, this would have no practical significance until the following fall. The intent was to make it easier for the machine tool industry to supply the aircraft industry, a sector in which employment would increase from 40,000 to over 2 million between 1939 and 1944 (Ballard, 1983, p. 140). In April of 1941, William S. Knudsen, the Director-General of the Office of Production Management, secured an agreement with car manufacturers to a twenty percent cutback in output, which took effect in August of 1941 (U.S. Bureau of the Budget, 1946, p. 60). Reinforcing the agreement's intent, the Federal Reserve issued Regulation W, restricting installment loans to no more than 18 months, and requiring a down payment of at least one third for car purchases (Klein, 2013, pp. 169, 172; U.S. Bureau of the Budget, 1946, p. 264).

The commencement of hostilities in December dramatically accelerated curtailment. Effective January 1, 1942, all sales of as well as the delivery of previously ordered cars, trucks, and parts were prohibited. Effective February 22, 1942, the production of all US passenger vehicles, commercial trucks, and auto parts ceased. Half-finished assemblies, along with some of the specialized tools and dies, were sent to salvage to be melted down and recycled. Most of the rest were stored in anticipation of the resumption of production after the war (Ballard, 1983, p. 137). Car dealers retained an inventory of 532,000 1942 model vehicles produced but not yet sold; those with a special permit could purchase one during the war.[15] Design work on new models ceased completely for thirty months, resuming again in the fall of 1944, subject to the restriction that it not interfere with still ongoing war work. Production of new vehicles recommenced in October of 1945. Passenger vehicles produced for the 1946 and 1947 model years were little changed from those manufactured during the 1941 and abortive 1942 model years.[16] Similarly, in May of 1941, nine months prior to the cessation of automobile production, General Electric shut down all R and D on civilian radio and television in order to focus on military orders (Klein, 2013, p. 105).

The suggestion that experience gained building B-24s or Sherman tanks generated major beneficial spillovers in civilian production after the war is inconsistent with the sectoral productivity data. Nor is it supported by what we know qualitatively about the evolution of technologies in these sectors. The 1930s were a fertile period for automotive engineering, during which many modern features, including automatic transmission, power steering, and the V-8 engine were introduced. New models were finally introduced during the 1948 and 1949 model years. During the 1950s and 1960s the industry settled into a marketing infused senescence distinguished by planned obsolescence, a continuing emphasis on annual model changes, many of which did little to improve functionality or performance, and deteriorating quality, which

[15] Permits were available for doctors, first responders (police and fire department employees), critical war workers, and travelling salesman, although the latter group lost access in January of 1944. Only 47,000 of the initial inventory remained as of May 1944 (Snyder, 2011).

[16]"The 1946 and '47 Chevys were just '42s with new grilles and trim". The source is a vintage car dealer quoted in Snyder (2011). The situation with respect to truck technology is somewhat more nuanced. Between 1942 and 1945 the US produced for the military close to 2.4 million light, medium, light-heavy, and heavy-heavy trucks (Smith, 1959, p. 9). There may have been more learning by doing relevant for the postwar era in these product lines (see Milward, 1977, pp. 191-2, for description of the special capabilities of the two-and-a-half-ton tuck produced for the U.S. army. Still, it is not clear how many of its features (such as four-wheel drive) made it into postwar U.S. truck production.

ultimately left it at the mercy of foreign competitors (Zeitlin, 1995, p. 75).[17] Raff and Trajtenberg contrast the vibrancy of the pre-1940 period with the "tight oligopoly and dull performance of the post-World War II decades" (1996, p. 72)

The story was not noticeably different in the appliance sector. Refrigerator and appliance production, including washing machines, cookstoves, metal office furniture, and vacuum cleaners became subject to limitation orders in the fall of 1941, and ceased entirely during the war. As in the case of the automobile industry, most of the specialized machine tools were mothballed in anticipation of the end of the war. Commercial television, developed during the 1930s, had been introduced at the 1939 New York World's Fair, but the war delayed large scale production and take up for at least six years. Production of TV sets was completely prohibited between April 1942 and August 1945.

The war was undoubtedly associated with advances in many military technologies, including the beginnings of the move from piston driven to jet aircraft, the supplanting of the battleship by the aircraft carrier, the development of rocketry, and the atomic bomb. Nuclear power, of course, did have civilian applications, but its benefits in the postwar economy were mixed, and, given the prewar state of scientific and technical knowledge, it likely would have arrived with or without the war. It took Enrico Fermi and his colleagues at the University of Chicago less than a year following Pearl Harbor to produce the world's first controlled nuclear chain reaction.

[17] "In the United States…wartime aircraft production appears to have had little impact on domestic manufacturing practice outside of the industry itself" (Zeitlin, 1995, p. 75). Even the latter can be questioned, however, since the industry never again mass produced aircraft on such a scale.

Based on the English experience, Davis and Stammers suggest that advances in gas turbine technology may have been an area where the war genuinely advanced a useful postwar technology (1975, p. 515). But since we cannot be sure of the counterfactual, the conclusion is uncertain: jet engines might well have arrived as quickly in the absence of the conflict. Aircraft design was advancing rapidly during the 1930s, with a high rate of obsolescence and technical progress. By 1938 US commercial aviation already transported more than a million passengers a year, a carriage that had increased more than twenty-fold over the previous decade (Holley, 1964, pp. 11-12).

The B-29 was the single most expensive weapons system in the Second World War (more than $3 billion as compared with $2 billion for the Manhattan project). It was entirely pressurized, boasted a state-of-the-art fire control system, and advanced monocoque technique – the external skin of the plane contributed to its structural integrity. But that design concept went back decades—and the last generation of bombers with propellers likely would have had it with or without the war. As was the case for every other aircraft discussed below, the design work on the B-29 was completed prior to Pearl Harbor, with the first orders placed in May of 1941 (Herman, 2012, pp. 293-296).

With the exception of approximately 14,000 gliders, all of the 276,000 military aircraft produced between 1942 and 1945 were piston driven. A 1971 Smithsonian Institution study (Fayette, 1971) documents that most of the technical improvements in such engines predated 1940 (see especially figure 71, p. 84). That is in part because development work shifted to jet engines, but it is also illustrative of the fact that the production of hundreds of thousands of aircraft engines under wartime conditions did not magically lead to major improvements in their performance or reliability. That said, the Army Air Force’s combat experience generated a steady stream of change orders, and incremental improvement meant that piston driven aircraft produced later in the war differed significantly from those produced earlier.

Learning by doing as a contributor to declining production cost at the product level would seem an attractive explanation for a boost to the manufacturing TFP growth rate. The problem is that sectoral TFP declined between 1941 and 1948, and even more sharply between 1941 and 1943 or 1944. In order to understand why, we must identify where the technological progress is claimed to have been most concentrated, and consider why it might not have benefitted sectoral productivity in the postwar period, or even during the war years.

The most frequently cited examples of such success involve stories of the declining cost per unit of ships, planes, tanks, and other ordnance. The 'miraculous' effects of learning by doing during the war are well known to economists, largely as the result of Kenneth Arrow's 1962 article in the Review of Economic Studies and Armen Alchian's 1963 article in Econometrica. Citing work by Wright, Verdoorn, and Lundberg, Arrow noted that it was well established that the number of labor hours required to complete an airframe dropped predictably with the number of previously completed airframes, that the Horndal iron works in Sweden had experienced a 2 percent annual increase in labor productivity over a fifteen-year period in the absence of any new physical investment. He then explored the theoretical implications of these observations.[18] Alchian also took the effects of learning by doing as well-established, and explored how reliable were statistically estimated learning parameters in airframe production in predicting the decline in labor requirements per pound of aircraft as a function of cumulated output.

[18] As Scott-Kemmis and Bell (2010) observed, Arrow's argument emphasized a stimulus given to the development and improvement of capital equipment resulting from experience in production. Most of the learning by doing literature, however, has emphasized the pure effects of learning and experience, presumably with a fixed set of capital goods.

Aircraft production (airframes and engines) absorbed a quarter of all wartime spending on munitions ($45 billion) (Koistinen, 2004, p. 38). Learning by doing might have generated three types of advance that could have contributed to a residual measuring ‘technological’ progress in manufacturing between 1941 and 1948 and on into the postwar period: 1) gains in producing a particular type or model of aircraft; 2) broader gains in the understanding of how to produce large quantities of aircraft within a very short time frame, and 3) gains that might have applied to manufacturing more generally.

The United States produced approximately 276,000 aircraft between 1942 and 1945, and over 300,000 between 1940 and 1945, and over those years, the U.S. military took delivery of over 800,000 aircraft engines (Klein, 2013, p. 505). Productivity gains in category 1 were large.[19] Wartime exigency, however, forced a dramatic change in output mix. One would expect productivity measures for the goods newly produced in quantity to have experienced gains, but from initial low levels. Consider Detroit’s shift from making cars, where there was significant cumulative experience, to airplanes and tanks, where there was little, or the Frigidaire plant in Dayton Ohio, which transitioned from making refrigerators to 50 caliber machine guns as well as airplane propellers (General Motors Corporation, n.d.). Or consider the tens of firms manufacturing fractional horsepower electric motors. Prior to the war, 90 percent went into household appliances (washing machines, mixers, vacuum cleaners). During the war, a similar fraction percent went into mechanized weapons (more than three hundred in a B-29 alone). Motors produced for these military applications had to be smaller, lighter, more rugged, and run on direct rather than alternating current. Making them required major changes in design and

[19] There is some controversy over how much this should be attributed learning by production workers (in the limit, working with unchanged equipment and physical plant, as opposed to improvements in the kind and quality of equipment and the organization of production which should be credited to mechanicam, electrical, and industrial engineers (see in particular, Thompson, 2001 and Scott-Kemmis and Bell, 2010).

tooling and the learning of new skills by workers (War Production Board, 1945a, pp. 103-104). Outputs produced during the war were not just different, they were often much more complex and typically involved many more individual parts. A 1941 Ford automobile required approximately 15,000 parts; a B-24 bomber, in contrast, about 1,225,000 (Ford Motor Company, 1945). ,

The sharp decline in sectoral productivity, whether measuring from 1941 to 1943 or to 1944 or 1945, may seem puzzling. One can be misled by focusing in isolation on the reductions from high initial levels in the unit costs of producing the new goods. As Kuznets noted in 1945, "There is no inconsistency in assuming a rapid rise in the relative efficiency of resource use in munitions and war construction and a low level compared with the efficiency" (in those industries in the prewar period) (1945, p. 51).[20] The data is dominated by the negative compositional effect resulting from the forced shift into the production of goods in which manufacturers had relatively little experience.

Corporations like Ford and GM eventually succeeded in manufacturing military goods in quantity using techniques and principles successfully exploited to make cars and refrigerators in the 1930s. The American system of mass-production featured custom designed single purpose machine tools fabricating interchangeable parts which were then assembled along a moving line.

[20] According to Kuznets, munitions producers hoarded labor and capital and behaved in other wasteful ways that reduced efficiency. See also Rockoff (1995, p. 5). Milward (1977, p. 73) argues that productivity was higher in the armaments sector in the United States, but provides little empirical foundation for his claim, which would imply that the expansion of military production should have raised rather than lowered productivity levels in the manufacturing sector as a whole. And in fact, he claims that in 1945 U.S. industries were operating "at higher levels of efficiency than ever before" (1977, p. 93). Milward's source appears to be War Production Board (1946b, p. 9), but the higher efficiency estimate is offered without great precision ("apparently') and seems to be heavily influenced by the gains within the munitions sector. Note that Milward also states that "there is no convincing evidence that the overall speed of technological advance was greater in wartime (p. 180), and that even in military goods, there were "at least as many forces inherent in the armaments and munitions industries in wartime retarding technological innovation as stimulating it" (p. 193).

