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The decline of US manufacturing productivity between 1941 and 1948

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Abstract

The view that war benefits potential output has been influential in treatments of US mobilization for the Second World War, where it has been largely premised on the benefits of learning by doing in producing military durables. If the thesis that war benefits aggregate supply is correct, it is indeed within manufacturing that we should most likely see its effects. Total factor productivity within the sector in fact fell at a rate of −1.4 per cent per year between 1941 and 1948, −3.7 per cent a year between 1941 and 1944, and −5.1 per cent a year between 1941 and 1945. The emphasis on learning by doing has obscured the negative effects of the sudden, radical, and temporary changes in the product mix, the behavioural pathologies accompanying the transition to a shortage economy, and the resource shocks inflicted on the country by the Japanese and Germans. From a long-run perspective, the war can be seen, ironically, as the beginning of the end of US world economic dominance in manufacturing.

KEYWORDS
manufacturing, productivity, petroleum, synthetic rubber, World War II

In 2011, *A great leap forward* argued that behind the backdrop of double-digit unemployment, the Depression years were, in the United States, extraordinarily technologically progressive, and as a consequence, potential output grew rapidly between 1929 and 1941. That book, and earlier papers by the same author, laid out a closely related thesis: that the supply foundations for the

golden age of US economic growth were already in place in 1941, and indeed, it was the growth of potential output across the Depression years that underlay US success in prosecuting the war.[1] That claim is the starting point for this paper, which challenges received wisdom about the effects of US mobilization for the Second World War.

The conventional take on the economic effects of the Second World War in the United States has three themes: First, that the massive fiscal and monetary stimulus associated with mobilization closed the negative output gap still prevailing in December 1941. Second, and closely related, that the United States succeeded in producing an enormous amount of ordnance and, indeed, total output between 1941 and 1945. And third, that learning, due to the accumulation of experience producing military durables, resulted in big increases in industrial productivity across the war years, with persisting benefits that established the supply side foundations for the golden age of US economic growth (1948–73).

The first two of these conclusions are largely indisputable.[2] However, the third cannot be correct if the argument advanced earlier by Field, that the supply side foundations for the golden age were already in place in 1941, is right.

I | RECEIVED WISDOM

The idea that war leaves a beneficial supply side legacy for an economy has, for decades, flourished in interpretations of the effects of US participation in the Second World War. In *Secrets of the temple*, the economic journalist William Greider described the 'economic consequences of World War II [as] extraordinarily bountiful', emphasizing how the government 'force fed the rapid development of new productive facilities across many industrial sectors [that] would become the basic industries of America's postwar prosperity' thus 'laying the groundwork for an abundant future'.[3] It was, he suggested, little short of an 'industrial revolution'. A similar perspective was reflected a year earlier in observations about relative rates of productivity advance in different epochs made by William Baumol.[4]

Alan Milward was a pioneering student of the war and remains one of its most perceptive, and many of his observations, particularly his nuanced and often skeptical views about the positive technological legacy of war, support positions advanced here. On the United States, however, he is sometimes uneven, misdating the establishment of the War Production Board (WPB), for example, and he ultimately arrives at the same position as Greider or Baumol: 'the United States emerged in 1945 in an incomparably stronger position economically than in 1941 … by 1945 the foundations of the United States economic domination over the next quarter of a century had been secured.… The USA emerged in 1945 into a world of exhausted nations, with its enormously expanded industries working at full capacity and at higher levels of efficiency than ever before'. The questions at issue are how much, if any of this, can be attributed to the experience of war production.[5]

[1] Field, 'Most technologically progressive'; idem, 'Impact of the Second World War'; idem, *Great leap forward*.

[2] On the fiscal and monetary stimulus associated with financing the war, see Goldin, 'War'; Rockoff, *America's economic way of war*; and Hall and Sargent, 'Three world wars'. For scepticism about the increase in real output during the war, see Higgs, 'Wartime prosperity'.

[3] Greider, *Secrets of the temple*.

[4] Ibid., pp. 323–4; Baumol, 'Productivity growth', pp. 1081–2.

[5] Milward, *War, economy and society*, pp, 63, 94, 112. The claims about efficiency levels and full capacity operation in 1945 are not supported by the data presented in table 2.

It is often also argued that the shop floor effects, which figure so prominently in the learning literature, were reinforced by spillovers from technological breakthroughs resulting from military research and development (R&D) and that these advances would not have occurred otherwise. In his 2006 book, *Is war necessary for economic growth?*, the economist Vernon Ruttan makes this argument forcefully, posing in the title a provocative question that he answered affirmatively: 'It is difficult to overemphasize the importance of the historical role that military procurement has played in the process of technology development'.[6] Without war, he suggested, the R&D spending necessary to develop new technologies would simply not be forthcoming. This in spite of the fact that the war shut down development of peacetime products and almost all basic scientific research for several years.[7]

In *The rise and fall of American economic growth*, Robert Gordon maintained that, driven by rapid advance in manufacturing, total economy total factor productivity (TFP) grew fastest during the decade of the 1940s. He explained this by citing the familiar narratives about airframes and Liberty ships, claiming that 'the shipyard example can be generalized to the entire manufacturing sector', and, indeed, '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'.[8] Gordon advertised his analysis as novel, but as the above references indicate, it has been the conventional wisdom for decades.

Treatments by historians of the supply side consequences of the Second World War reflect a similar robustness of the thesis as it applies to that conflict. Maury Klein, in *A call to arms: Mobilizing America for World War II*, echoed Ruttan's emphasis, enumerating a range of innovations he argued originated in the war and benefited the post-war economy: 'jet planes, radar, magnetic tape recording, early computers, and a host of electronic innovations'.[9] In *Warfare state*, James Sparrow wrote that 'the war brought opportunities for "creative destruction" on a scale that has yet to be matched'. The reference was not to artful bombing, but rather to an alleged Schumpeterian dynamic in which wartime innovation devalued older assets and businesses and sometimes led to their demise.[10] And in *Freedom's forge: How American business produced victory in World War II*, Arthur Herman gave as much credit as he could to America's business leaders for the success of American war mobilization, arguing that captains of industry both transformed the American military and 'laid the foundations for a postwar prosperity that would extend across three decades into the 1970s, and fuel the economic growth of the planet'.[11] In each of these instances, we see endorsement of positive and persisting supply effects resulting from the experience of war production, either generally or with specific reference to the Second World War.

In fact, productivity within US manufacturing declined sharply during the war and grew anemically after it compared with what had been true during the interwar years.

[6] Ruttan, *Is war necessary*, p. 3.

[7] Here, we can appropriately reference Milward's skepticism: 'And in spite of the ecstatic accounts of the achievements which such a concentration of resources brought in all economies, it is in fact not at all established that the so-called 'spin-off' from armaments development into more peaceful lines of scientific and industrial development was superior or even equivalent to what would have occurred without the pressure of war… There is no convincing evidence that the overall speed of technological advance was greater in wartime'. (Milward, *War, economy and society,* pp. 175, 180, but see also p. 2.)

[8] Gordon, *Rise and fall*, ch. 16, pp. 549–50.

[9] Klein, *Call to arms*, pp. 1–2.

[10] Sparrow, *Warfare state*, p. 7.

[11] Herman, *Freedom's forge*, p. x.

II | A FOCUS ON MANUFACTURING

If the thesis that war benefits aggregate supply is correct, it is within manufacturing that we should most likely see efficiency gains from the experience of economic mobilization. Mechanized conflict required huge increases in the production of airplanes, tanks, ships, and many other types of ordnance, and the plant, equipment, materials, energy, and intermediate goods necessary to make and (where applicable) operate them. This in turn was associated with an increase in the share of the civilian labour force devoted to manufacturing[12] and within manufacturing, the share of output consisting of military goods. The sector is the locus of all the well-known learning-by-doing narratives: the Liberty ships, the destroyer escorts, the C-47s, the B-24s, and the Oerlikon and Bofors anti-aircraft guns.[13] The narratives emphasize and imply that experience producing those goods generated sharp and persisting increases in efficiency, persisting in the sense that they moved the sector to permanently higher productivity levels.

The United States entered the war with a high, indeed world-leading, level of manufacturing productivity, the result of experience gained in decades prior to the First World War and capabilities refined during the Roaring Twenties and the Great Depression. It also entered the war with a negative output gap, the tail end of a more than decade-long depression.[14] That gap was more apparent in sectors other than manufacturing, but it meant that reserves of labour were available to help increase output within manufacturing, above and beyond what could be gained on the labour input side from patriotic appeals and encouragements to women, teenagers, and older individuals to enter or reenter the labour force.

