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The U.S. Rubber Famine during World War II

by

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ABSTRACT

Contrary to what is widely believed, manufacturing productivity fell sharply in the United States between 1941 and 1945. The main causes were the sudden, radical, and ultimately temporary changes in the product mix. By April 1942 Japan had created additional disruption, cutting off almost all supplies of natural rubber, the one strategic material for which the United States had effectively no domestic sourcing. The resulting famine aggravated downward pressures on U.S. productivity and adversely affected the country's military capability. The risks, widely foreseen, could be mitigated by stockpiling, cultivation of guayule, or production of synthetic. In his roles as head of the Reconstruction Finance Corporation and then Federal Loan Administrator, Jesse Jones slow walked the first and third of these strategies. This largely forgotten history has relevance for the reassessment of the benefits of cheap foreign sourcing, especially where there is minimal home capacity or possibilities for substitution.

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Introduction

Conventional wisdom regarding the effects of U.S. economic mobilization for the Second World War revolves around two key propositions. First, that war spending and monetary accommodation rapidly closed the negative output gap still prevailing in 1941 and thus ended the Depression. And second, that experience producing military durables led to dramatic reductions in unit costs, and that these learning effects persisted into the postwar period, establishing the supply side foundations for the golden age of U.S. economic growth (1948-73).

In a recent book and article (Field, 2022, 2023) I have challenged the second of these narratives, showing that productivity within U.S. manufacturing fell sharply between 1941 and 1945, leaving labor productivity in 1948 roughly where it had been in 1941 and total factor productivity (output divided by a combined measure of labor and capital service inputs) substantially below its prewar level. This analysis builds on earlier work (Field, 2003, 2011) which suggested that scientific, technological, and organizational advances across the Depression years greatly increased the country's potential output, and thus, consequently, that the supply side foundations for the U.S. golden age (1948-73), and its worldwide dominance in the immediate postwar period were, for the most part, already in place by 1941.

This body of research does not question the data underlying the various studies documenting or analyzing learning by doing in military production (Arrow, 1962; Alchian, 1963; Gemery and Hogendorn, 1993; Thornton and Thompson, 2001, LaFond, Greenwald and Farmer, 2022; and Ilzetzki, 2023, but see Scott-Kemmis and Bell, 2010, for a more skeptical interpretation). It argues however that the resulting improvements in productivity only partly compensated for the depression in those metrics resulting from the sudden, radical, (and ultimately temporary) changes in the product mix. The U.S. system of mass production relies for the most part on single or special purpose machine tools. When the goods produced change, the plants shut down, old tools, jigs, and frames are removed and scrapped, and new ones are installed. During periods of transition, both output and productivity drop to very low levels. It then takes time for both workers and managers to become proficient in making or assembling the new goods.

The main cause of the sharp drop in productivity between 1941 and 1942 was the transition from making goods in which manufacturers had a great deal of experience to those in which they had little. The wartime changes in product mix were far more extensive than those associated with the transition from one automobile model year to the next. During the second full year of the war (1943), manufacturing productivity recovered, but only partially, as the result of learning. Military production peaked in the fourth quarter and then plateaued for the remainder of the conflict, with output per unit input resuming a sharp downward trajectory in 1944 and 1945 as the result of secondary product mix effects and the emergence of nationwide labor shortage, both of which aggravated production intermittency. These negative movements were reinforced in 1945 by reversion to a largely prewar

product mix following the sudden end of the Pacific war in August. As a result of demobilization, the U.S. stopped making most of the goods whose cumulative production had given rise to the learning.

The effects of the product mix changes would have been serious even had there been no additional disruptions. But there were additional disruptions. Aside from Pearl Harbor, U.S. territory did not suffer from direct attack by enemy forces during the war. A Japanese submarine ineffectively shelled oil storage tanks near Santa Barbara in 1942 and in 1945 six people were killed in Oregon by an incendiary bomb carried by balloon on air currents from Japan.[1] The effects on the economy of both incidents were negligible. Nevertheless, actions by both Germany and Japan seriously disrupted the U.S. economy through means other than simply forcing the change in the product mix.[2] The Germans did so via U-boat predation, shutting down the 'tanker pipeline' that brought petroleum and petroleum products from East Texas and Louisiana to the Eastern seaboard (Field, 2022, ch. 4). The Japanese did so by overrunning Singapore in February 1942 and then rapidly taking control of almost all Southeast Asian sources of natural rubber. This deprived the United States of 97 percent of its supply of the one strategic material in which it had effectively no domestic sourcing. Other inputs, such as manila hemp, tin, and a range of strategic metals and minerals also faced wartime supply disruptions.[3] But, for the United States, no other material involved such limited alternate sources of supply or opportunities for substitution. There were simply no satisfactory substitutes for rubber in a variety of critical uses, particularly tire carcasses and treads, the ultimate end use of 70 percent of rubber inputs (Field, 2022, ch. 3; Howard, 1947, p. 207; U.S. Tariff Commission, 1940, pp. 1, 2).