But in no case was the transition easy. Postwar demand for the new products was highly uncertain and most likely to be low. To produce goods in which they had little experience, private corporations demanded tax subsidies in the form of accelerated amortization (prior to Pearl Harbor), and, after full scale mobilization began in 1942, that the government provide (and own) the physical capital.

Operating contracts were typically cost plus base fee. As Secretary of State Henry Stimson commented early in the process, "If you are going to try to go to war or to prepare for war in a capitalist economy, you've got to let business make money out of the process or business won't work" (Gropman, 1996, p. 5). Landon-Lane and Rockoff (1996) describe the generous terms on which the government invited private corporations to build war goods as creating an environment akin to the California gold rush. Businesses earned profits, understood as a return to capital, even when they risked none or little of their own (Gordon, 1970, p. 942; Higgs, 1993). Milward estimates that pretax industrial profits rose 350 percent during the war (120 percent after taxation the war), as opposed to considerably smaller percentage gains for labor (Milward, 1979, p. 67). Such arrangements may have been necessary to get military goods out the door, but, in contrast with competitive bidding or fixed fee contracts, they did not strongly incentivize efficiency (U.S. Bureau of the Budget, 1946, p. 140).

The longer run question is why manufacturing TFP was lower after demobilization in 1948 than it had been in 1941, and why it grew more slowly thereafter than had been true during the interwar period. To answer, we must consider in more detail how much relevance wartime learning had for manufacturing – either civilian or military – after the war. Wikipedia has compiled a list of most-produced aircraft, enumerating those with production runs greater than 5,000 (Wikipedia, 2017a, c). Twenty-one World War II aircraft in the United States meet this criterion: five bombers (two heavy, two medium, one light), eight fighters, three dive or torpedo bombers, three trainers, a transport aircraft, and a glider. These are described below, with production totals in parentheses, along with information on the year in which production ceased.

Increasing the production of heavy bombers was the centerpiece of Roosevelt's economic mobilization strategy. On May 4, 1941, roughly a year after he had announced a goal of producing 50,000 military and naval planes, he wrote that "the effective defense of the country and the vital defense of other democratic countries required" this (Baime, 2014, p.73). The two heavy bombers were the Boeing B-17 Flying Fortress (12,731) and the Consolidated B-24 Liberator (18,482).[21] The two medium bombers were the North American Mitchell B-25 (9,984), and the Martin B-26 Marauder (5,288). The light bomber/intruder aircraft was the Douglas DB7 (A-20 Havoc) (7,478). Production of all of these aircraft ceased in 1945, with the exception of the Douglas, for which production ceased in 1944. Each of these aircraft had been fully designed, tested, and flown prior to Pearl Harbor (Wilson, 2016, p. 58).[22] These bomber production runs exceeded by two orders of magnitude those common in the postwar period.[23]

Eight World War II fighters had production runs of more than 5,000: the Grumman F4F Wildcat (~7,800), the Curtiss P-40 Warhawk (13,738), the Chance-Vought F4U Corsair (12,571), the Grumman F6F Hellcat (12,275), the Lockheed P-38 Lightning (10,037), the

[21] These two aircraft models delivered 43 and 30 percent respectively of the 1.5 million tons of bombs dropped during the war within the European theatre during the war (Klein, 2013, p. 657).

[22] See also Herman, 2012, pp. 87, 116. This useful book is nevertheless marred by its ideological slant, reflected in repeated swipes at labor unions and government bureaucrats. The only heavy bomber that had not flown prior to Pearl Harbor was the B-29, 3,970 of which were built. This was the aircraft that delivered atomic bombs to Hiroshima and Nagasaki, as well as the Abel airblast at Bikini atoll in July of 1946. Production of B-29s ceased in 1946.

[23] The B-52, produced between 1952 and 1962: 742; the B-1A and B, produced between 1973 and 1974 and then again between 1983 and 1988: 104; the B-2, produced between 1987 and 2000: 21. Here are comparable numbers for postwar military transport aircraft, along with years of production in parentheses: Lockheed C-141 Starlifter: 285 (1963-1968). Lockheed C-5 Galaxy: 131 (1968-73; 1985-1989); Boeing C-17 Globemaster III: 279 (1991-2015). All data from Wikipedia.

Republic P-47 Thunderbolt (15,660), the North American P-51 Mustang (15,586), and the Bell P-39 Airacobra (9,584). Production of all of these aircraft had ceased by the end of 1945, with the exception of the Mustang and the Corsair, which remained in production until 1951 and 1952 respectively. All of these aircraft had been designed before the war. With the exception of the P-47, F4U, and F6F, all had flown prior to Pearl Harbor.

The Douglas SBD Dauntless dive bomber (5,936) and the Curtiss SB2C Helldiver (7,140) ceased production in 1945; the Grumman TBF Avenger torpedo bomber (9,837) in 1944. All three had flown prior to Pearl Harbor.

The Douglas C-47, the military transport version of the DC-3, remained in production until 1952, but the rate of production slowed greatly after the war. Total production was 16,079, including 607 civilian versions (DC-3s completed in 1942 or earlier), 10,048 C-47's built in the United States during the war, and 4,937 under license by the Soviets.

Three small training aircraft also continued to be built after the war. The North American T-6 Texan (15,495) remained in production into the 1950s. The Vultee BT13 Valiant (11,537) ceased production in 1947, and the Fairchild PT-19 (~7,700) in 1948. Finally, ~ 13,900 Waco CG-4 gliders were produced, with production ceasing in 1945.[24]

During 1944, the United States completed an airplane on average once every five and a half minutes (Walton, 1956, p. 540).[25] But the war did not effect a dramatic acceleration of the design process. Every military aircraft experiencing significant World War II deployment had

[24] See Smith (1959, p. 27) for statistics on Army aircraft production in close agreement with the comparable numbers from Wikipedia.

[25] The US produced 301,572 aircraft between 1940 and 1945. 6,086 were produced in 1940, and 19,433 in 1941. Peak production was in 1944, when the US manufactured 96,318 (Wikipedia, 2017b). There are 525,600 minutes in a year. 525,600/96,318 = 5.45, which is the basis of the statistic cited by Walton.

been fully designed prior to the war, and, as noted, all but four (the B-29 and the three fighters mentioned above) had been flight tested or were already in active service prior to Pearl Harbor. None of the experience acquired in producing these models – and incrementally improving their design in response to flight and combat experience -- can have had much direct bearing on US productivity levels and growth in the postwar period, because production of almost all ceased prior to or shortly after the end of the war.

What about category 2 – gains relevant perhaps not to the manufacture of specific aircraft per se, but to the manufacture of aircraft more generally? This was, after all, an industry in which the United States became a world leader after the war, with consequences that transformed regional economies, particularly in the West. It is important in this regard to appreciate the unusual and indeed unique characteristics of World War II aircraft manufacture. The country – indeed the world – never again produced such vast quantities in a similarly compressed time frame. In the postwar period, a very small number of aircraft models approached or exceeded cumulative production runs of 5,000, and most of those that did were small single engine piston driven aircraft produced for the general aviation market: Beechcraft, Cessnas, Pipers, and Aeroncas.

Following World War II, only four military aircraft experienced production runs greater than 5,000: the North American F-86 Sabre (9,860, 1947-56), the Republic F-84 Thunderjet (7,524; 1946-53), the McDonnell-Douglas F-4 Phantom II (5,195; 1958-81) and the Lockheed T-33 Shooting Star jet trainer (6,557; 1948-59). The subsonic heavy bomber, the B-52, originally built between 1954 and 1963, had a cumulative production run of 742. Only one US commercial aircraft has exceeded cumulated output of more than 5,000 in the postwar period. Production of the Boeing 737 began in 1967 and on March 13, 2018, surpassed 10,000. That cumulative output, however, took place over half a century, not two or three years.

We must, moreover, season the stories of aircraft production miracles with some grains of salt. Compromises had to be made to enable the extraordinary reported wartime rate of throughput. Mass producers of aircraft from the automobile industry, particularly Ford at the huge and problem-plagued Willow Run facility,[26] pushed back against the military's steady stream of change orders and eventually refused to accommodate more of them. To resolve the impasse, the War Production Board eventually allowed Ford to freeze the design, allowing some aircraft finally to be 'completed.' As the planes rolled off the production line they were flown immediately to modification centers, originally run by commercial aviation contractors, ultimately by the Army Air Force. Newly installed equipment was ripped out and replaced, and other changes made, some that customized the aircraft for its intended theatre of operations (Walton, 1956, p. 249; Klein, 2013, p. 532), but many because mass manufacture was simply not

[26] Ford insisted on using hard steel dies for his tooling, in spite of repeated warnings that the need for change orders would suggest using softer dies, which, though less durable, could be more easily and cheaply be replaced. He also insisted on building the factory – the largest in the world, in an L shape, with an expensive turntable at the vertex to rotate assemblies. To have built in a straight line would have pushed the plant out of Washtenaw into Wayne county, controlled by liberal Democrats, whom Ford detested (Baime, 2014, pp. 101, 172). Labor relations were anything but harmonious. Ford would not allow war housing to be built near the factory, which eventually employed almost 100,000 35 miles from Detroit, lest Washtenaw county voter rolls be diluted by an influence of pro-union Democrats. Average commutes for half the workers who couldn't find local housing were 40-70 miles round trip a day at a time when gasoline, tires and cars were in very short supply. The plant had been dedicated on June 16, 1941, almost six months before Pearl Harbor. As of July 1943, just four months before the peak of U.S. industrial production. the plant had still not produced a single combat ready plane. Prior to this it did produce components for other assemblers of the B-24, and on May 15, 1942 had rolled out Bomber Ship 1, assembled from components many of which had been produced in other facilities). By October of 1942 a few bombers were rolling out but they were far from combat ready. After flying a Ford built B-24, Lindbergh, now employed at the factory, described it as "the worst piece of aircraft construction I have ever seen… Rivets missing, rivets badly put in, rivet holes started and forgotten, whole lines of rivets left entirely out, wrong sized rivets, lopsided rivets, badly formed skin, corner cuts improperly made, cracks already started, soft metal used where hard metal is essential, control holes left out, pilot's escape hatch badly constructed." (Baime, 2014, p. 176) In January of 1943, less than a hundred aircraft had been produced. Five months later (June 17) That number had risen to 400, and by November, 1,000 (Baime, 2014, p. 191, 242, 261). After freezing the design, Willow Run finally produced aircraft in quantity: in 1944 8,865 (Klein, 2013, pp. 531, 675). But Ford's efforts can hardly be described as a miracle of productivity, let alone production.

compatible with the frequency of change requests desired by the military.[27] Huge backlogs developed at these centers, so actual delivery to the military services often lagged far behind the figures on factory output (Milward, 1977, p. 192).

The story is similar in the case of ship production. Between 1941 and 1945 eighteen shipyards in the United States produced 2,710 Liberty ships. No other ship model before or since has ever approached this record of cumulated output (the ship was based on an 1879 British design). The gains in labor productivity were partly enabled by replacing rivets with welds; the remainder has traditionally been attributed to more mundane learning by doing. As in the case of aircraft, the narrative needs some qualification. Thompson (2001) suggests that much of the measured labor productivity improvement over time was attributable to quality deterioration and capital deepening, rather than advance in TFP. The quality deterioration was evident in the more than 100 Liberty ships that sank within ten years of launch due to hull or deck fractures resulting from poor welds.

Analyzing a larger shipbuilding data set from World War II, Thornton and Thompson (2001) were more optimistic about the role of learning by doing. Even if we acknowledge significant contributions from this source, such knowledge was of questionable relevance after the war because the US economy has never been and likely never will again be faced with the challenge of producing so many similar ships in such a short period.