These preconditions meant that the sector could absorb a variety of adverse supply shocks and still, in the context of increases in labour and capital input and restrictions on production of metal-using consumer durables, achieve large increases in the output of goods destined for the military and US allies. That achievement does not require or imply increases in sectoral productivity, or that advances in producing specific military capital goods benefitted aggregate supply in the post-war period. Increases in output were achieved in spite of, rather than because of, overall movements in sectoral productivity. Localized learning by doing was insufficient to offset forces depressing productivity, and did not by and large persist when the economy stopped making the goods whose cumulative production experience had given rise to them. The bulk of the gains from learning in making aircraft, ships, tanks, and guns was experienced in 1943. The gains were already dissipating in 1944 as military production shifted towards heavier, more advanced, and more complex capital goods, as new goods such as the B-29 and the Pershing tank replaced B-24s and Shermans. Once again, factories retooled, suffering through agonizing production setbacks and initial low productivity levels.

This analysis builds on an earlier paper by Field that explores the contrast between aggregate (private nonfarm) TFP growth during the periods 1929–41 and 1941–8, and provides a detailed

[12] This reached 32% in 1943 (an all-time high); the share of national income originating in the sector that year was 34% (US Department of Commerce, *National Income and Product, 1929–65,* tables 1.12 and 6.4).

[13] Nelson, *Arsenal of democracy*; Walton, *Miracle of World War II*; Arrow, 'Economic implications'; Alchian, 'Reliability'; Gemery and Hogendorn, 'Microeconomic bases'; Thornton and Thompson, 'Learning from experience'. Thompson, 'How much did the Liberty shipbuilders learn', argues that some of the improvement in labour productivity over time was due to capital deepening rather than more generalized learning. To be clear, the intent in this paper is not to dismiss evidence of learning, but rather to place it in a broader interpretive framework that diminishes its import over the longer term.

[14] Economy-wide labour shortage did not emerge in the United States until sometime in the second half of 1943 (Field, *Economic consequence*s, ch. 5). Lebergott unemployment was 9.9% in 1941. The Darby rate was 6% (Lebergott, *Manpower*; Darby, 'Three-and-a half million').

TABLE 1 Total factor productivity growth in US manufacturing, 1899–2019 (per cent per year)

1899–1909	0.72
1909–19	0.29
1919–29	5.12
1929–41	3.06
1941–8	−1.40
1949–73	1.49
1973–89	0.57
1989–2008	1.39
2008–2019	−0.20

Sources: 1899–1929: Kendrick, *Productivity trends*, table D-1, p. 464. 1929–48: See table 2; text. 1949–89: US Bureau of Labor Statistics, 'Multifactor productivity', table 2. 1989–2019: https://www.bls.gov/data/#productivity (accessed on 5 January 2023).

analysis of the wrenching changes associated with industrial mobilization for war (1941–3) and demobilization (1943–8) by identifying sectors acquiring and releasing full-time equivalent workers (FTEs) during these two periods, and the magnitudes of the manpower flows involved.[15] This current article focuses not only on the evidence that the contribution of the mobilization of the US manufacturing sector to the growth of TFP and potential output was negative, but also more extensively on why.[16]

To understand the production achievement that allowed the United States and its allies to defeat their adversaries and the development of the capabilities that permitted the country to dominate the world economy in the post-war period, appreciation of the advance of productivity prior to the war is essential. Table 1 reports growth rates of TFP within manufacturing for intervals between 1899 and 2019. These data show that the years of mobilization were preceded by more than two decades of very rapid advance followed by rates of post-war productivity growth considerably lower than had been realized in the 22 years before Pearl Harbor. TFP in the sector was 88 log percentage points higher in 1941 than it had been in 1919 – a continuously compounded growth rate of 4 per cent a year over the period. There is nothing comparable in US economic history at any other time. This rate of advance compares with 1.49 per cent a year between 1949 and 1973.

Discussion of the intervals bracketing 1941–8 places the years of war mobilization and demobilization in perspective. The very high rates of advance during the 1920s (1919–29) reflect the transformation of the internal distribution of power within factories away from the metal shafts and leather belts that were the signature of the nineteenth-century power-driven factory towards electric wiring and a multiplicity of small, fractional horsepower electric motors. This was roughly two-thirds complete by 1929. The 1930s performance was world class by any standard of comparison other than the 1920s. It reflected the remainder of the transition to electrified power distribution within the factory, along with a remarkable expansion of research and development employment and expenditure in a variety of fertile areas, including chemicals, electronics,

[15] Field, 'Impact of the Second World War'.

[16] For a sectoral decomposition of the sources of total economy TFP growth over this interval, see Field, *Economic consequences,* ch. 8.

and aeronautics, all boosted by spillovers from the government build-out of the surface road infrastructure and investments in hydropower.[17] Increase across the golden age (1948–73; the Bureau of Labor Statistics (BLS) productivity data do not begin until 1949) was respectable, but slower than during the inter-war period, and slower than in other sectors of the post-war economy. The data for 1973–89 illuminate the dark ages of twentieth-century productivity advance in manufacturing, beginning with the first OPEC oil shock and continuing through the Carter and Reagan administrations. After a temporary boost due to information technology, the growth rate moved into negative territory following the financial crisis. From a long-run perspective, the war can be seen, ironically, as the beginning of the end of US world economic dominance in manufacturing.

III | CALCULATING TFP GROWTH WITHIN MANUFACTURING BETWEEN 1941 AND 1948

Y = real output (value added)
N = labour hours
K = capital service flow
Y/N = labour productivity
$y–n$ = labour productivity growth
$Y = A\,K^{\beta}\,N^{1-\beta}$ = production function (Cobb–Douglas, constant returns to scale)
$A = Y/(K^{\beta}\,N^{1-\beta})$ = TFP
$a = y - \beta k - (1–\beta)n$ = growth rate of TFP
$y = a + \beta k + (1–\beta)n$ = growth rate of output and its decomposition
$y–n = a + \beta(k–n)$ = growth rate of labour productivity and its decomposition

The above equations reflect the canonical approach to growth accounting, with upper case letters referring to levels and lower case to continuously compounded growth rates. To estimate TFP growth (a), we require series on the growth rate of output (y), labour hours (n), and capital services (k), as well as an estimate of the share of capital in national income (β). Following Gordon, the assumed share is 0.3.[18]

For the 1941–8 calculation, manufacturing output is based on income and product originating in the manufacturing sector, calculated separately for durables and nondurables, deflated by the respective price indexes from the same source, and then summed.[19] This yields a continuously compounded growth rate of real sectoral output of 1.98 per cent across the 7-year period. The

[17] Devine, 'From shafts to wires'; Field, 'Most technologically progressive'; idem, *A great leap forward*.

[18] Gordon, *Rise and fall*, ch. 16. Substituting a capital share of 0.25 (Kendrick, *Productivity trends*) would change the calculated 1941–8 manufacturing TFP growth rate from −1.40% to −1.33% per year.

[19] US Department of Commerce, *National income and product*, *1929–65*, tables 1.12, lines 13 and 24; table 8.6, lines 2 and 14. During the war the military calculated time series on war production in Standard Munitions Dollars on the basis of August 1943 unit costs (US Office of War Mobilization and Reconstruction, *First report,* p. 1). A post-war publication used August 1945 costs (Crawford and Cook, *United States army*, p. 20). The Department of Commerce's 1951 edition of *National income, 1951*, the first to provide series for real as well as nominal output, referenced reliance for war production on 'series compiled by the War and Navy Departments', and used price weights from 1944. The treatment of the real value of munitions output during the war presents in exaggerated form some of the same problems as does the introduction of new goods in peacetime, and the Commerce statisticians rejected using 1939 prices for war goods because munitions production was then still 'small scale and experimental' (US Department of Commerce, *National income*, *1951,* p. 145).

growth of labour hours (n) is the sum of the growth of manufacturing FTEs and the growth of average weekly hours.[20] This yields n of 1.94 per cent per year across the same interval. The estimates of capital input begin with chain type quantity indexes for the net stock of private fixed assets in manufacturing.[21] This shows a growth rate of the real privately owned capital stock of 3.90 per cent per year between 1941 and 1948. These data do not reflect the important contribution of government-owned manufacturing capital. To adjust private sector capital upwards, government expenditures on manufacturing plant and equipment are cumulated, and retirements subtracted.[22]

Gordon's government capital numbers are in 1958 US dollars, and the intent is to use them to augment US Bureau of Economic Analysis (BEA) estimates of private manufacturing capital. To enable this, the current cost net stock of private manufacturing capital for 1941–8 is converted into 1958 values using the implicit GDP deflator for nonresidential fixed investment.[23] That done, one can then calculate a ratio of government owned to total capital in manufacturing which is used to augment the BEA chained index series for fixed capital in manufacturing. This increases manufacturing capital by about 8 per cent in 1941, 27 per cent in 1942, 41 per cent in 1943, 50 per cent in 1944, and 32 per cent in 1948. These adjustments increase the 1941–8 growth rate of manufacturing capital to 6.75 per cent per year. On the basis of these data, TFP declined at −1.40 per cent per year between these two benchmarks. The arithmetic is straightforward: combined inputs grew faster than real output.[24] Labour productivity in US manufacturing was barely higher in 1948 than it had been in 1941.