It was widely anticipated that conflict with Japan would have this result. It was also understood that there were three principal means, beyond suppression of consumer demand and encouragement of the use of reclaim,[4] whereby the U.S. might protect itself: 1) accumulate a large strategic stockpile of natural rubber; 2) subsidize domestic production of alternative plant-based sources of latex; or 3) develop a synthetic rubber capability. At

[1] During the war Japan launched approximately 9,300 hydrogen filled Fu-Go balloons, painstakingly pieced together by millions of Japanese civilians including schoolgirls. 345 made it to the United States, wafted along by the same air currents that in the twenty first century carried Chinese surveillance balloons over the country (Neer, *Napalm*, pp. 39-40).
[2] One can also argue that, by waging war on the U.S., its enemies 'forced' large increases in the U.S. armed forces, eventually creating nationwide labor shortage in the civilian economy. That effect was initially delayed because of the negative output gap remaining in 1941 but became severe towards the end of 1943 (see Field, 2022, ch. 5).
[3] A 1940 report of the Army Navy Munitions Board classified fourteen materials as strategic: antimony, chromium, coconut shell char (used in gas masks), manganese (essential in steel production), manila fiber (hemp, essential for naval mooring cables or hawsers, and available from only a small part of one island in the Philippines), mercury, mica, nickel, quartz crystal, quinine (anti-malarial), rubber, silk, tin, and tungsten.
[4] Reclaim had historically been discouraged in the United Kingdom because of concern about reducing demand for Empire-produced natural rubber. In the U.S., in contrast, reclaim was often seen as the first line of defense against shortages and/or high cartel prices of natural (U.S. Department of Commerce, 1952, p. IV-4). Rubber can be reclaimed a maximum of about three times, its quality deteriorating in a process that is partially compensated for by mixing with new supplies of natural rubber. In 1940 natural rubber tires were reckoned to be good for 25-30,000 miles, all-reclaim tires for less than half that (United States Tariff Commission, 1940, p. 30; U.S. Senate, 1942, p. 4553).

the time of Pearl Harbor each of these possible remedies had been pursued either in a very limited fashion or not at all. Between 1942 and 1945 the rubber famine aggravated downward pressures on U.S. manufacturing productivity. From a military standpoint, the choices leading to this result threatened the ability of the United States and the United Nations to prevail in the conflict -- much more so than the controversial decision to move the U.S. Pacific fleet from San Diego to Pearl Harbor in March 1940.

This paper examines what underlay these failures and documents the severity of their consequences for the economy and the country's military capability. It considers why the strategic stockpile was so low. It explains why the passage of legislation in 1942 providing $45 million for an Emergency Rubber Program based largely on guayule cultivation was too late. It documents how the design and structure of the synthetic rubber program and the delays in initiating plant construction exposed the country to potentially catastrophic consequences. In the process, it considers the multiple channels through which the rubber famine adversely affected the country's wartime economy. Finally, it details the outsize role played by Jesse Jones, head of the Reconstruction Finance Corporation from 1933 through 1939, and then Federal Loan Administrator, in slowing pursuit of the first and third of these mitigation strategies. [5]

Stockpiling

Stockpiling was the most straightforward means of dealing with the threat of loss of supply. Warehousing entailed no biological/botanical uncertainty about how well a particular plant species might grow under U.S. soil and climate conditions. Unlike synthetic rubber, it did not rely on untested engineering or chemical processes. The storage 'technology' was simple, the costs predictable, and a strategic reserve provided almost perfect substitutes for timely imports of natural rubber. Although the stockpile quadrupled between its low level in 1939 and its peak in April 1942, it remained far too low given the needs of the country and its allies. As Federal Loan Administrator, Jones controlled the RFC, which had responsibility for building this stock, particularly following the formation of its Rubber Reserve subsidiary in June 1940, when it assumed sole responsibility. Both before and after, Jones slow-walked buying from the international cartel because he doubted a large reserve was necessary, and if it was, he wanted to wait until prices were lower.