US shipyards, including those owned and operated by the US Navy, also produced a prodigious number of naval vessels between 1941 and 1945 inclusive: 31 aircraft carriers, 6

[27] Ferguson (2005) provides a nuanced treatment of the different approaches to production taken by aircraft manufactures and General Motors as opposed to Ford. He makes it clear that, contrary to Ford's optimistic assertions, the manufacture of aircraft bore little relation to that of automobiles.

battleships, 42 battle, heavy, and light cruisers, 302 destroyers, 191 submarines, and 78,242 landing craft (U.S. Department of Commerce, 1947, table 247, p. 222). Here also there were learning effects, as labor productivity improved with cumulated output (see Gemery and Hogendorn, 1993, for evidence on destroyer production). The relevance of this to the postwar economy, civilian or military, however, is also questionable. As in the case of aircraft, in the postwar period the US built many fewer but far more expensive combat vessels.[28]

We can conclude that the gains in category 1 were significant, in category 2, moderate, and in category 3 almost entirely absent. Gains in category 3 had the greatest potential for persistence and general applicability. But there is scant evidence that organizational breakthroughs during the war, which would show up in TFP, help explain success after it, at least within manufacturing. We can get some perspective on this by examining the changing share of "other transportation equipment" (all transport equipment except automobiles) in US manufacturing. In spite of Lend Lease, foreign aircraft orders, and pre-Pearl Harbor increases in military spending, the category comprised just 2.2 percent of total manufacturing output in 1941. At its peak in 1944 that share had risen to 20.7 percent of a considerably expanded manufacturing sector. By 1948 it had fallen back to 2.7 percent (see also Field, 2011, tables 3.3 and 3.4). Even at the height of the Korean War in 1953, the share rose only to 6.9 percent of manufacturing output, or 2.4 percent of the private nonfarm economy (U.S. Department of Commerce, 1966, Table 1.12, p. 19).

As it applies to the Second World War, the 'war production benefits aggregate supply' argument, echoed by Gordon and others, was probably first made by Julius Krug, the second

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[28] The U.S. Navy currently (2018) operates 10 aircraft carriers. Klein (2013, pp. 516, 825), citing data from Darman, 2009, provides somewhat different numbers, noting in a footnote that "here, as elsewhere, the figures for total production vary widely among sources and cannot be reconciled."

chairman of the War Production Board. In his final report he wrote that: “We have come out of the war knowing a great deal more about how to produce efficiently, speedily, and cheaply than we knew when we went in. Much of this knowledge which we gained from war can serve us well in peacetime.” After pointing to the “miracle of atomic fission (and) the spectacular achievements of radar,” he mentioned

> the education of many hundreds of manufacturers in working to very close tolerances, or the speeding up of metal working by the widespread use of tungsten carbide cutting tools. The tremendous development of the electronics industry in process control and inspection operations; the advances in production volume and fabricating know-how in the light metals; the widespread experimentation with substitutes for scarce items which led to the development of new and in many cases superior raw materials (such as plywood or plastics, for example), the tremendous improvement in packaging and shipping techniques—these are only a few of dozens I could mention (War Production Board, 1945a, p. 23).

Krug, he wrote in the warm glow that suffused the country only a month after V-J day, and we can understand his enthusiasm and optimism. Probably the strongest case here is for advances in statistical process control and packaging and shipping (logistics). But much of what he says doesn’t stand up to disciplined inquiry. Tungsten carbide cutting tools were introduced commercially in 1927 in Germany and diffused widely in the United States during the 1930s. Plywood had been manufactured industrially for almost a century, and many of the wartime innovations in its use reflected responses to shortages of aluminum and steel. These new recipes were of little value once those materials were no longer in short supply. Much of the learning in how to make specialized military equipment was also of limited relevance after the war.

It is more appropriate to view the 1942-45 achievements as reflecting the application of techniques learned building automobiles and refrigerators in the interwar period to the mass production within a very compressed period of aircraft and other military goods designed, in most cases, before the war. The U.S. addressed the challenge of economic mobilization the same way it waged war: by directing toward the problem a firehose of government provided physical capital along with reserves of labor available in part because of the output gap remaining in 1941.

The Legacy of Wartime Capital Accumulation

The war resulted in an enormous accumulation of physical capital in the form of military hardware, producer durables such as machine tools and dies, and industrial structures, such as the massive Willow Run facility, the Chrysler tank production facility, and the Geneva integrated steel mill in Utah. In addition, the country experienced a large increase in physical capital associated with military command structures, forts, and bases. The utility of this capital after the war is an important issue, both in cases where the capital might contribute to postwar non-military production, and where it could only be used for military purposes. In the latter case, if a large accumulated stock of military ships, tanks, aircraft, hardware and structures produced or constructed during the war made it possible subsequently to devote a smaller share of US production capability to the manufacture or construction of such goods, that stock could, after the war, have allowed for greater accumulation of government infrastructure complementary to private production, or production and acquisition by the private sector of physical capital useful in civilian production.

With the temporary exception of B-29 bombers, most of the aircraft produced during the war were, at its conclusion, deemed surplus: obsolete and/or unneeded. Tens of thousands were flown to 'boneyards' in Arizona – air bases such as Kingman and Davis-Montham. Engines were removed for steel scrap and the airframes guillotined, fed immediately into onsite smelters where the metal reemerged as aluminum ingots. Towards the end of the war some aircraft were flown directly from the factory gate to Arizona for disassembly and recycling. Many aircraft operating overseas were never repatriated. Abandoned in their theatre of operation, it was simply not worth the cost in fuel and manpower to fly them back to the United States so they could be scrapped. Similar fates befell Liberty ships (scrapped and recycled for the steel), tanks, and other military equipment.[29] These goods had been produced to fulfill an extraordinary need. With the war ended, so did most of that need.

It was not just aircraft and freighters. A veritable flotilla of military ships, including two aircraft carriers, four battleships, thirteen destroyers, five submarines, and multitudinous other naval vessels were destroyed or made so severely radioactive in the South Pacific that almost all had to be scuttled. This was the result of two atomic blasts (Operations Crossroads), an airblast on July 1, 1946 (Abel) and an underwater detonation on July 26, 1946 (Baker). Several vessels sank immediately at Bikini as the result of the explosions. Most of the rest were towed to Kwajalein (about 400 kms) for tests, and then scuttled. A few were brought to Pearl Harbor or West Coast US harbors before being used for target practice and then sunk. Two submarines and four smaller ships were successfully decontaminated and sold for scrap. The tests had been designed to demonstrate that naval vessels could survive nuclear bombs, thus countering claims that such ships were obsolete in the atomic age. The tests demonstrated that ships could not withstand nuclear blasts and still operate, and the third planned atomic blast (shot) was cancelled. At the time some members of Congress complained that tons of steel that could otherwise have been recycled went to the bottom of the ocean (Weisgall, 1994, pp. 77-78; 317-322).

As thousands of tons of obsolete or no longer needed military equipment lay parched on the Arizona desert, as hundreds of rusting Liberty and naval war ships prepared for scrappage, or

[29] Weyerhauser maintained a small fleet of Liberty ships after the war, but surplus Liberty ships made more of a contribution to the postwar Greek and Italian merchant marines than they did to that of the US. Aristotle Onassis got his start by acquiring several. Most of the remainder were mothballed and ultimately scrapped.

targets for atomic bombs or conventional ordnance, the knowledge that was acquired in building these durables also dissipated. Creative destruction is a feature of production knowledge as much as it is of products, and was particularly severe under the extraordinary conditions of World War II production and its aftermath.

What of the enormous production of machine tools paid for by the government? Machine tool output increased two orders of magnitude during the war. Annual production during the Depression was approximately 7,000 per year, generated by roughly 200 specialized firms. In 1940, 110,000 were produced, and in 1941, 185,000. At the peak of production in August of 1942, machine tools were generated at an annual rate of 365,000, although by 1944, more than a year before the war ended, production had already fallen back to less than half the peak rate (Walton, 1956, p. 229; see also Ristuccia and Tooze, 2013, table 1). The War Production Board (1946b, p. 5) reported that the number of installed machine tools rose from 934,000 at the end of 1939, to just under 1.4 million in 1943 (this count included mothballed units).

There was indeed a huge investment in plant and equipment by the federal government. But the mass production techniques that made volume production of tanks and aircraft possible in the United States relied overwhelmingly on single purpose machine tools, and the majority of these tools and related jigs and frames were scrapped with reconversion.[30] The U.S. did use multipurpose machine tools, which could more easily be repurposed, but principally in the shops producing machine tools.

[30] (Describing conversion in Evansville, Indiana) "Here as elsewhere, conversion foundered on the plethora of single purpose machines used by the plants. Studebaker, for example, undertook to manufacture Wright airplane engines, only to find that only 414 of its 3,000 machines could be adapted to the new product, and all but 64 of them were simple drill presses. American factories were themselves huge single purpose machines designed to turn our one special product in enormous quantities" (Klein, 2013, p. 388). Again, See Ferguson (2005, p. 166) for a nuanced discussion of variation among manufacturers in their practices. See also Milward (1977, p. 188).

Already in 1944 the country confronted serious surplus and scrappage issues. By early 1945 disposal agencies had surplus inventories of roughly $2 billion– equivalent to the entire cost of the Manhattan Project. By V-J day that had risen to $4 billion, and ultimately to a peak of $14.4 billion in mid-1946 (Cook, 1948, pp. 10-11). Most military hardware, with the exception of jeeps and trucks, was not dual use. Automobile manufacturers, in any event, lobbied against repatriation of such vehicles, concerned they would spoil the postwar market. A few tanks were converted to tractors or bulldozers. Overall, recycling and disposal posed huge logistical challenges.

What, more generally of the billions of dollars of government funded equipment and structures built to produce all the military hardware? Valued at cost of construction, government owned plant included about $3B in aircraft, aircraft engine, and aircraft accessory plants, $900M in steel facilities, $800M in aluminum and aluminum fabrication, and about $700M in synthetic rubber plants (not sold off until 1955).[31] A large fraction of the government investment in plant and equipment was of relatively little value in the postwar period. As John Sumner wrote in 1944, "…many plants are so specialized in war equipment or so situated with respect to markets or sources of material as to be comparatively inefficient from the standpoint of postwar production" (p. 464). In his final report, War Production Board chair Krug observed that "The proportion of government-financed construction was naturally heaviest in those categories where there was the least assurance of postwar absorption of the facilities by the industrial economy. This means that a good deal of the federally financed plant is in a marginal

[31] Statement of Hans A. Klagsbrunn, Executive Vice President, Defense Plant Corporation, on April 12, 1944, US Congress, Senate, Committee on Military Affairs, Problems of Contract Termination, Hearings Before a subcommittee of the Committee of Military Affairs, 78th Congress, 2nd session, 1944, p. 868. Cited in Ballard, 1983, p. 159.

position." (1945a, p. 35). That is why so much of it was scrapped, or sold for pennies on the dollar in the postwar period (see also Jaszi, 1970, p. 936).

A competing narrative suggests these were giveaways, sweetheart deals for large military contractors. A careful reading of the literature suggests that the prices at which industrial plant was disposed of were generally reasonable. Disposal took place amid strong political currents favoring antimonopoly and the encouragement of small business. The aluminum industry, in particular, was restructured on a more competitive basis than had been the case prewar, an outcome anticipated from the start. Unlike other GOCO contractors, ALCOA had not been given an option to buy the new government plants it operated, and after the war it faced a new competitor in the form of the Reynolds Aluminum Corporation.