Table 2 provides the basic data displayed as index numbers for the years 1929 through 1948, and table 3 presents continuously compounded year-over-year growth rates of manufacturing TFP and labour productivity between 1940 and 1945. These show that TFP in US manufacturing declined at 3.7 per cent per year between 1941 and 1944 and 5.1 per cent a year between 1941 and 1945. Sectoral TFP grew rapidly between 1939 and 1941, reflecting the predictable effects on productivity of recovery as the output gap closed, overlaid on a strong Depression era trend growth rate of advance. The decline between 1941 and 1945 wiped out improvement between 1939 and 1941, and levels in 1948 were still substantially below where they were in 1941, despite recovery after demobilization.

Between 1941 and 1943, labour productivity growth was worse (more negative) than TFP decline because of capital shallowing: hours grew faster than capital input. Between 1943 and 1945, the reverse was true, reflecting the arrival of nationwide labour shortage.

The declines in 1942 reflect, above all else, the chaotic conditions associated with the changes in the product mix. Productivity took a huge hit as machinery to produce peacetime products made way for newly designed machine tools, and labour and management struggled to become proficient as they moved from making goods in which they had a great deal of experience to those in which they had little. Shortages, hoarding of inputs, and production intermittency plagued

The index number issues associated with the choice of wartime munitions deflators are of somewhat less concern for the 1941–8 calculation, since the manufacture of most of the new goods had, by 1948, ceased.

[20] US Department of Commerce, *National income and product, 1929–65*, tab. 6.4; Carter et al., *Historical statistics*, Series Ba4580.

[21] US Department of Commerce, Fixed Asset tabs. 4.2, line 9, https://apps.bea.gov (accessed 9 November 2022).

[22] Gordon, '$45 billion', tab. 4.

[23] US Department of Commerce, Fixed Asset tab. 6.1, line 12; National Income and Product table 1.1.9, line 9, https://www.bea.gov (accessed 9 November 2022).

[24] Even without the adjustment for government-owned contractor operated capital, manufacturing TFP would have declined at −0.55% per year between 1941 and 1948.

TABLE 2 Indexes: US manufacturing, 1929–48, 1929 = 100.0

	LP	TFP	Output	Hours	Capital
1929	100.0	100.0	100.0	100.0	100.0
1930	102.1	96.6	86.8	85.0	102.1
1931	98.9	88.3	68.6	69.4	101.4
1932	85.4	71.9	47.4	55.5	98.6
1933	83.2	71.8	49.5	59.5	97.3
1934	102.7	90.2	64.5	62.8	96.9
1935	108.5	98.6	76.7	70.7	97.1
1936	113.6	107.3	93.2	82.0	99.1
1937	120.2	115.0	106.6	88.7	102.8
1938	120.2	107.3	84.8	70.5	103.1
1939	125.9	116.9	102.7	81.5	104.4
1940	139.7	131.9	125.6	90.0	108.9
1941	147.1	144.3	170.2	115.7	123.4
1942	138.8	137.5	198.4	142.9	147.6
1943	136.2	138.1	231.4	169.9	162.3
1944	131.1	129.3	219.2	167.2	175.3
1945	126.4	119.2	181.2	143.3	181.0
1946	129.8	117.5	164.4	126.7	176.5
1947	135.7	122.3	180.9	133.3	188.6
1948	147.5	130.8	195.5	132.6	198.0

Source: See text.

TABLE 3 Year-over-year percentage change in labour productivity (LP) and TFP in US manufacturing, 1940–5

Year	LP	TFP
1940	10.4	12.1
1941	5.2	8.9
1942	−5.8	−4.8
1943	−1.9	0.5
1944	−3.8	−6.6
1945	−3.6	−9.2

Sources: See table 2, text.

the war effort. The positive effects of learning by doing are evident in the change in both labour productivity and TFP growth between 1942 and 1943. They were nevertheless insufficient to compensate for the sharp drop during the previous year. Productivity resumed an accelerated decline in 1944, as a secondary round of major product changes kicked in, and was even more negative in 1945, due in part to the disruptions associated with demobilization. Partial recovery between

1945 and 1948 still left the TFP level in US manufacturing substantially below where it had been in 1941.[25]

IV | SENSITIVITY ANALYSIS

If output growth (y) has been understated, TFP growth will be as well, and by the same amount, but if either of the input growth measures (k or n) has been understated, TFP growth will be overstated, and should have been even more negative. The output measure is fixed weight, using 1958 prices. Compared with series constructed using chained index methods, fixed weight measures usually understate growth before the base year. The reason is substitution bias. Those items that have experienced declines in their relative prices will likely have witnessed the largest quantity increases. Understating growth before a base year is not, however, inevitable. The wrenching changes in output within manufacturing over the years 1941–8 reflected the imperatives of war and then demobilization in the context of an administered economy, not the evolution of income-weighted consumer preferences communicated through the price mechanism.

Landefeld and Parker studied productivity advance across the entire economy between 1929 and 1987 and found that the use of fixed 1987 price weights as compared with chained index measures understated real growth by an average of 0.4 percentage points per year. They also examined advance over seven post-war expansions occurring within the 1949–87 period, comparing real output increase using 1987 prices and growth calculated using chained index methods. In six of the seven expansions, the estimated growth using fixed weight is lower than with chained index, as expected. The one exception is the 1949Q4–1953Q2 expansion, which included the ramp-up of military production for the Korean War. Their finding suggests that what is generally true during peacetime may not be true during war, when the increased production of military goods is driven by imperatives other than consumer response to prior declining prices.[26]

If the growth of either labour or capital inputs has been overstated or understated, the estimated TFP growth grate will be affected in the opposite direction. The workforce did become temporarily more feminized during the war, but employers frequently praised women's dexterity in manual operations. In aircraft assembly, which became the country's largest industry during the war, and accounted for a quarter of all military spending, women were valued because of their ability to crawl through small openings (dwarfs were employed for similar reasons). More generally, because the durables produced were mostly new, the role of prior experience in manufacturing, where women, on average, would have been disadvantaged, was less relevant than it might otherwise have been. Management claims that production difficulties and high absenteeism could be blamed on deteriorating labour quality are questionable.[27] One would need, in any event, to posit a very large decrease in labour quality to reverse the decline of wartime manufacturing productivity reflected in these calculations.

[25] Bakker et al., 'Sources of growth', are of little help in exploring productivity advance during and immediately after the war, because they completely exclude discussion of the 1941–8 period. Nor is recent work on fiscal multipliers (Fishback and Cullen, 'Second World War spending'; Brunet, 'Understanding the effects') directly relevant, because the principal concern here is aggregate supply. Once the economy approached full mobilization, one would not expect to see positive real multiplier effects of military spending at the macrolevel. See also Higgs, 'Wartime socialization'.

[26] Landefeld and Parker, 'BEA's chain indexes'.

[27] Tansey and Hyman, 'Public relations'.

Hicks described the measurement of capital input 'as one of the nastiest jobs that economists set to statisticians'.[28] It is widely agreed that we would like to measure service flows, not capital stocks.[29] In reasoning from stock data, what we aspire to are what the BLS calls productive stocks, not wealth stocks. In acknowledging the difference, we acknowledge the distinction between the deterioration of an asset's service flow over time, reflected in its age-efficiency profile, and the depreciation of asset value over time reflected in its age-price profile. Productive stocks are constructed so that they increase or decrease over time at the same rate as the service flows they yield.

The necessary use of wealth stocks as a proxy for productive stocks probably understates the growth of capital service input over this interval. Except under what the BLS views as the unrealistic assumption that depreciation and deterioration both decrease geometrically at the same rate,[30] age-efficiency profiles will differ from age-wealth profiles, and wealth stocks will grow at different rates than productive stocks. Wealth stocks are imperfect proxies for productive stocks because service flows do not generally deteriorate at the same rate as asset values. The extreme case for deterioration is one-hoss shay, but experience with consumer durables and observations of rental markets for cars and ski equipment suggests that most age-efficiency profiles are hyperbolic, with little service flow drop off in initial years. This generalization relies on impressionistic evidence but then, so too does the BLS.[31] Market validated data on the value of service flows are scarce. The rental markets for capital service flows are few, limited to some types of transportation or construction equipment. Much physical capital is special purpose, which militates against an active and thick rental market. In its work on the national income and product accounts, the BEA constructs net wealth stocks, whereas the BLS in its productivity program builds productive stocks.