[5] Jones headed the Reconstruction Finance Corporation from 1933 through 1939, when he resigned as chair to assume the post of director, Federal Loan Agency. The RFC, along with an alphabet soup of other federal lending agencies, remained under Jones' purview throughout the war, with close associates nominally running them. In 1940 he became concurrently (and after a special enabling act of Congress), Secretary of Commerce, and in 1942, at its inception, a member of the War Production Board. Because, up to a very generous debt ceiling, Congress had given the RFC authority to borrow on the full faith and credit of the United States by issuing its own bonds, either directly or through the Treasury, Jones and the RFC had a spending and lending authority more flexible than that of Congress itself. "You'd better see Jesse" was common advice in wartime Washington for those wanting funding for a program.

Inventories of natural rubber at the end of 1939 were historically low: 125,800 long tons relative to consumption that year of 592,000 long tons (Herbert and Bisio, 1985, pp. 9-10, 14-15).[6] So long as supply was cheap and reliable, it made little sense for private firms to hold large inventories, and they didn't. A just in time inventory approach minimized the risk and accounting headaches associated with gains or losses from inventory revaluations and, from a balance sheet perspective, avoided tying up working capital in potentially idle stocks.

But as the probability of U.S. involvement in war increased, and future access to imports came into question, U.S. companies were happy to have the government shoulder the burden of acquiring and holding a large inventory, particularly if rubber company executives had prime seats at the table directing the accumulation process, which they did. The U.S. strategic reserve grew to 533,344 long tons by the end of 1941, and peaked in April 1942 at 634,152 long tons, with the arrival of shipments already on their way to the U.S. as Japanese forces completed their seizure of Southeast Asian exporting sites (Rubber Reserve Company, 1945, pp. 5, 16.) Jones subsequently defended his actions (and inaction), hailing the reserve as the "largest stock of rubber that had ever been accumulated in any country", and blamed the inability to obtain even more on restrictions of deliveries by the international cartel (Jones, 1951, p. 399).

Given the risks faced by the United States and its Allies, this stock was pitifully inadequate (White, 1980, p. 41). In April 1939 Senator James Byrnes (subsequently a Supreme Court Justice and then Director of the Office of War Mobilization) characterized as desirable an inventory of 825,000 long tons (U.S. Senate, 1942, p. 4954). From the vantage point of 1939 this was intended to protect against price increases that might be associated with the European war, not a complete cutoff of supplies from the Far East. The U.S. consumed 591,000 long tons of natural rubber in 1939. By 1941, as the country's negative output gap closed, U.S. consumption had increased to 781,259 LTs, and imports had grown to 1,023,63 long tons as stocks were accumulated.

Then Singapore fell, and, as war planners and many others had long feared, complete cutoff ensued shortly thereafter. In the next four calendar years (1942-45), the United States managed to import a total of 583,053 long tons. At the end of 1944, natural rubber inventories stood at just 93,650 long tons. Import flows were lowest in 1943 but end-of-year inventory stocks reached their lowest point in December 1944. The eventual availability of synthetic rubber in quantity did not end the rubber famine. Synthetic had to be blended with natural in the manufacture of almost all products, and in some cases synthetic could not be used at all.[7] During World War II the United States never escaped the threat of running out of rubber, which stood as a sword of Damocles over the entire economic and military effort. In 1944 the county almost ran out of natural rubber and would have had the war continued into 1946 (U.S. War Production Board, 1945b, p. 94).

[6] Imports and inventory stocks of rubber were, for historical reasons, reckoned in long tons (2,240 pounds).
[7] "… synthetic was inferior to natural in most uses…" (White, 1980, p. 108).

The unsatisfactory level of the stockpile in April 1942 was largely due to resistance by Jesse Jones to building it during the period prior to the truncation of exports from that region. Sensitive to subsequent criticism, he wrote in his memoir that his "introduction to our rubber situation came late in May 1940, as France was falling."[8] This is hardly credible, since Edward Stettinius and William Batt from the National Defense Advisory Commission had laid out the severity of the risks of cutoff in a letter to the President and in meetings with Jones in September 1940 (see timeline below). The vulnerability of the U.S. to disruption of rubber supplies was well known and had been widely discussed for at least two and arguably three decades.

During the interwar period, rubber was the country's largest single commodity input. In the 1920s, U.S. consumers paid as much attention to the world price of natural rubber as they do today to the price of a barrel of crude oil (Harp, 2016, p. 4). In February 1939 the journalist Eliot Janeway warned: "It is on the economic front that Japan's drive threatens us most dangerously. The American economy and with it American defense cannot be operated without rubber and tin, which at present cannot be obtained in adequate quantity except from the British and Dutch colonies in southeastern Asia" (Janeway, 1939, cited in Marshall, 1995, p. xi).