The problem of scrappage extended not just to the tools of war but also to the tools and parts that made them. Often the cost of scrappage was greater than the quantity of recoverable materials. But inaction was not an option, because unless the now obsolete or no longer needed parts and equipment, machine tools and dies, and finished tools of war were cleared out and disposed of, they would clog production facilities and adversely impact the revival of civilian production. Scrappage was already a serious challenge prior to V-J day. Change orders for tanks or bombers could instantly obsolete assembled parts, tools, jigs and frames, as well as completed (but now obsolete) units. Mass production techniques pioneered in the 1920s and 1930s and used to build military equipment in the 1940s relied on single purpose jigs, frames, and machine tools. These were of no more use after the war than most of the military equipment they had helped produce. Whereas many of the jigs, frames and machine tools used to produce cars and refrigerators had been covered in oil or wrapped in brown paper in 1942 and then stored in anticipation of a postwar resumption of production of similar products, the mass production of propeller driven aircraft was a one-off event. These tools had value only as scrap.

Government plants were frequently sold for a fraction of their construction cost in part because they were often not ideally suited to the needs of postwar production. There was often only a single bidder. Plants had been constructed to manufacture a product mix some of which would never return. Some were not built to last more than a few years. Within individual aircraft production facilities, the locations of structures were uneconomically dispersed, to make the facility less vulnerable to air attack. More generally, they were sometimes dispersed around the country to protect them from bombing, a questionable precaution given the new realities of military technology. A prime example was the Geneva steel mill[32] built in Vineyard, Utah, a heavily polluting white elephant operated by US Steel during the war. In 1945, the WPB considered its postwar fate uncertain (1945, p. 36), but it was bought by the operating company in 1946 for what critics said was a fraction of its worth. After being sold in 1987 it ceased operations in 2002. Government built industrial facilities after the war did have value, but it was on average a fraction of their cost of construction.

The conflict also left the country with a vastly expanded network of military structures, a physical plant substantially in excess of the country's needs in the postwar period. The Pentagon, completed in 1943 at a cost of $78 million, was the small tip of a very large iceberg. As of June 30, 1945, the Army had spent within the United States $7.2 billion on command (non-industrial) plant. This total compares with a total of $8 billion for industrial facilities, of which $7 billion was for government plants and $1 billion for equipment in privately owned plant. Along the way, the Army acquired ownership of additional acreage in the country exceeding the

[32] The integrated mill covered 1,600 acres and included 11 miles of railroads (White, 1980, p. 74).

combined area of the six New England states (Smith, 1959, pp. 441, 444, 447). Once built, new forts and bases created political coalitions in favor of their retention. It took decades, including the establishment of multiple Base Realignment and Closure Commissions, for the country to make a dent in that surplus.

Influences on Potential Output

Are there other ways whereby the Second World War might have had a large and persisting positive impact on potential output in the United States? It might have done so by sweeping away retardative institutional obstacles through a permanent change in the philosophy or instrumentalities of government. It might have done so by destroying infrastructure, plant or equipment, allowing it to be replaced or rebuilt along more efficient lines. These two varieties of 'prairie fire' explanation, common in the literature, suggest that in spite of, indeed, because of its destructive power, war burns away historical underbrush, clearing paths for modern, more dynamic growth.[33]

The Second World War did leave significant institutional, normative, and economic legacies for the United States. It solidified a compression of wages that endured for three decades, and this included new opportunities for black workers to move from unskilled to semiskilled occupations, opportunities that might not otherwise have been available (Ferrara, 2018). Experience with high tax rates and the introduction of withholding gave the federal government expanded fiscal capacity. Controls on wages led inadvertently to the U.S. system of largely employer provided health care insurance. And the war presaged, after a brief lull,

[33] These ideas draw strength from an older and highly evocative tradition that saw war as rejuvenative. Theodore Roosevelt was a notable exponent of this view. The 'benefits' of destroyed infrastructure as well as reconfigured institutions are often referenced as partially explaining rapid growth in Germany and Japan in the thirty years after the Second World War. Voightländer and Voth (2013) draw links between war, human capital losses, higher land-labor ratios, and the ability to sustain increases in per capita output in early modern Europe.

permanently higher levels of military spending, which had persisting regional economic effects (Wright, 2017, but see also Jaworski, 2017). The war was not, however, associated with a political revolution or fundamental changes in the instrumentalities of government. Nor, aside from the destruction on the island of Oahu and possibly the wear and tear on plant and equipment resulting from running double and triple shifts (Higgs, 2004, pp. 504, 515-16) did the war damage infrastructure within the United States and its territories.

The prairie fire analogy may be relevant for other countries in other historical instances, but not, by and large, for the United States in World War II. The argument must therefore turn on something other than "prairie fire" reasoning: longer run effects on total factor productivity growth and/or the growth of hours and physical capital services. In other words, it must turn on more straightforward growth accounting explanations.[34] Because the impact on potential hours is so clearly negative (more on this below), and because the effect on capital services, although more complex, is likely mildly retardative, any argument that the war accelerated the advance of potential output must rely on a strong persisting boost to TFP.

As noted, TFP in manufacturing declined between 1941 and 1948, and it is in that sector that we would most have expected to see longer run consequences of the wartime production experience. The immediate postwar impact of the war on potential hours was also clearly negative. 405,399 mostly prime age males never returned. Most would have been alive in the absence of the war. There were another 607,000 casualties. To this one must add the 8,651 deaths in the U.S. Merchant Marine resulting from sunk cargo ships.[35] As Alan Milward put it,

[34] 'Prairie fire' effects might of course, ultimately be reflected in any of the components of a growth accounting exercise.
[35] Kendrick (1961, Table D2, p. 466, Table G3, p. 545; Carter et al, 2006, Series Ba4742, Ba4678, Ba4679.

"The only recurrent demographic phenomenon relating to all or most wars is the fact that war kills many people" (1977, p. 209).[36] The 50 percent wartime rise in female labor force participation (Schweitzer, 1980, p. 90; Rose, 2018) largely dissipated during the immediate postwar period.

The counterfactual with respect to capital is more complex. The country emerged in 1948, inter alia, with a vastly expanded aluminum production industry and a reduction in its industrial concentration, a synthetic rubber capability that had been developed basically from scratch, and the Big Inch and Little Inch pipelines, bringing crude oil and refined petroleum products from East Texas to the East Coast.[37] But both public and private capital accumulation in areas not militarily prioritized had been repressed. Wartime priorities starved the economy of government investment in streets and highways, bridges and tunnels, water and sewage systems, hydro power and other infrastructure that had played such an important role in the growth of productivity and potential across the depression years. These categories of government capital complementary to private capital grew at a combined rate of .15 percent per year between 1941 and 1948, as opposed to 4.17 percent per year between 1929 and 1941 (BEA Fixed Asset Tables, tables 7.1 and 7.2).

Portions of the private economy not deemed critical to the war effort also subsisted on a thin gruel of new physical capital. Trade, transportation, and manufacturing not directly related to the war are cases in point. Private nonfarm housing starts, which had recovered to 619,500 in

[36] Surgical and other improvements in treating trauma resulting from experience with battlefield injuries had persisting benefits in the postwar period, but this was at best a mild offset.

[37] Between 1939 and 1943, capacity in the aluminum industry increased seven-fold, from 325 million pounds per year to 2.3 billion pounds per year. This contributed critically to U.S. dominance in military and commercial aviation after the war. The new synthetic rubber industry was created in response to the cut off during the war of access to natural rubber supplies in the Far East. Output increased from 28 million tons in 1942 to 922 million tons in 1945 (Koistinen, 2004, pp. 138, 149). The Big Inch and Little Inch pipelines transported fuel without exposing it to the risk of submarine predation along the Gulf and Atlantic coasts.

1941, still 32 percent below the 1925 peak (937,000), plunged to 138,700 in 1944, barely above the 1933 trough of 93,000 (NBER via FRED, series A0261AUSA610NNBR). All "nonessential" construction in the country was restricted effective October 9, 1941 (U.S. Bureau of the Budget, 1946, p. 83; Herman, 2012, p. 153).

Abramovitz and David wrote that "the war … imposed restrictions on civilian investment, caused a serious reduction in private capital accumulation and retarded normal productivity growth" (2000, p. 547). These effects were most pronounced in manufacturing and construction, the sectors most heavily disrupted during the war.[38] Higgs (2010) adds an additional twist to this argument by emphasizing the wear and tear on the capital stock caused by double and triple shifts, and the understatement of depreciation allowances caused by the repressed inflation during the war. Once price controls were removed and inflation accelerated between 1945 and 1950, those allowances were inadequate to repair the ravages of intensive wartime utilization. On the other hand, investments by the Defense Plant Corporation added significantly to manufacturing capacity in war prioritized sectors.

The Macro Evidence on Total Factor Productivity

Between 1941 and 1948, national economy TFP rose, reflecting the influence of sectors other than manufacturing and construction. These included those starved of capital and manpower such as transportation and wholesale and retail distribution, not those emphasized in the traditional learning by doing narratives (see Appendix Tables A1-9). One might interpret

[38] While endorsing for the most part Abramovitz/David's conclusions about the war, Field took issue with their broader narrative of the twentieth century as reflecting a dependence on knowledge-based growth that differed fundamentally from what had been true in the nineteenth. Abramovitz/David generalized from the high TFP growth of the first half of the twentieth century, a generalization which the data from the second half did not support. TFP growth in the last third of the twentieth century was in fact lower than it had been during the comparable period in the nineteenth.

developments in improving sectors as reflecting positive and persistent aggregate supply effects attributable to the war. From this perspective, it is worth asking how national economy TFP growth between 1941 and 1948 compared with what came before and after.

Table 2 reports private domestic economy (PDE) TFP growth rates across different intervals between 1919 and 2017. Like the private nonfarm economy (PNE), the aggregate excludes government product which, because it is valued at the cost of inputs, cannot show productivity gains. Again, the key intervals here are 1929-41 and 1941-48. Prior to 1929 we don't have the BEA's chained index measures of GDP (I rely on Kendrick for 1919-29), and after 1948 we can use the BLS productivity data.

For the years 1929-48 the BEA provides chained index output for GDP but not for the PDE. I estimate the latter by extracting GDP and PDE output in 1929 dollars from Kendrick (1961, table A-III, columns 5 and 7), and GDP chained index output from the BEA NIPA table 1.1.6, and then multiply the latter by the ratio of Kendrick's PDE output to his GDP.[39] I combine this with the BEA's chained index series for the net stock of physical capital in the private sector (BEA FAT table 1.2, line 3)) and Kendrick's series for (quality adjusted) labor input (1961, table A-XXII) to generate a new PDE TFP series for this period, again assuming .3 for capital's share.

Without a cyclical adjustment, the new series rises 2.57 percent per year between 1929 and 1941, and 2.86 percent per year between 1941 and 1948. Kendrick's series for PDE TFP increases 2.27 percent per year between 1929 and 1941, and just 1.51 percent per year between

[39] The changes are relatively modest. Between 1929 and 1941 the ratio dropped from .96 to .93 as the share of government product in total output increased. Between 1941 and 1948 it declined to .87 before rising back up to .94.

1941 and 1948). The upward revisions (compared to Kendrick) are principally the consequence of using chained index measures of GDP, which increase for both periods more rapidly than Kendrick's output estimates, with the increase for the latter period (1941-48) especially large.