The construction of productive stocks is not a simple matter. It requires the classification of heterogeneous capital goods into a finite number of asset types – and two aggregations. The first is among vintages of a given asset type, using weights for the older vintages derived from the asset type's posited age-efficiency profiles. This generates a productive stock for each asset type. The growth in a type's productive stock can be thought of as the growth of the type in standard efficiency units or new unit equivalents, and the growth of the stock will occur at the same rate as the growth of the service flows from it. The second aggregation is among productive stocks of different asset types, whose growth rates must be weighted by the asset types' respective shares in capital compensation.

There are three reasons why the necessary use of wealth stocks as proxies for productive stocks probably understates the growth of capital service flows during the war. These considerations collectively suggest that the negative TFP growth rates reported in tables 1 and 3 should be considered an upper bound on manufacturing productivity performance during the war years.

First, the share of shorter-lived assets – particularly equipment – in the overall manufacturing capital stock was growing. The growth rates of shorter-lived types receive higher weight in the second aggregation than would be true in a wealth stock calculation, because, per dollar of value, they receive a higher share of gross capital compensation due to the larger role of depreciation in their annual user cost.

[28] Hicks, *Capital and growth*, p. 204, quoted in Hulten, 'Measurement of capital', p. 119.

[29] Organization for Economic Cooperation and Development, *Measuring capital*; idem, *Measuring productivity*; idem, *Measuring capital*, 2nd edition; US Bureau of Labor Statistics, *Handbook of methods.*

[30] Jorgenson and Griliches, 'Explanation'.

[31] Harper, 'Estimating capital inputs', p. 332.

Second, the overall manufacturing capital stock (setting aside how its distribution among asset types might be changing) was growing and was therefore getting younger: newer vintages were increasingly dominant. If we assume that service flow drops off less rapidly than asset value, a properly constructed productive stock will grow more rapidly under these circumstances than a wealth stock.[32] Finally, asset lives, particularly of equipment, were even shorter than would have been the case under peacetime conditions, because as was anticipated, the production of many of the military goods terminated at the end of the war or shortly thereafter. Prematurely obsolete due to the rapid reversal of the product mix after V-E and then V-J day, many assets, particularly machine tools, were scrapped.

V | WHY THE WARTIME DECLINES IN PRODUCTIVITY?

How do we reconcile the data in table 1 – and the even sharper drops during the war years reflected in tables 2 and 3 – with the widely recounted learning-by-doing narratives – the cost reductions as output of Liberty ships, C-47s, B-24s, and other durables increased? One solution, of course, is simply to say that the sectoral productivity numbers are wrong in their underlying data or in their construction. My intent is to persuade that the story told by the numbers is basically correct, and to explain why the fascination with and continued repetition of the learning stories have misled. One argument is simple. If a firm switches temporarily from making goods in which it is experienced to those in which it is not, and its productivity declines, a high subsequent growth rate will not necessarily return it to where it started. In *National product in wartime*, Kuznets made it clear that there was no contradiction between allowing for a rapid growth in efficiency following its initial sharp depression and a conclusion that the 1943 level of productivity was below levels in 1941.[33]

Between 1942 and 1945, the United States mobilized economically the way it would wage war on the battlefield: by directing a firehose of men and women and material at the targets. Efficiency improvements in the production of a radically changed output mix were low on the country's list of priorities, the quantity of output and the speed with which it could be produced far outranking them. With learning and experience, productivity in the manufacture of well-known military capital goods eventually improved. However, this only partially counterbalanced the negative influences of disruptions in resource supply inflicted by the Japanese and Germans and the initial sudden, forced, and radical change in the output mix, an echo of which was experienced in 1944 as the war (for the United States) entered its bloodiest and most brutal phase. Throughout the war, these effects were reflected in and augmented by shortages of materials, machine tools, subassemblies, and ultimately manpower that were persisting features of the wartime industrial economy.

The principal argument can be stated succinctly: TFP in manufacturing fell during the war because the conflict forced a wrenching shift away from products and processes in which manufacturers had a great deal of experience towards those in which they had little. Enormous quantities of new physical capital – both buildings and machinery – were constructed and deployed in this effort, and the portion of the manufacturing and total labour force working on

[32] Arnaud et al. 'Measuring multifactor productivity', p. 5; Oliner and Sichel, 'Resurgence of growth', p. 6.

[33] Kuznets, *National product in wartime,* pp. 49, 51. See also Fabricant, 'Armament production', pp. 30–1; Backman and Gainsbugh, 'Productivity and living standards', and, for disagreements on this question during and immediately after the war, Hagen and Fitzpatrick, 'National output', p. 488; Hirsch, 'Productivity', p. 401.

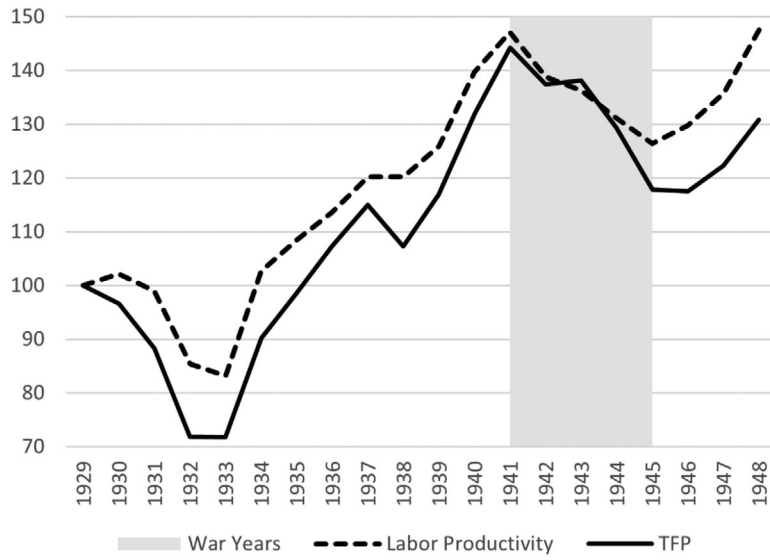

FIGURE 1 Indexes of labour and total factor productivity, US manufacturing, 1929–48, 1929 = 100.0.
Sources: See table 2; text.

war production grew considerably. The exigencies of war demanded that this be done quickly and it was. Raw material shocks, shortages of machine tools, components, and subassemblies, and ultimately a severe scarcity of manpower, created additional and continuing disruptions, all aggravated by producer hoarding. This concatenation of negative influences retarded productivity advance in manufacturing. These disorders were worsened by the behavioural pathologies and compliance burdens that accompanied the systems of non-price rationing of producer and consumer goods to which these shortages gave rise.

Figure 1 shows that between 1929 and 1948 there were two 4-year periods in which manufacturing productivity plummeted: 1929–33 and 1941–5. In both cases, idle resources were implicated, but the causes of the idleness were different. Between 1929 and 1933, this was principally the consequence of a deficiency of aggregate demand, and the productivity decline reflects a predictable, though very large, cyclical effect. Between 1941 and 1945, the inability within a shortage economy to obtain complementary inputs contributed to production intermittency, one of several factors dragging down measures of productivity.

In 1941, the US material supply chain was optimized for the pre-war output mix, and the radical changes in the output mix during the war operated to depress potential. The change in the final output vector meant arrival at shortages and inflationary waypoints at lower aggregate output levels than would have been the case had the closing of the output gap proceeded along more normal peacetime lines. In particular, the production of metals-intensive durables soared, leading to immediate shortages in steel, copper, aluminium, magnesium, and several of the ferroalloys, as well as a severe shortage of machine tools, which were rationed beginning in December 1940.[34]

The output mix was greatly, and ultimately temporarily, distorted. The share of other transportation equipment in manufacturing grew from 2.2 per cent in 1941 to 20.2 per cent of a

[34] Ramey and Shapiro, 'Costly capital reallocation', detail and explain similar interactions in postwar US military buildups.

much-expanded manufacturing sector in 1944, and then fell back to 2.7 per cent in 1948.[35] Among manufacturing industries, aircraft production grew in rank from 44 to 1, with employment increasing from roughly 50 000 to over 2 million. Machine tool production went from an average of about 7000 units a year in the 1930s to a peak annual production rate of 365 000 in August 1942, before declining to half that rate in 1944. Installed units (stocks, rather than flows) went from 934 000 in 1939 to 1.4 million in 1943 to 1.9 million in 1945.[36]

To counteract priorities unemployment, firms hoarded inventories, which made the shortages worse. Some plants ran double or triple shifts, but their incidence was much less common than popular histories of the war suggest.[37] Average paid weekly hours in the sector did increase during the war by about eight. However, shortages and intermittent idleness of productive resources were endemic during the war, a chronic inflammation whose loci might change but which never went away. A total of 8 per cent of pre-war manufacturing capacity shut down due to limitation orders but could not be converted to wartime production.[38] All too often, the mantra in Second World War production, as in the armed forces, was 'hurry up and wait'.