In June 1939, the U.S. inked a barter deal with Britain, swapping 600,000 bales of cotton for about 90,000 long tons (LTs) of rubber.[9] Title to the rubber was held by the Commodity Credit Corporation, and the rubber was stored in six warehouses administered by the War, Navy, and Interior Departments under the auspices of the Army Navy Munitions Board (United States Tariff Commission, 1940, p. 27). This deal was the first significant move by the U.S. to accumulate a government owned strategic reserve. Jones certainly knew about it, since between its establishment in 1933 and July 1, 1939 the Commodity Credit Corporation was funded and managed by the RFC (oversight was subsequently transferred to the Department of Agriculture).

In June 1939, as the shadows of war lengthened, Roosevelt persuaded Congress to pass the Strategic and Critical Materials Stockpiling Act. $100 million was appropriated for this purpose, and, prior to June 1940, the Treasury, War, or Navy departments could buy rubber on government account, with rubber manufacturers free to replenish their own inventories on the open market if they wished. At the time France fell in June 1940, however, just $13 million had been expended for these purposes.

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[8] Jones (1951, p. 396). This appears to refer to a meeting he held at this time with the heads of the major rubber manufacturing firms (see Timmons, 1956, p. 303). Timmons, who was the Washington correspondent for the *Houston Chronicle*, a paper owned by Jones, offers an incomplete and highly exculpatory account of Jones' actions with respect to rubber.

[9] See *New York Times,* June 24, 1939, p. 1. To mollify rubber producers in Malaya, who feared the U.S. would dump the rubber on world markets, the agreement specified that the U.S. would not disburse any of this stock for seven years except in the case of a war emergency of "major proportions." According to the Department of Commerce, (1952, p. VIII-3), the final quantities were 500,000 bales of cotton for 90,500 LT of rubber. The deal had originally been proposed by then Secretary of Agriculture Henry Wallace (U.S. Senate, 1942, p. 4954).

On June 25, 1940, three days after the armistice marking the fall of France, Congress amended the RFC's original authorizing act, greatly increasing its authority. Its powers and responsibilities now included financing the production of airplanes, tanks, and guns, the construction, equipping, and operation of plants for so doing, and the stockpiling of strategic metals and materials. Three days later, on June 28, the RFC created the Rubber Reserve Company (RRC), with half its $5 million equity subscribed to by the RFC and the other half by rubber products manufacturers. The RFC then loaned its subsidiary $140 million to finance purchases (U.S. Tariff Commission, 1940, p. 27). Rubber Reserve became the country's sole buyer of rubber, private or public, and the subsidiary's main efforts would be to procure and stockpile natural rubber on government account, store it in warehouses, and distribute to qualified users.[10] From that point on, accountability for the size of the stockpile lies almost entirely with Jones.

In his memoir Jones justified his reluctance to proceed more rapidly on the grounds that he had been advised (by private rubber company executives) that if he bid aggressively, pushing up the world price by even a few cents, the rubber growers, rather than shipping more, would "begin to hold their stocks in the expectation of still higher prices." (Jones, 1951, p. 397.) The defect in this justification is revealed in his next chapter, which allows that in fact he held a powerful weapon to use in negotiations with the cartel: the threat that the U.S. would develop synthetic rubber. As he wrote both in his memoir and in a letter to Roosevelt on September 16, 1940: "they are extremely anxious to sell the rubber and are not enthusiastic about our building synthetic plants (Jones, 1951, p. 405; Fenberg, 2011, p. 361; see also Jones' testimony before the Truman Committee (U.S. Senate, 1942, pp. 4530-1). The real reason for the slow walking was that Jones doubted the need for a large stockpile or for a synthetic program beyond perhaps the construction of small experimental facilities (Howard, p. 131, Jones, 1951, p. 404; Solo, 1959, p. 19). But those with whom he was negotiating didn't need to know that.

Perhaps the most damning piece of evidence in support of those who criticize Jones for applying a 'banker's mentality' to a national security problem was his reaction when a government warehouse storing rubber in Fall River, Massachusetts burned down on October 12, 1941, destroying at least 15,000 tons of crude rubber. Jones reportedly exclaimed, in a remarkable display of near-sightedness, given how critical the size of the stockpile would be less than half a year later, "Good thing we have it insured" (*New York Times*, October 13, 1941; Janeway, 1951, p. 82).

As RFC head in the 1930s Jones played an effective role in liquifying and recapitalizing the U.S. banking system through loans and purchases of preferred stock, a program that ended up (as he reminded his correspondents and

[10] In 1941, reserves accumulated by the Rubber Reserve Company were merged with the existing government stocks held by the Commodity Credit Corporation (U.S. Department of Commerce, 1952, pp. VI-1, VIII-4).

the public repeatedly) yielding profit to the U.S. Treasury.[11] His default practice, from which he could sometimes be dislodged if pressed hard enough by others with power, was to loan conservatively on good collateral at robust rates that made it unlikely the RFC would lose money. What mattered most was avoiding an accusation that he had spent taxpayer money unwisely, or loaned funds in what he judged an imprudent fashion. Jones "had no philosophical objection to state capitalism as long as it wasn't bad capitalism…. Jones would not risk money on bad loans" (Olson, 1988, pp. 156, 204). That record, and his reputation for probity and conservative management, was the key to the high levels of esteem in which he was held by members of both political parties in Congress. This, along with his close personal relationship with Roosevelt, underlay the power and influence he wielded in Washington.