It is widely accepted that measures of TFP are strongly procyclical (see Field, 2010), and a significant output gap remained in 1941. To calculate a cyclical adjustment to the level of TFP in 1941, I regress the change in the natural log of the new series for PDE TFP on the change in Lebergott unemployment in percentage points (Lebergott, 1964), and then use the coefficient on the right hand side variable to estimate what TFP in 1941 would have been had the economy enjoyed in that year the 3.8 percent unemployment of the fully employed civilian economy of 1948, as opposed to the actual 9.9 percent. The 6.1 percentage point difference in unemployment rates implies that had the US economy been fully employed in 1941, the level of TFP would have been 5.64 log percentage points higher, resulting in an estimated 3.07 percent continuously compounded trend growth rate between 1929 and 1941 and 2.01 percent per year between 1941 and 1948.[40]

In estimating a cyclicality coefficient, I use Lebergott (1964) rather than Darby (1976) unemployment because the Lebergott numbers offer, in my opinion, a better proxy for the utilization gap in the private domestic economy. The hiring of unemployed into government provided relief jobs in the CCC, the WPA, or the PWA would have had almost no influence on the ratio of capital to labor in the private sector, the principal factor driving measured procyclicality. The difference between the two series is the inclusion by Darby of federally

[40] Here are the regression results, t stats in parentheses:

$$\Delta \text{Ln (PDETFP)} = \underset{(3.30)}{.0270} - \underset{(-4.23)}{.00925}*\Delta \ln(\text{unemployment rate})$$

Adj R^2 =.510

funded workfare (emergency workers) during the depression as employed. Darby distinguishes between what he calls a "normal-jobs-to-be created" measure of unemployment and a "job seekers" definition, which he equates with the current practice (for the U3 measure) of counting anyone with as little as one hour of paid employment in the prior week as employed.

Table 2

	Total Factor Productivity Growth in the U.S. Private Domestic Economy 1919-2015 (percent per year)	Source
1919-1929	1.97	Kendrick (1961), table A-XXII, p. 334.
1929-1941	3.07[a]	Kendrick (1961), table A-XXII; BEA NIPA table 1.1.6, FAT table 2.2.
1941-1948	2.01[a]	Kendrick (1961, table A-XXII; BEA NIPA table 1.1.6, FAT table 2.2.
1948-1973	2.13	U.S. Bureau of Labor Statistics (2004), table 1
1973-1995	.53	U.S. Bureau of Labor Statistics (2004), table 1
1995-2005	1.62	www.bls.gov, accessed 10/4/2018
2005-2017	.48	www.bls.gov, accessed 10/4/2018

[a] Includes a cyclical adjustment to the level of TFP in 1941 (see text), as well as an adjustment to capital growth based on the increasing share of equipment in the net physical capital stock (see Gordon, 2016, Appendix A).

Proponents of the Darby measure maintain that emergency workers should be classified as employed. I view emergency work programs as unemployment benefits with a public service work requirement. The issue of whether the positions held were necessarily good substitutes for "normal" jobs, to use Darby's terminology, turns on how they were compensated. Darby's table 1 shows that between 1934 and 1941 annual wages for those in emergency work programs averaged 45 percent of those for full time workers in all industries. This is within the range of current replacement ratios for state unemployment compensation. Postwar practice counts those receiving such benefits as unemployed.[41]

The choice of Lebergott vs. Darby affects the size of a cyclical adjustment through two channels. The estimated regression coefficient on the change in the unemployment rate using Darby data is somewhat larger in absolute terms (-.0097), but the difference in rates between 1941 and 1948 is much smaller: 2.6 percentage points. Using Darby we would have PDE TFP at 2.78 percent per year for 1929-41 vs 2.50 percent between 1941 and 1948.

Some, such as Backer, Crafts, and Woltjer (2017) go beyond just advocating for Darby, and argue that there shouldn't be any cyclical correction at all because the US economy was already at potential in 1941. This, I believe, is an untenable position. 1942 GDP was 18.9 percent higher in real terms than it was in 1941 (BEA NIPA table 1.1.1). This is the largest year over year percent increase in U.S. economic history, or at least as far back as the BEA maintains data.[42] Using an Okun's Law coefficient of 2.5, the 5.2 percentage point decline in Lebergott unemployment from 1941 would suggest that roughly two thirds of the increase can be attributed to the elimination of the remaining output gap. Even using the 2.9 percentage point decline in Darby unemployment we would conclude that roughly a third of the increase could be so attributed.

Had the U.S. been at potential in 1941, it would have been impossible for the country to wage and win the war in the manner it did. Between 1942 and 1945, the country was able to

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[41] This discussion is a reminder that it is not obvious how we should divide the civilian population into employed, unemployed, and not in the labor force, one of the reasons the BLS now publishes six measures of the unemployment rate. In explaining his different classification of federal vs state and local emergency workers workfare, Darby acknowledges that judgments about the level of compensation relative to "normal" jobs matter.

[42] In only four other years since 1930 has the output increase in percentage terms entered double digit territory: 10.8 percent in 1934, 12.9 percent in 1936, 17.7 percent in 1941, and 17 percent in 1943.

produce enormous quantities of military hardware while putting over twelve million people in uniform, mobilizing a much smaller fraction of prime age women than was true for other combatants (Harrison, 1988)[43] and, unlike Britain, avoiding resort to an industrial draft. To be sure, the gap closed rapidly after 1939, and continued to do so during 1941. Spot shortages of skilled labor, machine tools, and some materials became evident as early as midsummer 1940 (Klein, 2013, p. 158, citing Donald Nelson), and these became more frequent in 1941. The shortages of machine tools and materials were the results of an upsurge in metal-using foreign and domestic military orders combined with strong demand from reviving consumer industries such as automobiles, gravely aggravated by concerted efforts by private business to avoid constructing new capacity. Resistance by steel manufacturers and others was motivated by a wish to avoid an overhang of excess capacity after the war, as had been the case following World War I, the experience of running at less than capacity for most of the depression, and finally a generalized wish to preserve an oligopolistic industry structure. Similar concerns limited capacity expansion in the monopolized aluminum industry. That said, considerable plant expansion, particularly in the aircraft industry was begun during the defense period. The attack on Pearl Harbor along with the government's subsequent willingness through the RFC's Defense Plant Corporation to pay directly for plant and equipment dramatically increased construction activity, but resistance continued even after the country entered the war (see Vatter, 1985, pp. 24-27).

The idea that the country faced serious labor shortages anytime in 1941 is belied by the official government history of economic mobilization:

[43] Participation increased during the war from 28 to 36 percent, and then fell back for a decade after the war, before beginning to climb again, reaching 42.6 percent in 1970 and 50 percent in 1978 (Vatter, 1985, p. 18).

> The problems of raw material supply, transportation, and production planning…had become urgent before Pearl Harbor. Our labor reserves, however, were so ample, that no acute problems of labor supply appeared until later. Shortages of unskilled and industrial workers did not become acute until 1943, and then only in a few production areas (U.S. Bureau of the Budget, 1946, p. 173).[44]

Even in 1943, the year of peak military production, problems of recruitment and retention were not "sufficiently acute to arouse serious concern among production and procurement officials. Facilities and materials were the important production bottlenecks" (1946, p. 175). The most serious concerns did not emerge until late 1944 and the first few months of 1945, following the Germans' unexpected offensive in the Ardennes (1946, pp. 8-9). By the end of February 1945, all of the Army's combat division were committed overseas. There was no military manpower in reserve, and many industries feared losing skilled labor as the consequence of Selective Service withdrawals of industrial deferments (Gropman, 1996, p. 52; War Production Board, 1945a, p. 9).

What of the macro evidence on inflation? The GDP deflator in 1941 was indeed higher than it had been in 1940. After four years it had finally caught up with and then risen above where it has been in 1937, and now stood 3.9 percent above its level in that year. In 1937, in comparison, the deflator was 13.6 percent higher than it had been four years earlier (BEA NIPA Table 1.1.9). In December 1941 the wholesale price index was up a dramatic 22.7 percent from the previous December. But this represented an annual increase of 1.4 percent per year from the previous peak in July of 1937. The fact that inflation was much higher over the four years prior to 1937 does not necessarily mean we were closer to potential in 1937. The fact that inflation

[44] While acknowledging some skilled labor deficiencies in the metal industries as early as the fall of 1940, the authors maintain that these were localized, and remedied by job simplification, training programs and the promotion of partly trained workers. Relative to Britain, Milward writes, "There was no comparable labour shortage in the United States until 1944 (1977, p. 235).

was positive in 1941 and virtually nonexistent in 1929 does not necessarily mean the U.S. was closer to potential in 1941 than it was in 1929.

Hourly wages (nominal) in US manufacturing also rose in 1941: up 7 cents an hour (10.6 percent) from 1940, and up 17.7 percent (11 cents) from 1937. In 1937, however, hourly wages were up 7 cents from 1936 (a 13 percent increase) and up 18 cents from 1933 (a 43 percent increase) (HSUS, series Ba4361). Moreover, the GDP deflator increased only 3.7 percent between 1936 and 1937, vs. 6.8 percent between 1940 and 1941, so the increase in real wages in manufacturing was larger between 1936 and 1937 than it was between 1940 and 1941.

Although the price level or the inflation rate can clearly have an empirical association with the size of an output gap, the relationships are not as reliable or stable as some of our textbooks might suggest. Other indicators reveal an economy in 1941 with substantial remaining excess capacity. Monthly auto production peaked in June of 1941 at 419,000, 5 percent below output in April of 1937, and 22 percent below peak production in April of 1929 (FRED series M0107AUSM543NNBR). And single family private nonfarm housing starts in 1941 remained 32 percent below the peak in 1925 (FRED series A0261AUSA610NNBR). Perhaps no one appreciated the size of the remaining output gap in 1941 better than Robert Nathan and Simon Kuznets, whose calculations undergirded the feasibility debate (see Edelstein, 2001, p. 64).

Gordon's TFP Calculations

Gordon (2016) suggests a rather different pattern of TFP growth over the Depression and war years. The aggregate (total economy) TFP growth rates presented in his chapter 16 are the principal, indeed the only quantitative empirical support for his interpretation of the beneficial supply side effects of the war. His figure 16-5 appropriately highlights the generally strong advance between 1920 and 1970, as compared with the decades prior to and following these years. The symmetric bar graph shows TFP growth rates peaking in the decade of the 1940s and falling off monotonically in the decades immediately preceding and following

For several reasons, however, this figure offers a misleading picture of the supply side consequences of the war. The chart suggests TFP growth in the 1940s almost twice as high as during the 1930s: 3.4 vs 1.8 percent per year, apparently echoing Baumol's interpretation of the Maddison data. These numbers are almost the reverse of those reported in table 2 for the intervals 1929-41 and 1941-48.[45] Why these large variances? Gordon has kindly shared his spreadsheets with me, making it possible to identify and quantify the sources of our differences. Here are some of the most important: We measure over slightly different time intervals. I make a cyclical correction for the level of TFP in 1941. The series we use for labor hours and labor quality growth rates differ, and, although we both start from BEA Fixed Asset data on private sector capital growth, Gordon makes a number of adjustments that raise his capital input growth rates, especially for the earlier interval.

Table 3 summarizes the sources of our differences and their relative importance. The row labels describe how one gets from Field to Gordon, but the table can, with some accommodation,

[45] The Rise and Fall of American Growth brought to a popular audience as well as many economists an interpretation of the broad contours of US economic growth since 1870. Gordon considered the evolution of productivity, consumption, and more generally the U.S. standard of living from the end of the Civil War to the present day. Although the research was determinedly historical – sixteen of eighteen chapters focused principally on the past -- it was the pessimistic forecast for the future developed in previous working papers and summarized in chapters 17 and 18 that generated the lion's share of critical discussion and commentary. The debate featured dueling TED talks from Gordon on the one hand and Eric Brynjolfsson and Andrew McAfee on the other (both from 2013), as well as optimist rebuttals to Gordon from his colleague Joel Mokyr (2016), Deirdre McCloskey (2016), and others.

be read from top to bottom or from bottom to top, moving from Field to Gordon or vice versa. The first two columns show growth rates for 1929-41 and 1941-48 respectively (these are bolded), and the third shows the percentage point spread between the former and the latter. The first row is from Field, table 2, and the last row is from Gordon, figure 16-5. For each adjustment the percentage point effect (non-bolded) on the growth rate for each interval is shown in columns 1 and 2 and the combined impact on the spread in column 3.