In the early years of US participation in the war, a massive construction program collided with huge increases in orders for military ordnance, all in the absence of an agreed upon Allied military strategy. The consequence was chaotic scheduling and sequencing of production. The economy was subject to government controls, but to describe it as 'planned' is unfair to the conventional meaning of the word.[39]

Consumer durable firms, particularly those using metals, were forced to shut down by limitation orders, but even if they had orders for war goods, they often could not get the machine tools, raw materials, and subassemblies needed to start making the new goods. They needed priority ratings as well as cash, and often even this was not enough because of the inflation of the former. As a result, labour and capital stood idle. Materials shortages were especially severe during 1942, when the demand to immediately expand military goods production to meet Roosevelt's 'must have' objectives competed with the effort to build industrial facilities necessary for the war effort, and an even larger military construction program, including airfields, training camps, cantonments, and the Pentagon. Citing again the Bureau of the Budget history: 'We built many new 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 could 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 materials that might have gone into something else'.[40] Unnecessary construction in any sector – a severe problem in the first two years of the war – worsened priorities unemployment and any such idleness depressed productivity in manufacturing.

The wartime military and industrial construction programs were mostly complete by the end of 1943, and employment in the sector dropped dramatically for the remainder of the war. But the

[35] US Department of Commerce, *National income and product, 1929–65*, tab. 1.12.

[36] Walton, *Miracle of World War II*, p. 229; Ristuccia and Tooze, 'Machine tools', table 1; U.S. War Production Board, *American economy in war*, p. 5; Milward, *War, economy, and society,* p. 334.

[37] US Civilian Production Administration, *Minutes of the War Production Board*, p. 85. See also Milward's observation that in the United States, 'the use of shift working, which might have brought an increase of capital, was much less developed'. (*War, economy, and society*, p. 229.)

[38] US Civilian Production Administration, *Minutes of the War Production Board*, p. 66.

[39] US Bureau of the Budget, *United States at war*, p. 113.

[40] US Bureau of the Budget, *United States at war*, pp. 113–4.

conflicts to which the building programs gave rise were only one of a number of dynamics dragging down manufacturing productivity. A reading of the minutes of the War Production Board and its Planning Committee repeatedly calls attention to a range of pathologies afflicting the military production program.

At the 18 August 1942 meeting of the board, Stacy May, Director of Planning and Statistics, described the lack of balance in the production and use of machine tools, as well as the coordination of floor space with scheduled production:

> Only about two-thirds of the machine tool requirements for the new airplane projects will be provided on time. A number of these projects plan for a capacity far in excess of their production schedules, while others will have inadequate facilities under current plans. . . . 43 airplane plants will have nearly 13 million square feet of productive floor space in excess of estimated requirements at the peak of scheduled airplane output in June 1944, while the area of 16 other plants will be about 10 million square feet below estimated requirements.[41]

At the 24 November 1942 meeting, May reported that October production was 'disappointing in almost every category', suggesting that the failure to meet scheduled production was attributable to materials hoarding and not just to shortages per se. As evidence of the former, he compared increases in input deliveries during 1942Q1 with the considerably lower increases in final output production from 1942Q2 to Q3.[42]

Undersecretary of War Robert Patterson and former head of the Office of Production Management William Knudsen countered by blaming materials shortages alone for production shortfalls. Knudsen asked the foolish question, 'What could have become of the available materials if they have not gone into production of finished items?' Chair of the Board Donald Nelson provided the obvious answer: 'a substantial quantity of materials has gone into badly distributed stocks of raw materials and into inventories of finished and semi-finished components which have been immobilized because of the lack of balance in output'.[43]

The 27 April 1943 meeting reported that many manufacturing plants were not using their facilities to the maximum: curtailed second shifts and the absence of a third shift were common. Favoured plants (the large established companies that procurement officers preferred to deal with) that could do the most difficult work had grabbed low hanging fruit: they were tied up manufacturing more easily produced goods, while others that could make only the more easily produced items could not get enough orders to schedule efficient runs.[44]

In his memoir, Nelson casually commented that 'a number of destroyer escorts [were] tied up for six months after launching because needed components had not been delivered' and 'There were times in 1942 when production in munitions plants was delayed a few months because copper was not available'.[45]

Government-mandated business-to-business rationing tried to ameliorate the negative effects on production and productivity, initially by awarding priority ratings for delivery, and ultimately

[41] US Civilian Production Administration, *Minutes of the War Production Board*, pp. 118–9.

[42] Ibid., p. 158.

[43] Ibid., p. 159.

[44] Ibid., p. 216.

[45] Nelson, *Arsenal of democracy*, p. 255.

by directly allocating key industrial materials among various claimants via the Controlled Materials Plan. Competitive expediting: the scramble to obtain needed inputs, ultimately a zero-sum enterprise, was a persisting drain on managerial attention.

VI | NATIONWIDE LABOUR SHORTAGE

Despite periodic complaints during the defence period and in 1942 about shortages (typically of specific categories of skilled workers), the United States did not suffer from system-wide labour shortage until 1943Q3. The pool of unemployed workers remaining in 1941, and the ability to draw into the labour force women, teenagers, older workers, and marginally attached agricultural workers (both Black and white), particularly from the South, prevented this. Military production peaked in 1943Q4 and plateaued at a slightly lower level for the remainder of the war. Why then was labour shortage acute only in the last two years of the war?

By late 1943, the continuing (although no longer increasing) demands of war production collided with the voracious appetite of the Selective Service System for manpower. During 1942 the armed forces, including the marine corps and coast guard, grew from 2.2 to 7 million. Between January 1943 and July 1944, the military withdrew an additional 4.6 million people from availability for work in the civilian labour force.[46] This squeezed most of the remaining juice out of US labour reserves. The civilian unemployment rate fell from 4.7 per cent in 1942 to 1.9 per cent in 1943 and 1.2 per cent in 1944.

VII | NEGATIVE SUPPLY SHOCKS RESULTING FROM ENEMY ACTION

The dynamics and pressures just described are sufficient to make plausible the negative wartime TFP growth rates reflected in tables 1–3. But adversaries inflicted additional negative supply shocks. Milward claims that there was never 'any active interference by the Axis powers on the workings of the United States economy, apart from sinking its ships or killing its citizens, whereas a considerable amount of industrial plant in the Soviet Union and the United Kingdom was reduced to rubble by the German armed forces'.[47] Japan and Germany did, however, actively interfere in the workings of the US economy even if this did not, for the most part, involve dropping explosive or incendiary devices on US territory.[48] Their actions, whose nature and consequence have largely faded from historical memory, added to the powerful internal forces depressing productivity, including radical changes in the product mix, eventual severe labour shortage, inadequate and congested housing in centres of war production, work stoppages, wildcat strikes, and government plant seizures due to labour–management conflict.

[46] US Selective Service System, *Selective Service and victory*, p. 154.

[47] Milward, *War, economy and society*, p. 73.

[48] One could argue that the very act of waging war on the country, which compelled its military and economic mobilization, disrupted the workings of the US economy. But cutting off access to natural rubber and disrupting the interregional distribution of petroleum and petroleum products represented interference of a qualitatively different nature.

VIII | RUBBER

The fall of Singapore to the Japanese on 15 February 1942 presaged the loss for the United States of 95 per cent of its natural rubber supply. As Milward observed, rubber was the one strategic material in which the United States was effectively devoid of domestic supply.[49] In three months of conflict following Pearl Harbour, the Japanese reversed the relative abilities of the two combatants to wage economic war on the other. Prior to Pearl Harbour, Japan depended on the United States for 80 per cent of its oil. With the rapid expansion of the Greater East Asian Co-Prosperity Sphere came control of the Dutch East Indies, eliminating much of that dependency (imports to Japan could still be harassed by US submarines, and increasingly were as the war progressed). Since Japan then also controlled the sea lanes to and from all sources of Southeast Asian rubber, the country had the ability and will to cut off almost all of the US natural rubber supply. The prospect, and then actuality, of this threat was well understood prior to and during the war.