Jones was flexible in his conservatism, but his default inclinations and reliance on his own judgement served him (and the country) poorly in the case of rubber. He was reluctant to spend on the stockpile because he doubted how much was needed[12] and because he awaited the price of natural rubber falling to lower levels. The contracts struck between Rubber Reserve and the International Rubber Regulation Committee on June 29 and August 18, 1940 were contingent on an open market price within a very narrow range. If the price were above that, the U.S. would not buy (U.S. Tariff Commission, 1940, pp. 27-28). For example, the June 29 agreement with the IRRC entitled the U.S. to purchase between 100,000 and 150,000 LTs by December 31, 1940, provided the price in the open market was between 18 and 20 cents a pound. By the end of November 1940, less than 25,000 LT had been delivered (Solo, 1959, p. 28). Yet the contract provisions, whatever their merits, cannot be the explanation. The British blockade of Germany had stabilized the world price of rubber between 17 and 20 cents a pound and would have been lower without the U.S. buying. Why wasn't more acquired?

Jones made a fortune in lumber, tobacco, newspapers, banking, and as a hotel and commercial real estate developer in Houston and New York City, and played a major role in the development of Houston as a city and inland port. Politically astute, he operated at the pinnacles of American economic and political society, despite having left school after the eighth grade. Intimately familiar with borrowing and lending, both as a consumer and provider of financial services, he held strong views about what constituted sound business and banking practice. Jones "hoarded the Rubber Reserve Corporation fund, searching for bargains that did not exist because war was inflating commodity prices" (O'Neill, 1993, p. 79; see also Nelson, 1946, p. 39, and Janeway, 1951, pp. 80-82).

[11] This was true even though stabilizing the banking system did not lead to the large expansion of commercial credit Jones and others thought necessary for recovery. Between June 1933 and December 1936, member bank loans rose only from $11.3 to $11.6 billion, The industrial expansion of 1936-7 appears to have been financed largely by retained earnings, stimulated in part by government spending on naval construction and public works, as well as various relief payments, including the World War I veterans' bonus payments as well as RFC loans to finance rebuilding in response to floods and other natural disasters (Olson, 1988, pp. 168, 179, 187). The recapitalization work may have been necessary for recovery, but it was not sufficient.

[12] "Jones was much more skeptical of [the defense effort's] urgency and more concerned that RFC funds not be wasted" (White, 1980, p. 39).

Herbert Feis wrote that he and others at the State Department wished to pursue purchases more aggressively, but were thwarted by Jones, who placed sharp limits on what Rubber Reserve would pay (Feis, 1947, cited in Rockoff, 2000). A consequence was that the country almost ran out of natural rubber during the war and would have had the conflict persisted into 1946 (War Production Board, 1945, p. 94).

Jones enjoyed positive press during most of the thirteen years he spent in Washington. But competencies that served him well in other venues did not do so in his dealings with rubber. His management of the threat and then actuality of rubber shortage coincided with the worst press and Congressional criticism he received during his career, as well as a physical altercation with longtime antagonist Eugene Meyer, former head of the Federal Reserve System, first head of the RFC, and publisher of the *Washington Post* (Fenberg, 2011, pp. 401, 406-10).

In addition to slow walking the accumulation of a stockpile, he also significantly delayed the development of a synthetic rubber capability. The need to develop such an industry might have been avoided if more aggressive action had been taken on either or both of the other mitigation strategies. His actions with respect to stockpiling and synthetic rubber reflected his pre-1942 skepticism about the need to address U.S. vulnerability, along with his enduring, and in other circumstances, praiseworthy concerns about not wasting taxpayer money.

For all his success in the private sector and then as a government banker, Jones lacked the experience to design, let alone evaluate the merits or size of a proposed synthetic rubber industry. When confronted with a program designed by an oil company with an interest in its evolution, Jones acted to stall its forward momentum, and appears to have influenced or at least reinforced Roosevelt in taking (at least initially) a similarly skeptical view of its necessity. Questions about the design of Standard Oil of New Jersey's proposed program can justifiably be entertained, but, under the circumstances, blocking its advance demanded articulation of something to take its place. Jones exhibited little interest in doing so, or assembling on his staff the disinterested technical competencies that might have helped him develop an alternative.