We begin at the top (row 1) with a 1.06 point spread in favor of 1929-41 (Field), and end at the bottom (row 19) with a 1.58 point advantage for the 1940s as compared with the 1930s (Gordon). Rows 2 and 3 show the effect of removing the cyclical adjustment for the level of TFP in 1941. Rows 4 and 5 factor in the impact of switching to Gordon's measure of output (total economy), as opposed to Field's estimate for the private domestic economy. Rows 6 and 7 show the consequences of switching to Gordon's labor input series. Gordon starts with total economy hours from Kendrick (1961, table A-X), and then adds a labor quality adjustment based on Goldin and Katz's calculation that educational quality improved at a rate of .50 percent per year between 1915 and 1940, and .49 percent per year between 1940 and 1960 (2008, table 1.3, p. 39). Field starts with Kendrick's hours for the PDE (1961, table A-XXII) and then includes Kendrick's labor quality adjustment. Gordon's labor input rises substantially more rapidly than Field's over the 1929-41 period (see bottom panel of table 3).

Rows 8-17 cover the impact of the three adjustments made by Gordon to capital input. Rows 8 and 9 deal with the slight differences between our measure of "official BEA capital" in the private economy (my source is BEA FAT table 2.2, line 1). The most empirically significant of Gordon's three adjustments is 'variable retirement' (rows 10 and 11). Gordon observes that because gross investment was low during the depression years, the average age of both structures and equipment increased. He then notes that the BEA, employing perpetual inventory methods (gross investment added, depreciation subtracted) to construct its estimates of net fixed assets, uses fixed depreciation schedules, ignoring the fact that assets fully depreciated according to its conventions often continued in place. In other words, fully BEA depreciated assets were not necessarily retired. Consequently, we need to adjust upward the implied flow of capital services from the BEA stock estimates, particularly across the Depression years.

We do not know, however, the extent to which this dynamic may have been operative in other periods. Gordon writes that when "gross investment was high, depreciation was also high" (p. 662), by which he seems to mean that *actual* retirements were high. But this is simply asserted.[46] It may well have been the case that during the 1920s or the 1940s, for example, previously produced assets also remained in place even after they were fully depreciated according to BEA conventions. Indeed, such possibilities are suggested by Gordon's remarks about the almost infinite life of some residential and nonresidential structures (2016, p. 663). To be comfortable with this adjustment we would need to have detailed information about how the incidence of this dynamic varied across different intervals.

[46] Since rises in gross investment presumably followed period of low gross investment, and thus slow or even declining net stocks of capital, it is quite likely that BEA depreciation was relatively low when gross investment was high.

Table 3: Field - Gordon TFP Growth Reconciliation, 1929-41 and 1941-48 (National Economy)

		1929-41	1941-48	% Point Difference
1	**Field Table 2 (growth rates are for 1929-41 and 1941-48)**	**3.07**	**2.01**	**1.06**
2	Remove cyclical correction for level of 1941 TFP	-0.50	0.84	-1.34
3	Subtotal	**2.57**	**2.85**	**-0.28**
4	Use Gordon (total economy) rather than Field (PDE) output growth	0.27	-0.18	0.45
5	Subtotal	**2.84**	**2.67**	**0.17**
6	Use Gordon labor input growth (including quality adjustment)	-0.57	0.32	-0.89
7	Subtotal	**2.27**	**2.99**	**-0.72**
8	Use Gordon measure of "official capital"	0.03	0.02	0.01
9	Subtotal	**2.30**	**3.01**	**-0.71**
10	Include Gordon's variable retirement adjustment to capital growth	-0.30	-0.02	-0.28
11	Subtotal	**2.00**	**2.99**	**-0.99**
12	Include adjustment to capital growth for growing share equipment	-0.08	-0.16	0.08
13	Subtotal	**1.92**	**2.83**	**-0.91**
14	Include Gordon adjustment for government capital	-0.13	-0.03	-0.10
15	Subtotal	**1.79**	**2.80**	**-1.01**
16	Intervals: Measure 1930-40; 1940-50 rather than 1929-41; 1941-48	0.04	0.58	-0.54
17	Subtotal	**1.83**	**3.38**	**-1.55**
18	Statistical Discrepancy	-0.01	0.01	-0.02
19	**Gordon Table 16-5 (growth rates are for 1930-40 and 1940-50)**	**1.82**	**3.39**	**-1.57**

	Labor Input		**Capital Input**		**Output**	
	Field	Gordon	Field	Gordon	Field	Gordon
1929-41	-0.06	0.76	0.25	1.85	2.60	2.87
1941-48	1.71	1.26	1.57	2.19	4.52	4.34

Note: Both Field and Gordon assume a capital share of .3.

An additional concern is this. To the degree that we worry about unmeasured quality improvement in capital goods, the slowdown in replacement of vintages would suggest an adjustment in the opposite direction (Abramovitz and David, 2000, pp. 28-29; see also Field, 2011, pp. 29-30). This concern is typically motivated by reference to machinery. But the change in the optimal layout of factory buildings and shift away from multi-storied construction associated with replacing the means of internally distributing power in the 1920s suggests it might have been applicable to structures as well. For 1941-48, the variable retirement adjustment makes little difference for a TFP growth rate calculation. But it makes a significant difference for 1929-41.

Gordon's second adjustment to BEA capital addresses the growing share of equipment in the fixed asset stocks (rows 12 and 13). Since machinery has a higher annual user cost per dollar of net stock than structures, changes in shares of fixed assets may require adjustments to the estimate of the service flow from the overall stock (this adjustment has relatively little effect on the difference between the growth rates in the two intervals). Gordon's third adjustment to capital growth is based on the possible effect on private sector productivity of government capital that might be complementary to private production (rows 14 and 15). The logic here is sound, even if we are interested in PDE rather than total economy output (see also Field, 2003, 2011, pp. 27-30). But the implementation raises concerns. Somewhat surprisingly, given his 1969 JPE article, Gordon does not include government owned manufacturing plant and equipment. He argues persuasively that most military hardware should be excluded, but includes military structures. Many should probably be excluded on the same grounds as are bombers, aircraft carriers, and fighter airplanes.

Finally, rows 16 and 17 show the impact of shifting to Gordon's 1930-40 and 1940-50 intervals. Kendrick (1961), Abramovitz and David (2000), Field (2003, 2011) and Gordon all operate within an NBER tradition emphasizing the desirability, to the extent possible, of estimating trends in macroeconomic series by measuring between peaks. We can't expect census years necessarily to coincide with business cycle peaks, and in most instance they don't. 1941 is the closest we can get to full employment prior to the economic distortions associated with full scale war mobilization. For the postwar peak 1948 is preferable to 1950 – since the unemployment rate was lower in 1948 than in 1950. As for the pre-Depression peak, 1929 is preferable to Gordon's sometime preference for 1928; since unemployment was lower in 1929 in the absence of any evidence of goods and services price inflation. Either should be preferred to 1930, which had an 8.7 percent unemployment rate. The use of 1940 as a benchmark is the most problematic. Because of the procyclicality of TFP, measured productivity levels were substantially lower in 1940 than in 1941, reducing a calculated growth rate to 1940 and increasing a calculated growth rate from 1940, as compared with calculations that measure to and from 1941. As a consequence, decadal rates of TFP growth between census years are unlikely to be good proxies for peak to peak measures, especially across the war years (1941-48).

The case for preferring the table 2 numbers in this paper to those offered by Gordon is based on arguments against or reservations about some of the adjustments he makes, combined with arguments in favor of those made by me. I remain particularly concerned that the use of Gordon's adjusted capital input may move us away from rather than towards more informative TFP growth rates for the two intervals in question. But the case for preferring the table 2 numbers goes beyond these considerations. It is based as well on the argument that these numbers are consistent with the historical narrative and other evidence developed and discussed in this paper in ways that Gordon's numbers simply are not. Ultimately, readers will make their own judgments. In doing so, they may wish also to consider Kelly, Papanikolaou, Seru, and Taddy (2018), which proposes a quality adjusted time series of US patents (raw patent data is not particularly useful in differentiating periods in terms of their technological progressivity). Their series shows the 1930s to be a peak period for influential patenting, with rates falling off rapidly during the war and remaining at low levels for several decades thereafter.

Conclusion

The 'economic miracle' narrative emerged against the backdrop of a continuing contest over how to organize, characterize and credit the production successes. The use of the word 'miracle' to describe US war mobilization took shape in 1942 in an address by Eugene Wilson, CEO of United Aircraft. Picking up on this theme, the Ford Motor Company ran advertisements describing its production efforts as "the greatest miracle of mass production the world has ever seen", language echoed in the firm's public relations film about the Willow Run plant (Ford Motor Company, 1945).

In his January 1943 SOTU address, Roosevelt used similar words, referring to the "miracle of production" (Wilson, 2016, p. 106). The spread of this language was in part the result of efforts led by the U.S. Chamber of Commerce to insure that private business got all or most of the credit for winning the war. Business was determined to reestablish and reassert a dominant status from which it had been, in its view, temporarily dislodged during the New Deal.

This narrative was reflected and reinforced in Francis Walton's <u>The Miracle of World War II: How American Industry Made Victory Possible</u> (1956) and many other publications, including Arthur Herman's 2012 best seller, <u>Freedom's Forge: How American Business Produced Victory in World War II</u>. The reality is that even beyond the government owned and operated Navy Yards and Army Arsenals,[47] production took place largely within plants wholly owned by the U.S. government, which by the end of the war comprised between 15 and 25 percent of U.S. manufacturing capacity (Wilson, 2016, p. 258). Tens of thousands of US

[47] Contrary to the situation today, the US Navy built roughly half its warships in its own government owned and operated shipyards, and the US Army controlled arsenals where design, testing and some production of weaponry, particularly artillery and small arms, took place.

government employees,[48] both military and nonmilitary, negotiated contracts, assigned priorities (or, eventually, raw material allocations), audited books, inspected output, and in some cases, with the backing of armed soldiers, took over production facilities where labor or management recalcitrance threatened the war effort. Even after paying excess profit taxes, business did extremely well during the war, while risking very little (Higgs, 1993).

Business leaders were so focused on who should get credit for the production achievements that they eventually began expressing unease about references to 'miracles', believing it did not fully credit the contribution of the production experience gained in "150 years of free enterprise" prior to the war, as put by the president of the National Association of Manufacturers in a speech in December of 1943 (Wilson, 2016, p. 106). While the repeated insistence by private sector leaders that achievements were in spite of the bureaucratic hamstringing of government officials was self-serving, their claim that success depended on prior production experience and their eventual push back against appeals to the supernatural can be endorsed. It is important to understand the agendas reflected in the public relations efforts. We should be skeptical of magical thinking about World War II production successes, just as we are of mystical (and mythical) evocations of the 'greatest generation' (Klein, 2013). As the official government history of economic mobilization put it,

> …there was terrific waste in conversion. After a tragically slow start, many a plant was changed over to war production when its normal product was more needed than its new product.…we built many factories, and expanded many others, which we could not use and did not need. Many of these new factories we could not supply with labor or with raw materials, or if we had we would not have been able to fly the planes or shoot the ammunition that would come out of them. But in the process we used up critical material

[48] The War Production Board, which had 6,000 employees when established in 1942, had 18,000 by midyear (Vatter, 1985, p. 67). At its peak, the Armed services directly employed more than two million civilian employees (U.S. Bureau of the Budget, 1946, p. 176).