In certain critical uses, rubber may be the exception to the rule, beloved of economists and endorsed by Milward, that at the right price there are always possibilities for substitution.[50] There was effectively no satisfactory substitute for the use of rubber in tire treads and carcasses and a variety of other uses critical to the civilian and military economies, and there were, effectively, no domestic sources of supply. Consumer demand could be repressed, up to a point. But absent supply enhancement, this would ultimately be to no avail. It was understood before the war that there were three ways in which the country's vulnerability could be addressed on the supply side: (1) stockpile a large reserve of natural rubber, (2) plant acreage in the United States in crops that could also produce latex, and (3) build a synthetic rubber capability. All three approaches would be expensive and appear after the fact to have been wasteful if rubber supply was not disrupted. At the time of Pearl Harbour, each of these risk mitigation strategies had been pursued either in a very limited fashion or not at all.

The country began the war with 27 million passenger vehicles and 5 million trucks on the road. On 11 December 1941, four days after Pearl Harbour, the OPA moved to halt all tire sales, while setting up 5600 local ration boards. On 5 January 1942, each board received an allocation based on local vehicle registrations. The need to conserve rubber was brutally underlined in a 1942 report of the Petroleum Industry War Council: 'without reductions in average speed and mileage, and in the absence of more rubber, 18 million passenger vehicles would be off the road by the end of 1943, 26 million [in other words, almost all of them] by the end of 1944'.[51] A joint committee of automotive engineers and tire specialists concluded in 1943 that 'an automobile simply could not be kept on the road and in useful service by any known device save the rubber tire'.[52] The result was near panic in 1942, and the threat of an exhaustion of rubber supplies hung over the economy and military effort throughout the duration of the war.

To produce a synthetic rubber that could be used for tire treads and carcasses, butadiene had to be copolymerized with styrene to make GR-S (the US nomenclature for what the Germans called Buna-S). In the midst of an explosive political battle over which feedstock would be used to make the butadiene (petroleum or ethanol), Roosevelt appointed a Rubber Survey Committee chaired

[49] Ibid., p. 48.

[50] Ibid., p. 32.

[51] US Bureau of the Budget, *United States at war*, p. 167.

[52] Howard, *Buna Rubber*, p. 207.

by Bernard Baruch, and including James Conant, president of Harvard, and Karl Compton, head of MIT, as well. Their September 1942 report acknowledged the dire situation in which the United States then found itself:

> We find the existing situation to be so dangerous that unless corrective actions are taken immediately this country will face both a military and civilian collapse…of all critical and strategic materials, rubber is the one which presents the greatest threat to the safety of the Nation and the success of the Allied cause…if we fail to secure quickly a large new rubber supply, our war effort and our domestic economy will collapse.[53]

Other knowledgeable war planners expressed a similar urgency. In a letter to Baruch in May 1942, Ferdinand Eberstadt wrote that 'unless synthetic rubber is available in quantity by the time the crude stockpile is exhausted, around July 1 [1943], we would appear to have no alternative but to call the whole thing [the US military effort in World War II] off'.[54]

Following the recommendations of the Baruch Committee, Roosevelt issued executive orders mandating speed and distance limitations in domestic transportation. This included a 35 mph nationwide speed limit and nationwide gas rationing in a country that, in the aggregate, was awash in gasoline. This meant increased difficulties getting to and from work (gasoline rationing driven by the need to conserve rubber should be distinguished from the special problems on the Eastern seaboard, discussed below, which reflected a severe distribution problem created by the Germans).

The synthetic rubber program started late, was plagued by delays, and was initially designed exclusively around the use of petroleum rather than alcohol as a feedstock for the butadiene. The program as it was executed absorbed construction materials and components such as valves and heat exchangers desperately needed elsewhere, contributing to output intermittency. In addition, synthetic rubber required up to a third more labour time, as well as mixing with natural rubber, in final fabrication of rubber products.[55] Since it lacked the plasticity and tack of natural rubber, GR-S was an imperfect substitute, particularly in airplane tires. As Julius Krug wrote in the final report of the (WPB):

> This residual technological dependence on natural rubber meant that our precarious supply outlook for that raw material persisted to the very end of the Japanese war. Forward demand estimates for 1945 and 1946 under the stepped-up military tire

[53] United States Special Committee to Study the Rubber Situation, *Report,* p. 23.

[54] Quoted in Tuttle, 'Synthetic rubber "mess"', p. 38.

[55] A rough estimate of the impact on labour productivity in rubber manufacturing can be obtained by dividing US total rubber consumption in long tons (synthetic and natural) by the number of FTEs in the subsector. This statistic moves from 4133.7 in 1941 to 2087.0 in 1942, 2180.9 in 1943, 2974.0 in 1944 and 3660.1 in 1945. US Department of Commerce, *National income and product, 1929–65*, tab. 6.4, line 22, p. 103; US War Production Board, *Wartime production achievements*, p. 95. Since the services of $700 million of new physical capital were also required, it is likely that TFP in the sector declined as well. The knock-on effects of nationwide gas rationing and 35 mph speed limit, as well as the component and raw material shortages imposed on other sectors by the design of the program, meant that the negative productivity impacts were not limited to the rubber subsector.

schedules for those years had indicated exhaustion of our reserve stocks during the first half of 1946.[56]

Aside from its effects on the economy, the rubber shortage had serious military implications, constraining options, including contributing to the delay of the cross-channel invasion by at least a year. Even then, as the 1945 *Annual Report* of the Army Service Forces (ASF) noted: 'It was necessary during the last 3 months of 1944 and first 2 months of 1945 to place in effect stringent restrictions on the use and issue of tires for military vehicles in zone of the interior [the 48 states] … only vehicles in special categories were allowed to be equipped with spares'. Tires were removed from all vehicles in storage and undergoing repair and shipped overseas. Finally, 'Vehicles were accepted from manufacturers without spares, and it was necessary to accept a considerable number of vehicles without any tires on them'.[57]

The United States consumed 775 000 long tons (LT) of rubber in 1941, 70 per cent of which went into tires. In that year the country imported 1 029 007 LT; and the end of year stock had increased from its 1939 level of 125 800 LT to 533 344 LT in 1941. The stockpile would reach its peak of 634 152 LT in April 1942 after ships on route prior to cut-off reached the United States.[58] Given the country's appetite for rubber, and even with successful repression of non-military demand, this stockpile was dangerously inadequate, unless either a domestic supply of latex, imports from other areas, or synthetic rubber production could be ramped up quickly. In 1939, Congress appropriated money to grow a strategic stockpile, and as noted, there had been some increase. However, Jesse Jones, head of the Reconstruction Finance Company, dragged his feet, waiting for prices to come down, not wanting to waste taxpayer money. Since the country had passed up opportunities to increase domestic supply, because imports from Latin America, Africa, and Ceylon were a trivial fraction of what Southeast Asia had previously supplied, and because synthetic rubber got off to a late and shaky start, these stocks were the only protection against real catastrophe until well into the second half of 1943.

If the United States wished to have a significant domestic supply of natural latex, its best option would have been guayule. At the turn of the twentieth century, wild guayule had a record of successful commercial exploitation by the Intercontinental Rubber Company (IRC), which numbered among its investors a pantheon of Wall Street notables, including, in addition to Baruch, Nelson Aldrich, John D. Rockefeller Jr., Jacob Schiff, and Daniel and Sol Guggenheim. The IRC operation in Mexico, through its subsidiary, the Continental Mexican Rubber Company, harvested the desert shrub, and then, using capital-intensive and patented processes, extracted rubber from the plants. Polished stones in rotating drums crushed the leaves and stalks. The output was placed in settling tanks, where the rubber floated to the top and was then dried in sheets.[59] In 1910 guayule provided almost a fifth (19 per cent) of US supplies of natural rubber. The IRC controlled over 3.8 million acres in Mexico, which gave it a practical monopoly of the shrub's natural habitat.

Beginning in 1910, Mexican revolutionaries repeatedly disrupted operations at the Torréon facility, and in 1916 the IRC took seeds to the United States with the intent of converting the wild plant into a cultivated crop, planting acreage near San Diego, California, and south of Tucson, Arizona, and in 1926, in Salinas, California. Over five months during the spring of 1930, an obscure US Army

[56] US War Production Board, *Wartime production achievements*, p. 94.

[57] US Army Service Forces, *Annual report*, p. 199.

[58] US War Production Board, *Wartime production achievements*, p. 45; Herbert and Bisio, *Synthetic rubber*.

[59] Van Harmelen, 'Scientists', p. 70.

major named Dwight D. Eisenhower toured IRC operations in California, Arizona, and Mexico as part of a two-man team. Eisenhower understood the vulnerability of the country to a cut-off of rubber supply and recommended that the government subsidize 400 000 acres of guayule cultivation in the United States, with a quarter replanted every year, to ensure a renewable supply of about 71 000 long tons per year; a fifth of annual consumption during the 1930s, and just under a tenth in 1941. This production flow would have exceeded the entirety of US rubber imports in 1943 and would have substantially relaxed wartime constraints.