By November 1940 a program designed around a blueprint provided by Standard Oil had progressed to a planning stage. Jones believed he knew oil (both the industry and the men), and we can speculate that he viewed Standard's efforts as something of a scam. In February 1941, driven by doubts about the need for a subsidized synthetic rubber program, Jones *completely cancelled it*, defending his action on the grounds that he did not want to waste government money on "expensive plants," except in an "extraordinary emergency," which in his judgment did not then exist. On February 26, 1941, Standard's CEO received the memo explaining this, which included the claim that the RFC had accumulated a stockpile of natural rubber sufficient "to carry us for three years." That claim, which could be supported only under the most unrealistic set of expectations, was developed

by William L. Clayton, Jones' deputy, and presumably reflected the judgments of his boss.[13] In March, Jones backtracked a bit in response to protest about the cancellation, proposing that each of the big four rubber product manufacturing companies build a small 2,500 ton per year demonstration plant to gain experience with copolymerization. But there was no money for butadiene production. In subsequent testimony before the Gillette Committee that year, Jones stated that "the RFC only carries out policies, it does not formulate them", which might have been true formally but was not so in practice (Solo, 1959, p. 28). Jones was in an extraordinary position of power to affect America's preparedness. Relying with great confidence on his own judgment, he hamstrung both the stockpiling and synthetic rubber routes to remediation.[14] Guayule escaped his restraining influence (it was in the Department of Agriculture's bailiwick) but, as we shall see, by the time funds were appropriated for it by Congress, it was too late. In testimony to the Truman Committee in 1942, Jones also displayed strong skepticism about prewar efforts to develop guayule cultivation (U.S. Senate, 1942, p. 4548).

In his memoir, Jones gives himself and his organization credit for amassing the world's largest stockpile of natural rubber and rejects the suggestion that he and the organizations he controlled could have done more. "We never got as much natural rubber as we wanted or tried to acquire, but we did get all that was available" (Jones, 1951, p. 400). To his credit, he does acknowledge that it wasn't enough.

The synthetic rubber program produced approximately three billion pounds of synthetic rubber during the war (Jones, 1951, p. 401). Most of this was GR-S, where it would substitute for natural rubber.[15] Three billion pounds is about 1.34 million long tons.[16] If the stockpile had been that much higher than its maximum in April 1942 (634,152 tons), it could have substituted for the entire wartime output of the synthetic rubber program, with the additional bonus of avoiding the milling penalties of working with synthetic–natural blends in fabrication.[17] If for every warehouse then holding government rubber, the country had built or contracted for roughly two more of the same capacity, this additional stock could have been stored, at a fraction of what it cost to build let alone operate the 51 synthetic rubber plants. Warehouses required regulating temperatures (ideally between 32 and 72 degrees Fahrenheit) but only minimal labor – mostly security -- and minimal interior equipment compared to any of the synthetic plants constructed. Natural rubber in storage deteriorates, but has a recommended shelf life of

[13] Clayton came to Washington in November 1940 to assist fellow Houstonian Jones as deputy federal loan administrator "with what proved to be a too conservative stockpiling of strategic materials" (White (1980, p. 93).
[14] For a more sympathetic view of Jones, see Marshall, 1995.
[15] A small amount was neoprene, a specialty rubber with good oil resistance that DuPont had made prior to the war, and a tiny amount was butyl, another specialty rubber developed prior to the war by Standard Oil of New Jersey, but not sold commercially. It had high gas impermeability, and thus was best suited for inner tubes.
[16] 1 long ton = 2,240 pounds.
[17] "At one time the figure of 1 million tons was discussed as the possible goal of the government stockpile, but the maximum reached in April 1942 was 630,000 tons…" (United States Tariff Commission 1946, p. 3).

between three and five years, which would have made it feasible to ride out the war with a significantly larger prewar stockpile.

The remedy for the country's poor preparedness for the rubber famine could not have been simply entrusting preparedness to the private sector. Private companies were not willing to risk their own money developing a capability to produce a product, synthetic rubber, that might or might not have a commercial market after the war. The design of Standard's proposed program served its long-term financial interests, not necessarily the national security interest of the United States in winning the war. Thatt the oil company had a plan for remediating the risk of rubber cutoff at a time when others, particularly in the government, lacked interest in formulating one, and pressed hard to implement one, can, however, be seen as congruent with the country's national security.