> which could better have gone into something else… (U.S. Bureau of the Budget, 1946, pp. 113-14).

Lack of systematic planning and scheduling led to multiple claimants for limited resources, particularly aluminum, steel, and copper. "During the summer and fall of 1942 scores if not hundreds of production lines were closed down for brief periods when the flow of materials ceased" (1946, p. 280). The feasibility debate reached crisis proportions with the October 6, 1942 report by Robert Nathan. That the country was able to proceed in the fashion it did and still win the war was a reflection of its unrealized potential in 1941, not a productivity miracle quickly incubated during the limited months of mobilization. The sheer quantity of production should and must be acknowledged. But as Paul Koistinen concluded, given its "prewar potential and when compared with other belligerents, America's World War II munitions production effort was not outstanding" (1984, pp. 102-103).

In 1948 the U.S. stood astride the world, both militarily and economically. Japan, having endured two atomic bombings as well as the earlier firebombing of Tokyo, lay prostrate. Germany and much of Europe was in ruins. The Soviet Union had suffered 20 million war-related deaths. England had sold off much of its remaining overseas economic empire to pay for military spending. The United States appeared relatively unscathed, and it was easy to connect the country's success in producing hundreds of thousands of aircraft and other military hardware with the level of its potential output after the war and the large productivity gap between the US and the rest of the world then evident. But the connection is a mirage. The economy's postwar capabilities are almost entirely attributable to conditions already in place in 1941. As far as its impact on the long run advance of aggregate supply, the military conflict and the economic mobilization for war that it required was a detour, as had been the case for the Civil War and, it appears, the Revolutionary War and its aftermath as well (Lindert and Williamson, 2016, ch. 4).

Although the conflict did leave the economy with assets that benefited postwar production capability, it distorted physical capital accumulation, crowding out investment in sectors of the economy not critical for the military effort. The U.S. suffered more than a million military casualties.[49] On the home front, the increase in the female labor force between 1940 and 1944 proved to be a flash in the wartime pan. The country achieved production success, but this was not the consequence of a productivity miracle. Between 1941 and 1948 TFP declined in manufacturing and construction, and in the aggregate, grew more slowly than had been true between 1929 and 1941.

When subject to critical analysis, the learning by doing narratives, which seem so compelling on their face, break down as an explanation for an alleged boost to postwar TFP advance which is not evident in the productivity data. The paper looks in depth at the case of aircraft (the largest category of spending on munitions during the conflict) as well as the Liberty ships. The learning that took place during the war was largely irrelevant afterwards, because the output mix was different and we never again mass produced such large quantities of aircraft or ships in such a limited time frame. Creative responses to shortages of critical raw materials such as aluminum and steel were irrelevant after the war when more “normal” peacetime availabilities and factor prices returned.

For economists and economic historians who work on the United States, the war often remains a cipher, a series of years to be omitted from time series regressions or otherwise passed over. But it continues to play an important role in the macro narrative of the twentieth century – both in closing the output gap remaining in 1941, and in (allegedly) laying the groundwork on

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[49] Other countries suffered more, both in absolute terms and relative to their size. The argument here is with the optimistic view of the war’s impact on U.S. aggregate supply.

the supply side for postwar advance. For the United States, as for other combatants, the Second World War was in fact an enormous and tragic waste of human and physical resources. Economically disruptive, it greatly distorted the economy for a period of several years, as sectors critical to the war effort expanded several-fold and then as rapidly shrunk. The impact on the growth of U.S. potential output of this unique and never to be repeated experience was, on balance, almost certainly retardative.

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APPENDIX

This appendix provides the data underlying the conclusion that TFP in manufacturing between 1941 and 1948 declined, estimates TFP growth in other sectors during this same period, and examines sectoral contributions to private domestic economy TFP growth between 1941 and 1948. In contrast to the treatment of trends in aggregate TFP in the main body of the paper, there is no attempt at the sectoral level to make cyclical adjustments for the level of TFP in 1941. Second, as in Field (2011), the calculation of sectoral contributions to aggregate TFP growth does not utilize the newer chained index measures of output. Such data are not available at the sectoral level for these time periods. Finally, the approach uses single rather than double deflation. The Bureau of Economic Analysis's preferred method for calculating sectoral output growth in the GDP by industry section of its website is to deflate the nominal value of gross output, deflate the nominal value of intermediate inputs, and treat the difference between the deflated series as real value added. Whatever the merits of this method, data available prior to 1947 will not support it, so the approach followed, in instances where the calculations go beyond index numbers available in Kendrick (1961), is single deflation of nominal income generated in a particular sector.

We begin by examining productivity growth between 1941 and 1948 in comparison with the depression years (1929-41) for the following sectors: manufacturing, wholesale and retail trade, and railroad transportation. According to Field (2011, table 2.5, p. 59), these three sectors accounted for over 90 percent of total TFP growth in the private nonfarm economy between 1929 and 1941. We then look at agriculture (not part of the PNE) as well as trucking and warehousing, electric and gas utilities, mining, and construction. Table A9 brings these sectoral estimates together and estimates their respective contributions to aggregate TFP growth. The calculations reflected in table A1 are described in the main text.

We adopt a similar approach for other sectors, beginning with wholesale and retail trade (table A2). Nominal income generated in the sector is from Department of Commerce 1966, table 1.12. These flows are deflated by the personal consumption expenditure (PCE) deflator (Department of Commerce, 1966, table 8.1, p. 158). This shows real output growing in the sector at 3.2 percent per year between 1929 and 1941, and 5 percent per year between 1941 and 1948. For labor input, FTEs for both wholesale and retail trade are drawn from BEA NIPA Table 6.5A. It is not possible to adjust the 1941 FTEs for changes in the average hours per week, but retail FTEs for 1948 are adjusted downward because of the decline from 42.8 to 40.2 hours reported in HSUS Series Ba4580. We have labor input growing at 1.5 percent per year between 1929 and 1941, and 2.7 percent per year between 1941 and 1948. Together with the output growth numbers, we can estimate labor productivity growth at 1.64 percent between 1929 and 1941 and 2.23 percent between 1941 and 1948.

Capital input is estimated from BEA Fixed Asset Table 2.2, lines 44 (multi-merchandise shopping structures) and 46 (warehouses). Growth rates for the two series are combined, weighted according to the average value of these two components at the beginning and end of each period (BEA Fixed Asset Table 2.1). We have capital growing at -.8 percent between 1929 and 1941, and -.9 percent between 1941 and 1948. Bringing all three series together, and assuming a capital share of .3, we have TFP growing at 2.27 percent per year between 1929 and 1941, and 3.26 percent per year between 1941 and 1948 (table A2).

Because of its relatively large size and robust rate of TFP advance, the sector contributed .71 percentage points to PNE TFP growth between 1941 and 1948 – the largest contribution of any sector. In contrast to manufacturing, labor input in trade declined through 1942 and 1943 before beginning to recover, although FTE levels in both subsectors were still lower in 1945 than they had been in 1941. And in contrast to manufacturing, capital input declined. Learning by doing without seems to have been a powerful stimulus to advance.

For railroads (table A3), a sector which, in contrast with 1917-18, performed well during the war, productivity growth remained about as high between 1941 and 1948 (or 1950) as it was during the 1929-41 period. The huge loads carried during the war were the swan song for American railroads, at least with respect to passenger traffic, which began dwindling in the 1950s until all that remained were a few subsidized routes run by Amtrak. But productivity growth in freight transportation after the war remained respectable (Field, 2011, pp. 112-115). Faced with exceptionally strong demand and tight labor availabilities, the sector was able to extend the trajectory of advance displayed between 1929 and 1941 (2.56 percent per year between 1941 and 1948 vs 2.94 percent in the earlier period). The Depression years had seen a shift toward diesel electric motors and progress toward unlimited freight interchange, and systematic rationalization in which hours, locomotives, and rolling stock all declined by a quarter or a third, while output changed hardly at all. Here the data is drawn from Kendrick; in contrast to the two previous sectors, Kendrick has annual data in levels throughout the relevant time intervals. The sector contributed .11 percentage points per year to PNE TFP advance.

Trucking and warehousing (table A4) takes output and employment from Kendrick, and capital from BEA FAT table 2.2, line 19: trucks, busses, and light trailers. Data limitations in Kendrick require measuring to and from 1942 rather than 1941, and the use of employment numbers rather than hours for labor input. They show TFP growth retreating from the torrid advance between 1929 and 1941 of 12.61 percent per year to a still very strong 3.36 percent per year between 1942 and 1948. The sector contributed .04 percentage points per year to PNE TFP growth between 1941 and 1948.

The analyses of the electric and gas industries (table A5) are also based on Kendrick. Both sectors had experienced strong growth in TFP between 1929 and 1941, and growth continued at a slightly higher rate between 1941 and 1948: 5.87 percent for electric, and 5.45 percent for gas. In the absence of a better way to do this, these growth rates are weighted by data on the number of employed persons in the respective subsectors in 1929 (Kendrick, 1961, table H-X). Even though the sector is roughly half the size of railroads, the high rate of TFP advance means that utilities contributed .13 percentage points to PNE TFP growth, as compared with railroads' .11 percentage points. Shortages of domestic generating capacity (naval ships represented a huge competing demand for boilers and turbines) led to innovations in distribution which improved the efficiency of the national electrical grid (see War Production Board, 1945a, pp. 40-41). Again, the lasting benefit was the consequence of learning by doing without, and did not accrue within the manufacturing sector.

Mining is covered in table A6, with output and hours from Kendrick, and capital from the BEA's Fixed Asset Table 2.2. TFP growth fell to .64 percent per year between 1941 and 1948 as compared with 2.09 percent per year between 1929-41. The much slower advance after 1941 is consistent with deteriorating productivity in this sector in the economies of other combatants (Milward, 1977, p. 231). Because of its relatively small share and modest TFP advance, the sector's contribution to PNE TFP growth is a negligible .02 percentage point.

The depression years had been a dismal period for construction, with TFP declining at .91 percent per year. Measuring between 1941 and 1948 the situation got worse, with TFP falling at

2.71 percent per year, contributing -.15 percentage points to the overall PNE TFP growth rate (table A7).

TFP growth in agriculture (table A8) is based on Kendrick for net output and hours, and the BEA for capital (FAT tables 2.1 and 2.2; see source note). They show that between 1941 and 1948, TFP in the sector increased respectably (1.55 percent per year), although not as rapidly as between 1929 and 1941 (2.20 percent per year).

The remainder of the private domestic economy (sectors not covered in tables 1-8) is split between finance, insurance and real estate (10 percent), transportation services other than railroads and trucking (1.6 percent) and other services not elsewhere classified (9.5 percent), for a total of roughly 21 percent of the PDE. Based on Kendrick's data, PDE TFP growth between 1941 and 1948 was 1.51 percent per year. The sectors discussed in tables A1-8 contribute on net .79 percentage points, implying 1.01 percent points in the residual sector, which in turn implies a 5.00 percent annual TFP growth in the residual services category (see table A9).

Between 1941 and 1948 the biggest percentage point contributors to PDE TFP growth were the residual service category, followed by wholesale and retail trade, agriculture (where advance just balanced the loss in manufacturing), electric and gas utilities, and railroads, with much smaller contributions from trucking, telephone and telegraph, and mining. TFP growth was negative in manufacturing, and strongly negative in construction. A combination of strong demand, scarce labor and (in most cases) meagre capital growth seems to have been a more powerful stimulus to TFP growth over the course of mobilization and demobilization than conditions within wartime manufacturing, which joined a disruptive and temporary new product mix with massive government infusions of physical capital and priority access to materials and labor. Among the positive contributors, agriculture was something of an exception since, with the exception of 1943, it suffered less from wartime restrictions on access to new machinery (Vatter, 1985, p. 53).