Nothing came of the proposal, largely because Southeast Asian rubber at the time was so cheap. The United States ended up spending $45 million on guayule cultivation during the war, but it was a poor emergency rubber source since the plant took four years to reach maturity. Thomas Edison, who spent the last four years of his life researching alternate plant-based sources of rubber, was never a fan of guayule for this reason.[60]

The synthetic rubber program started late and proceeded initially along a route exclusively focused on petroleum as the feedstock for the butadiene. Butadiene could also be made from alcohol, where the capital requirements for the process were lower, there was an abundant supply of plant material that could be converted to ethanol, and the processes were well tested.[61] Far from a smooth and miraculous creation from scratch of an industry without which the war might have been lost, the economics and the politics of the country, and the imperfect navigation of the conflict between the commercial interests of private US corporations and the national interest in defeating adversaries, led to a development path that severely jeopardized military capabilities in 1943 and could arguably have led to the loss of the war.

The program failed to deliver in quantity until late in 1943, and then only because political pressure had succeeded in designating three of the twelve government-financed plants producing butadiene to do so along the alcohol pathway. Alcohol plants produced 82 per cent of butadiene from all sources in 1943 and 65 per cent in 1944. Without those plants, the war effort would have been even more severely jeopardized than it was. The country came close to running out of natural rubber in 1944, and almost certainly would have, had the war continued into 1946.

IX | PETROLEUM SUPPLY TO THE EASTERN SEABOARD

The second major enemy-inflicted supply shock for the US economy came courtesy of the Germans. Again, this is an effect that was well understood and appreciated in 1942 and 1943 but has faded from historical memory. In 1941, most US oil production came from California, Texas, Oklahoma, and Louisiana. Refinery capacity in the United States was concentrated in East Texas, Louisiana, and California, in Chicago and St. Louis, and, in part for historical reasons, in the New York–New Jersey–Philadelphia area, where it had developed to process the crude oil from the by then depleted eastern and mid-western fields.

In 1941 the 17 Eastern Seaboard states ran through 1.5 million barrels of petroleum a day; 40 per cent of national consumption. To satisfy this demand, a fleet of 260 tankers brought petroleum

[60] Wendt, 'Control of rubber'; Finlay, *Growing American rubber.*

[61] Solo, *Synthetic rubber*; Field, *Economic consequences*, ch. 3. Milward is simply off base when he claims that the pressure from agricultural interests to use alcohol 'retarded' the development of the synthetic rubber industry (*War, economy, and society*, p. 179). That the use of ethanol benefitted agriculture does not necessarily mean that in this case it was contrary to the US national interest, although that may be commonly presumed.

and petroleum products from East Texas and Louisiana: crude to feed the refineries in the New York/New Jersey/Philadelphia areas, and refined products to satisfy the demand that local refineries could not. The Eastern Seaboard was as dependent on imports of petroleum and petroleum product by tanker as was Great Britain. Tanker transport was cheap and (unlike pipelines) flexible with respect to pickup and delivery locations. Pre-war rates in mills per ton mile were 1.25 by tanker, 3.2 by pipeline, and 8.3 by railway tank car.[62]

Between January and June 1942, German U-boats sank almost 400 ships in waters protected by the US Navy, including 171 along the Atlantic Coast, 62 in the Gulf, and 141 in the Caribbean frontiers. In the summer of 1942, pumps went dry all along the Eastern Seaboard. Most filling stations closed. Automobiles would follow a gasoline tanker truck until it stopped for a delivery, trailed by a string of desperate drivers.[63] The disruptive effects rivalled, and in some cases exceeded, what Americans would experience in 1973–4.

Crisis conditions returned in October, November, and December 1942, when inventories fell and could not be distributed evenly to retail outlets according to planned allocations. At a 6 October 1942 meeting of the WPB, Paul McNutt, chairman of the War Manpower Commission, reported that 500 000 workers were idle in New York City, and at the same time that there were complaints of labour shortages in 35 other areas.[64] Critical war workers could not get to their jobs, and war production was disrupted.[65] Again, idle labour and capital had corrosive effects on productivity and production.

In April and May 1943, at the nadir of tanker deliveries resulting from the peak of the U-boat offensive in the Atlantic, many filling stations ran dry, which again disrupted transportation and war production. 'Famine' conditions returned in August.[66]

In addition to gasoline, the Seaboard also needed fuel oil, especially during the winter, and particularly in the Northeast. Serious deficiencies developed in the winters of 1942–3 and 1943–4, but the worst shortages hit the region in the winter of 1944–5. People shivered in their houses. Schools closed because they could not be heated. Businesses went on short weeks.[67] In January, James F. Byrnes, director of War Mobilization and 'Assistant President' for domestic affairs, imposed an electrical brownout on the country to save coal and fuel oil.[68]

By the fall of 1943 the Allies were beginning to prevail against the submarines, but the tanker pipeline remained effectively shut down for the duration of the conflict.[69] The German naval

[62] Maxwell and Balcom, 'Gasoline rationing I', p. 562.

[63] Lingeman, *Don't you know,* p. 243.

[64] US Civilian Production Administration, *Minutes of the War Production Board*, pp. 132, 141. New York City's 1942 population was about 7.5 million, so half a million idle workers represented a serious disruption for an economy aiming for full mobilization for war. Much of this reflected difficulties New York City manufacturers (unlike those in Detroit) faced in obtaining contracts enabling them to use their labour and capital for war production. But some was also due to fuel shortages, which had even worse effects in other East Coast locales, such as northern New Jersey war plants, where workers were more dependent on automobiles to get to and from work. See for example, *New York Times,* 20 July 1942, p. 12; 24 August, 1943, p. 1; 25 August 1943. p. 21. The Petroleum Administration for War repeatedly denied published reports that war production was adversely affected by gasoline shortages, presumably because it wanted to deprive Germany of any information on the effectiveness of its U-boat campaign.

[65] Maxwell and Balcom, 'Gasoline Rationing I'.

[66] *New York Times,* 22 April 1943, p. 15; idem, 27 April 1943, p. 25; idem, 21 August 1943, p. 1; idem, 22 August 1943, p. 30.

[67] Ibid., 12 January 1943, p. 1.

[68] Lingeman, *Don't you know,* p. 267.

[69] US Petroleum Administration for War, *History*, p. 93.

offensive forced the United States to switch from cheaper to much more expensive means of delivering petroleum and petroleum products to the Eastern seaboard (initially rail cars and barges, and ultimately the Big Inch and Little Big Inch pipelines). Disrupted supply contributed to intermittency in production in the industrial Northeast. Again, these developments contributed to the overall downward trend in wartime manufacturing productivity.

The historian Michael Gannon described the submarine campaign along the Atlantic Seaboard as 'one of the greatest maritime disasters in history and the American nation's worst-ever defeat at sea'. On 19 June 1942, Army Chief of Staff George C. Marshall wrote, 'The losses by submarines off our Atlantic Seaboard and in the Caribbean now threaten our entire war effort'. In *The Hinge of Fate*, Winston Churchill observed, 'For six or seven months, the U-boats ravaged American waters almost uncontrolled, and in fact almost brought us to the disaster of an indefinite prolongation of the war'.[70]

X | THE LEGACY OF THE WAR

The Second World War did leave significant institutional, normative, and economic legacies for the United States. It solidified a compression of wages and a reduction in overall income inequality that endured for three decades, and this included new opportunities for Black workers to move from unskilled to semi-skilled occupations, opportunities that might not otherwise have been available.[71] Many veterans pursued a college education or bought a house, courtesy of the GI Bill.[72] Experience with high and progressive tax rates and the introduction of withholding gave the federal government expanded fiscal capacity. Controls on wages during the war led inadvertently to the US system of largely employer-provided healthcare insurance. Aside from the aluminium industry, procurement practices reinforced, or at least did not lessen, tendencies towards economic concentration, and the war presaged, after a brief lull, permanently higher levels of military spending, which had persisting regional economic effects.

The war was not, however, associated with a political revolution or fundamental changes in the instrumentalities of government. There was no significant expansion or contraction of the franchise.[73] Appeals to 'prairie fire' explanations of the benefits of war emphasize how armed conflict can clear the ground for new growth by burning away retardative institutional structures or destroying outmoded productive capacity, thus paving the way for improved productivity in the future. But aside from the destruction on the island of Oahu and the overexploitation of some domestic petroleum reserves, the war did not directly damage infrastructure within the United States and its territories.