Alternate sources of latex

The loss of access to Southeast Asian rubber was potentially devastating to the United States because the country had virtually no domestic sources of latex and because there was hardly any supply elsewhere in the world not then under enemy control. Annual production available to the United Nations could satisfy just two weeks of U.S. consumption in 1941 (Wendt, 1947, p. 204). *Hevea brasiliensis*, the preferred source of natural rubber, requires a moist, warm climate generally found near the equator. It had not been and cannot be successfully grown within the United States.[18]

As compared with the exploitation of wild *hevea,* plantation cultivation offers the promise of higher yields per hectare because of much higher density, and the opportunity to raise yields per tree through selective bud grafting and vegetative propagation from cuttings.[19] Unfortunately, plantation cultivation, had not and has not been successful anywhere in the Western hemisphere. Henry Ford made the most ambitious attempt. He obtained a land grant from the Brazilian government of 2.5 million acres (almost three times the size of Rhode Island) located 600 miles up the Amazon and about 190 miles south of Santarém. Beginning in 1928 his organization planted seedlings on thousands of cleared acreage and built Fordlandia, a transplanted midwestern company town

[18] Even Hawaii, it turned out, where rubber plantations were attempted on Maui, did not have the ideal combination of temperature and moisture, although some success was realized between 1905 and 1915. The industry shut down because it could not compete effectively with Southeast Asian producers, and there was no organized production in 1941, so it could not serve as an alternate source of supply. A small number of trees were planted in Florida before the war for experimental purposes (U.S. Senate, 1942, p. 4950).

[19] Rubber trees in the Amazon grow at a density of about 1 per acre, whereas on a plantation they can be and are planted densely. A modern rule of thumb is that a plantation tree can be expected to yield about 19 pounds of rubber annually. A calculation in Whaley (1944) suggests that wild *hevea* can be expected to yield about 2.7 pounds per tree per year (300,000,000 trees yielding 50,000 long tons). A more optimistic estimate of the potential yield of wild rubber from the Western Hemisphere was 100,000 tons (Caldwell, 1942, p. 46) implying 5.4 pounds per tree annually, which would be more consistent with oft quoted remarks that plantation methods "tripled" the yield in comparison with wild.

replete with schools, hospital, swimming pool, cafeteria, golf courses, and suburban housing for his managers (Grandin, 2009). His efforts were ultimately stymied by insensitivity towards his Brazilian workforce – trying to impose a diet and living regime on his workforce that might have been acceptable stateside -- but more fundamentally by a microorganism (*Microcyclus ulei)* that causes leaf blight and eventually killed the trees.[20] In 1934, acknowledging defeat at Fordlandia, the company persuaded the Brazilian government to trade 700,000 acres of the original grant for a new site (Belterra) closer to Santarém, and began anew. This time the company exhibited less cultural insensitivity in managing the local work force, and planted blight resistant strains. It looked initially as if the second effort might be successful. But the resistant strains proved to be low-yielding, and the plantation continued to struggle with leaf blight (Whaley, 1948, p. 208; Grandin, 2009; Neeleman and Neeleman, 2017, pp. 17-18). In 1945 Henry Ford II sold both parcels back to the Brazilian government at a loss to the company over the 17-year period of about $20 million.

Ford's failures are consistent with the conclusion that the United States could not and cannot expect cheap plantation rubber to be grown anywhere in the Western hemisphere.[21] Harvey Firestone did have more success in Africa, persuading the Liberian government to grant him a 99-year lease of 1 million acres of Firestone's choosing (about 40 percent of Ford's initial acreage) and on them creating the world's largest rubber plantation (Mittman, 2021). Firestone's Liberian operations began in 1926, and continued to operate almost a century later, sometimes at reduced capacity depending on the state of the world rubber market and Liberian internal political conflict. After Pearl Harbor, Rubber Reserve contracted with Firestone for the entire output of the Liberian operation, but its contribution to the overall war effort was small. In 1943, the year of the United States' lowest imports, these holdings supplied almost a quarter (23 percent) of a greatly reduced flow of imports, but this was never enough to account for more than about two percent of overall U.S. consumption (Herbert and Bisio, 2019, p. 18; Wendt, 1947, p. 208).[22]

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[20] The wild trees in the Amazon survive because they are dispersed, on average about one per acre; in plantations, close together, they invite attack. Remarkably, the infestation has not spread to Southeast Asia. Almost all of the rubber trees in Southeast Asia were and are genetically identical to those growing wild in Brazil; this lack of biodiversity makes them vulnerable.