Table A1

Manufacturing Productivity Growth: United States, 1929-48

	Nominal Output	Nominal Durables	Deflator Durables	Deflator Nondur	Real Output	FTEs	Weekly Hrs	Hours Growth	Manu Capital BEA	Adjusted Manu Capital [a]	Labor Prod	TFP
Levels											1929=100	
1929	21945	11303	56.4	54.5	395.67	10428	44.2		9.673	9.673	100.0	100.0
1939	18094	9001	46.0	43.8	403.28	9967	37.7		10.094	10.094	125.0	116.1
1940	22481	12167	46.5	43.8	497.14	10882	38.1		10.429	10.530	139.7	131.9
1941	33211	20317	50.4	47.7	673.43	13137	40.6		11.046	11.941	147.1	144.3
1942	45437	28853	59.3	55.6	784.83	15284	43.1		11.233	14.275	138.8	137.5
1943	58253	38606	64.2	62.5	915.69	17402	45.0		11.161	15.695	136.2	138.1
1944	60331	39325	71.5	66.2	867.31	17050	45.2		11.302	16.952	131.1	129.3
1945	52186	30964	75.9	68.7	716.87	15186	43.5		11.746	17.511	126.4	117.9
1946	49134	24270	76.8	74.3	650.66	14493	40.3		12.692	17.069	129.8	117.5
1947	59496	31461	82.7	83.6	715.77	15215	40.4		13.759	18.240	135.6	122.3
1948	67571	35448	86.3	88.5	773.72	15530	40.0		14.511	19.153	145.1	129.3
Growth Rates												
1929-41					0.0443	0.0192	-0.0071	0.0122	0.0111	0.0176	0.0322	**0.0305**
1939-40					0.2092	0.0878	0.0106	0.0984	0.0326	0.0423	0.1109	**0.1277**
1940-41					0.3035	0.1883	0.0636	0.2519	0.0575	0.1258	0.0516	**0.0895**
1941-42					0.1531	0.1514	0.0598	0.2111	0.0168	0.1785	-0.0580	**-0.0483**
1942-43					0.1542	0.1298	0.0431	0.1729	-0.0064	0.0948	-0.0187	**0.0047**
1943-44					-0.0543	-0.0204	0.0044	-0.0160	0.0126	0.0771	-0.0383	**-0.0662**
1944-45					-0.1905	-0.1158	-0.0383	-0.1541	0.0385	0.0324	-0.0364	**-0.0923**
1945-46					-0.0969	-0.0467	-0.0764	-0.1231	0.0775	-0.0256	0.0262	**-0.0031**
1946-47					0.0954	0.0486	0.0025	0.0511	0.0807	0.0664	0.0443	**0.0397**
1947-48					0.0779	0.0205	-0.0100	0.0105	0.0532	0.0489	0.0673	**0.0558**
1939-41					0.2564	0.1381	0.0371	0.1751	0.0840	0.0840	0.0812	**0.1086**
1939-44					0.1532	0.1074	0.0363	0.1437	0.0226	0.103694	0.0095	**0.0215**
1941-43					0.1536	0.1406	0.0514	0.1920	0.1756	0.1367	-0.0384	**-0.0218**
1941-44					0.0843	0.0869	0.0358	0.1227	0.1428	0.1168	-0.0383	**-0.0366**
1941-45					0.0156	0.0362	0.0172	0.0535	0.0154	0.0957	-0.0379	**-0.0505**
1945-48					0.0254	0.0075	-0.0280	-0.0205	0.0705	0.0299	0.0459	**0.0308**
1941-48					0.0198	0.0239	-0.0021	0.0218	0.0390	0.0675	-0.0019	**-0.0157**

Sources: Bureau of Economic Analysis, Fixed Asset Table 4.2, line 9
Department of Commerce, 1966, tables 1.12, 6.4, 8.1, 8.6
Historical Statistics of the United States, series Ba4580
See text for full description.

[a] Based on Gordon (1969, table 4) see text.

Table A2
Productivity Growth in Wholesale and Retail Trade

	Nom. Income	PCE Deflator	Real Output	FTEs WT	FTEs RT	FTEs RT Adjust.	Hours Proxy	Multimerch. Shop.	Warehse	Capital Comb.	Labor Prod.	TFP
Levels												
1929	13511	55.3	244.32	1631	4215	4215	5846	13.95	16.499			
1941	17411	48.7	357.52	1952	5075	5075	7027	13.318	14.946			
1948	41674	82.3	506.37	2428	6477	6084	8512	12.822	14.053			
Growth rates												
1929-41			**0.0317**				**0.0153**	-0.0039	-0.0082	**-0.0057**	0.0164	0.0227
1941-48			**0.0497**				**0.0274**	-0.0054	-0.0088	**-0.0068**	0.0223	0.0326

Sources: US Department of Commerce, 1966
BEA NIPA Table 6.5A; FAT tables 2.1 and 2.1
HSUS series BA 4580
See text for full discussion.

Table
A3
Productivity Growth in US Railroads

	Output	Hours	Capital	Labor Prod	TFP
Levels					
1929	100	100	100		100
1941	105.5	68.6	94.5		141.8
1948	141.8	79.4	93.9		169.6
1950	128.6	63.5	95.6		184.8
Growth rates					
1929-41	0.0045	-0.0314	-0.0047	0.0359	**0.0291**
1941-48	0.0422	0.0209	-0.0009	0.0214	**0.0256**
1941-50	0.0220	-0.0086	0.0013	0.0306	**0.0294**

Source: Kendrick, 1961, table G-3, p. 545.

Table A4

Productivity Growth in Trucking and Warehousing

	Output	Employment	Capital	Labor Prod	TFP
Levels					
1929	10.4	56.9	6.258		
1942	74.5	89.7	6.484		
1948	123.9	107.2	11.918		
1950	174.2	129.7	14.054		
Growth rates					
1929-42	0.1515	0.0350	0.0027	0.1164	**0.1261**
1942-48	0.0848	0.0297	0.1015	0.0551	**0.0336**
1942-50	0.1062	0.0461	0.0967	0.0601	**0.0449**

Sources: Output and Employment from Kendrick, 1961, table G-VIII, p. 553.
Capital from BEA FAT 2.2, line 19, trucks, busses, and light trailers.
See also Field 2011, table 2.6, p. 51.
Note that labor input is employment, not FTEs or hours.

Table A5
Productivity Growth in Electric and Gas Utilities

Electric

	Output	Hours	Capital	LP	TFP
Levels					
1929	100	100	100		100
1941	186.5	82.5	107.8		194.7
1948	314.8	95.7	116.3		293.7
Rates of Growth					
1929-41	0.0519	-0.0160	0.0063	0.0680	**0.0555**
1941-48	0.0748	0.0212	0.0108	0.0536	**0.0587**

Natural Gas

	Output	Hours	Capital	LP	TFP
Levels					
1929	100	100	100		100
1941	163.6	91.6	110.3		164.6
1948	321.3	138.6	128.7		241
Rates of Growth					
1929-41	0.0410	-0.0073	0.0082	0.0483	**0.0415**
1941-48	0.0964	0.0592	0.0220	0.0373	**0.0545**

	Manhours 1929
Electric	756
Natural Gas	231
Manufactured Gas	172

Electric share	0.6523
Gas Share	0.3477

1941-48 Weighted Average TFP Growth:
0.0572

Sources: Kendrick, 1961, table H-VIII, H-IX, H-X, pp. 592-98.

Table A6
Productivity Growth in Mining

	Output	Hours	Capital	LP	TFP
Levels					
1929	100	100	27.435		
1941	106.5	77	26.989		
1948	133.3	88.9	35.147		
Rates of Growth					
1929-41	0.0052	-0.0218	-0.0014	0.0270	**0.0209**
1941-48	0.0321	0.0205	0.0377	0.0115	**0.0064**

Sources:
Output and Hours: Kendrick, 1961, table C-2, p. 397.
Capital: BEA FAT table 2.2, line 30, mining and oilfield equipment.

Table A7
Productivity Growth in Construction

	Nominal income	Deflator	Real Output	FTEs	Capital	LP	TFP
Levels							
1929	3835	37.6	102.0	1484	7.711		
1941	4219	38.6	109.3	1774	8.553		
1948	10612	76.7	138.4	2278	19.699		
Rates of Growth							
1929-41			0.0058	0.0149	0.0086	-0.0091	**-0.0072**
1941-48			0.0337	0.0357	0.1192	-0.0020	**-0.0271**

Sources:
Nominal Income: US Department of Commerce, 1966, table 1.12
Deflator for Total Structures: US Department of Commerce, 1966, table 8.7, p. 165
FTEs: US Department of Commerce, 1966, table 6.4.
Capital: BEA FAT table 2.2, line 29, Construction Machinery

Table A8

Productivity Growth in Agriculture (net output)

	Output	Hours	Capital	LP	TFP	Structures	Equipment	Capital Calculations Value Struct	Value Equip
Levels									
1929	100	100				56.819	20.978	6.9	2.3
1941	114.8	86.6				48.542	23.098	5.5	2.5
1948	119.2	73.9				54.415	38.073	14.3	5.8
Rates of Growth									
1929-41	0.0115	-0.0120	-0.0072	0.0235	0.0220	-0.0131	0.0080		-0.0072
1941-48	0.0054	-0.0227	0.0192	0.0280	0.0155	0.0095	0.0416		0.0192

Sources:

Output and Hours: Kendrick, 1961, table C-2, p. 397.

Capital: BEA FAT table 2.2, lines 28 and 65, weighted by shares of equipment and structures in total capital,. average of beginning and end year, from BEA FAT table 2.1, lines 28 and 65.

Table A-9
Sectoral Contributions to TFP Growth within the U.S. Private Domestic Economy, 1941-48

	1941 Nominal Income (billion $)	1941 Share of Nominal Income	1948 Nominal Income (billion $)	1948 Share of Nominal Income	1941-48 Sector TFP Growth	1941-48 % Point Contrib. to PDE TFP
All Industries	104.2		224.2			
Less Government	93.7		204.4			
Negative Contributors:						
Manufacturing	33.2	0.354	67.6	0.331	-0.0157	**-0.0054**
Construction	4.2	0.045	10.6	0.052	-0.0271	**-0.0013**
Positive Contributors:						
Wholesale and Retail Trade	17.4	0.186	41.7	0.204	0.0326	**0.0064**
Agriculture	8.4	0.090	21.5	0.105	0.0192	**0.0019**
Electric and Gas Utilities	2.1	0.022	3.7	0.018	0.0572	**0.0012**
Railroad	3.8	0.040	7.1	0.035	0.0256	**0.0010**
Trucking and Warehousing	1.0	0.011	2.3	0.011	0.0336	**0.0004**
Telephone and Telegraph	1.1	0.012	2.8	0.014	0.0181	**0.0002**
Mining	2.4	0.025	5.4	0.026	0.0064	**0.0002**
TOTAL of Above	73.6	0.786	162.7	0.796		**0.0044**
Residual Services						
FIRE	9.3	0.099	18.4	0.090		
Other transport services	1.5	0.016	3.5	0.017		
Services n.e.c.	8.9	0.095	19.5	0.095		
TOTAL Residual Services	19.6	0.210	41.4	0.203	0.0527	**0.0107**
TOTAL PDE	93.2	1.020	204.1	0.999	0.0151	**0.0151**

Sources: Share of private domestic economy: US Department of Commerce, 1966, table 1.12
Sector share = average of 1948 and 1941 nominal income in sector divided by income in all sectors less government
Sectoral TFP Growth: see tables A1-8. PDE TFP Growth: Kendrick, 1961, table A-XXII.