Prairie fire arguments may be applicable at other times or in other places, but they have little relevance in understanding the consequences of what transpired in the United States between 1941 and 1945. The legal and institutional rules governing the operation of the economy changed after Pearl Harbor, but those changes lacked permanence. Most, like price controls, were unwound quickly (some have argued too quickly)[74] with the coming of peace.

[70] Cited in Gannon, *Operation Drumbeat*, p. 389.

[71] Maloney, 'Wage compression'; Margo, 'Explaining'; Ferrara, 'World War II'.

[72] Bound and Turner, 'Going to war'; Stanley, 'College education'; Fetter, 'How do mortgage subsidies'.

[73] Ferejohn and Rosenbluth, *Forged through fire.*

[74] Bernstein, 'Removal of controls'.

The war did result in an enormous accumulation of physical capital in the form of military hardware, producer durables such as machine tools and dies, and huge industrial structures. In addition, the country experienced a large increase in physical capital associated with military command structures, forts, and bases that it would take decades of base closure commissions to shrink.

With the temporary exception of B-29 bombers, most of the aircraft produced during the war were, at its conclusion, deemed surplus: obsolete or unneeded. Tens of thousands were flown to boneyards in Arizona: air bases such as Kingman and Davis-Monthan. Engines were removed for steel scrap and the airframes guillotined, fed into onsite smelters where the metal reemerged as aluminium ingots. Some aircraft were flown directly from the factory gate to Arizona for disassembly and recycling. Many aircraft operating overseas were never repatriated. 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 including field artillery. These goods had been produced to fulfil an extraordinary need. When the war ended, so did most of that need.

It was not just aircraft and freighters. A flotilla of military ships, including 2 aircraft carriers, 4 battleships, 13 destroyers, 5 submarines and multitudinous other naval vessels were destroyed or made so severely radioactive in the North Pacific that almost all had to be scuttled. This was the result of two atomic blasts (Operations Crossroads), an air blast on 1 July 1946 (Able), and a spectacular underwater detonation on 26 July 1946 (Baker). The tests demonstrated that in fact ships could not withstand nuclear blasts and still operate, and the third planned atomic blast 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.[75]

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- or special-purpose machine tools, and most of these tools and related jigs and frames were scrapped with reconversion. The United States did use multipurpose machine tools, which could more easily be repurposed, but this was principally in the shops producing machine tools. 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 US $4 billion, and ultimately to a peak of US $14.4 billion in mid-1946.[76] Most military hardware, except for jeeps and trucks, was not dual use. Overall, recycling and disposal posed huge logistical challenges.

The counterfactual with respect to plants is more complex. The country emerged in 1948 with, inter alia, a vastly expanded aluminium production industry and a reduction in its industrial concentration, increased capacity in steel and magnesium, a synthetic rubber capability that had been developed basically from scratch, and the Big Inch and Little Big Inch pipelines, which had brought crude oil and refined petroleum products from East Texas to the East Coast but ceased doing so at the war's end as the tanker pipeline reopened. Valued at cost of construction, government-owned plants included about US $3 billion in aircraft, aircraft engine, and aircraft accessory plants, US $900 million in steel facilities, US $800 million in aluminium and aluminium fabrication, and about US $700 million in synthetic rubber plants (the bulk of which were not sold off until 1955).

[75] Weisgall, *Operation Crossroads*, pp. 77–8, 317–22.

[76] Cook, *Marketing of surplus war property*, pp. 10–1.

A large fraction was of relatively little value in the post-war period: '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'.[77] Julius Krug, the WPB's final chair, observed: '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 position'.[78] That is why so much of it was scrapped or sold for pennies on the dollar in the post-war period.[79]

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 anti-monopoly sentiment and political currents favouring the encouragement of small business. The aluminium industry was restructured on a more competitive basis than had been the case before the war, an outcome expected from the start. Unlike other government-owned, contractor-operated agreements, Alcoa's had not included an option to buy the new government plants it operated, and after the war it faced a new competitor, the Reynolds Aluminum Corporation.

As for labour, the immediate post-war impact of the war on potential hours was clearly negative: 407 000 mostly prime-age males never returned. Most would have been alive in the absence of the war. As Milward put it, 'The only recurrent demographic phenomenon relating to all or most wars is the fact that war kills many people'. There were another 607 000 military casualties. The 50 per cent wartime rise in female labour-force participation largely dissipated during the immediate post-war period.[80]

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 output across the Depression years. These categories of government capital complementary to private capital grew at a combined rate of 0.15 per cent per year between 1941 and 1948, as opposed to 4.17 per cent per year between 1929 and 1941.[81]

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 1941, still 34 per cent below the 1925 peak (937 000), plunged to 138 700 in 1944, barely above the 1933 trough of 93 000. All 'nonessential' construction in the country was restricted beginning on 9 October 1941, almost two months before the Japanese attack.[82]

Production of most Second World War military durables ceased at or shortly after the end of the war. The United States has never again and never will produce planes and ships in such quantities in such a compressed time frame. The product-specific knowledge and experience gained, as well as the tooling and many of the structures used, were of relatively little value after the war.

[77] Summer, 'Disposition of surplus war property', p. 464.

[78] US War Production Board, *Wartime production achievements*, p. 35.

[79] See also Jaszi, '$45 billion', p. 936.

[80] Mowery, *War, economy, and society*, p. 209; Schweitzer, 'World War II', p. 90; Rose, 'Rise and fall'.

[81] Field, *Great leap forward,* p. 35. Calculations are based on US Bureau of Economic Analysis, Fixed Asset tabs. 7.1 and 7.2.

[82] US Bureau of the Budget, *United States at war*, p. 83; Herman, *Freedom's forge*, p. 153.

What of more general scientific and technological advance? Kelly, Papanikolaou, Seru, and Taddy digitized almost the entire corpus of US patent filings between 1840 and 2010, and analysing word counts, identified breakthrough patents: those that were novel at the time and influential afterwards. Such patents had low backward similarity and high forward similarity scores, net of year fixed effects. Their time series of such patents shows a peak in the 1930s, particularly the first half of the decade, and a noticeable trough during the war years.[83]

Much of what occurred during the war represented the exploitation of a preexisting knowledge base. In 1945, Vannevar Bush published *Science, the endless frontier*, a work often viewed as distilling the lessons and achievements of the war into an actionable blueprint for post-war science and technology policy.[84] However, as David Mowery noted, 'the Bush report consistently took the position that the remarkable technological achievements of World War II represented a depletion of the reservoir of basic scientific knowledge', a view echoed in Conant's recollections after the war.[85]

In waxing enthusiastically about the impact of a new product or process innovation attributable to the war, one must always entertain the counterfactual: what would have been the trajectory in the absence of the war. In addition, one must also consider post-war relevance: if the innovation was in response to a set of resource scarcities that would not recur after the war, we cannot expect it to have had a large effect on the level or rate of growth of post-war productivity.

XI | CONCLUSION

The war greatly distorted the economy for a period of several years as sectors critical to the war effort expanded several-fold and then as rapidly shrank. What the United States accomplished in the production of military hardware was indeed exceptional. However, the impact on the growth of US potential output of this unique and never-to-be-repeated experience was almost certainly retardative. When subject to critical analysis, the learning-by-doing narratives, which seem so compelling on their face, disintegrate as an explanation for an alleged boost to post-war TFP advance, which is, in any event, not evident in the productivity data. The learning that took place during the war was largely irrelevant afterwards, because the country never again produced such large quantities of aircraft or ships in such a limited period.

It is worth reflecting on how an apparently questionable narrative could have become so deeply ingrained in the United States and elsewhere. It reflects in part a celebratory imperative, perhaps understandable in a victorious nation, that, along with wartime efforts at persuasion, have clouded our vision. In *Looking for the good war*, Elizabeth Samet wrote that 'we search for a redemptive ending to every tragedy'. She also asserted that 'a pernicious American sentimentality about nation and war has triumphed, typified by demonstrative expressions of, and appeals to an emotion that short circuits reason'.[86] A human predisposition to surrender to faith in embracing the benefits of the war for long-run economic growth is one manifestation of this dynamic. Our willingness to continue to reference 'miracles' in accounting for alleged productivity bonanzas does, after all, literally represent an appeal to the supernatural.

[83] Kelly et al., 'Measuring technological innovation'; Field, 'Most technologically progressive; idem, *Great leap forward*; idem, *economic consequences,* ch. 7.

[84] Bush, *Science.*

[85] Mowery, 'Bush Report after 50 years', p. 26; Conant, 'Mobilization of science', p. 203.

[86] Samet, *Looking for the good war*, pp. 81, 86.

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