[21] During the summer of 1940, the Department of Agriculture, using $500,000 finally appropriated by Congress for this purpose (the request had been turned down three times before), sent four expeditions to Central and South America to survey possible sites for plantation *hevea* and conduct experimental plantings (U.S. Senate, 1942, pp. 4944-46). This might over the longer run have mitigated U.S. dependence on Southeast Asian supplies but could not in any case be a solution to the impending rubber famine, since the trees would take 6-7 years to reach maturity (Caldwell, 1942, p. 113; Wendt, 1947, p. 205). Nor was there an obvious solution to leaf blight, although it was hoped it could ultimately be addressed by selecting resistant strains of *hevea* for propagation (Whaley, 1942, p. 20). Subsequently, spraying with copper or sulphur fungicides had some success (Whaley, 1948, p. 207). When war came, the Emergency Rubber Project did fund some *hevea* planting in Haiti, but, along with efforts to cultivate *cryptostegia*, initiatives in that country made no noticeable dent in the rubber famine.

[22] Ceylon, sometimes considered part of South Asia, remained in British hands, and through the Combined Materials Resource Board, 60 percent of its output was allocated to the US in 1944 and 1945, helping to avoid an almost complete exhaustion of its natural rubber stocks (Wendt, 1947, p. 208).

That left hemispheric wild rubber. In Spring 1942 the United States negotiated agreements with twenty-six South American and Central American governments, calling for those countries to provide the U.S. (at a negotiated price) all their rubber production beyond that required for domestic consumption. Like the Liberian contract, this program succeeded in covering only a small fraction of U.S. wartime consumption needs.[23] U.S. consumption (synthetic and natural) totaled 488,535 LT in 1943 and 710,783 LT in 1944. Of this, Latin America provided 26,200 LT in 1943 (5.4 percent) and 32,800 LT in 1944 (4.6 percent). This contrasts with confident predictions for 1942 of 75,000 to 100,000 LT from Latin American wild rubber (Caldwell, 1942, p. 46), and for 1943 and 1944 of 60,000 LT and 120,000 LT respectively. As Wendt concludes, "The Western Hemisphere natural rubber program was not a success" (1947, pp. 205, 227).

Neither wild nor plantation grown rubber in the Western hemisphere or Liberia would alleviate the U.S. rubber famine. After imports from South Asia ceased to be available, stockpiling was no longer an option, and, setting aside synthetic rubber for the moment, the remaining possibility was to increase the cultivation within the United States of other plant-based sources of latex. The most promising of these was guayule (*Parthenium argentatum).* In the first decade 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, included Nelson Aldrich, Bernard Baruch, Daniel and Sol Guggenheim, Jacob Schiff, and John D. Rockefeller Jr. The IRC operation in Mexico, through its operating subsidiary, the Continental Mexican Rubber Company, harvested and then, using a capital-intensive process patented in 1904, 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 (van Harmelen, 2021, p. 70). Production increased sharply between 1905 and 1910, and in the latter year guayule provided the raw material for almost a fifth (19 percent) of U.S. rubber consumption. The IRC eventually controlled over 3.8 million acres in Mexico, giving it a practical monopoly of the shrub's natural habitat.

Wild guayule's contribution to U.S. rubber consumption in 1910 was impressive, but there are questions about how sustainable it might have been, given that extraction of rubber from the plant could be done only once, as opposed to *hevea*, which could be tapped again and again for decades. In any event, beginning in 1911 Mexican revolutionaries repeatedly disrupted operations at the Torréon facility, and in 1916 the IRC took seeds to the U.S. with the intent of converting the wild plant into a domesticated cultivated crop, planting acreage in southwestern Texas near Laredo, south of Tucson, Arizona and, in 1926, in Salinas, California. During the spring of 1930, following an invitation from the company, the U.S. Army detailed an obscure major named Dwight D.

[23] Neeleman and Neeleman (2017), while bringing together much useful information on the Brazil effort, misleads in terms of its overall contribution to the war effort, although it documents the often terrible conditions under which the 50,000 'rubber soldiers' recruited for this effort labored and often died.

Eisenhower to tour IRC operations in California, Texas, and Mexico as part of a two-man team. The diary of his visit and his official report are available in his published collected papers (Holt and Leyerzapf, 1998, pp. 117-138).

Eisenhower toured cultivated acreage in Texas and California (Salinas) as well as the remnants of the IRC facilities in Mexico used to process wild guayule, where he also observed the mixed success with attempts to reseed the semiarid terrain. Eisenhower was one of many who correctly feared what would happen in the case of war with Japan. In his report to the Assistant Secretary of the Army he observed, "Should our sea communications with [Southeast Asia] be cut in an emergency, shortage of rubber in the United States would rapidly become acute" (Holt and Leyerzapf, p. 126).

Visiting acreage near Laredo, Texas, Eisenhower was told by IRC personnel that they believed such cultivation would be profitable if the international market price for rubber were above 12 cents a pound (Holt and Leyerzapf, 1998, p. 125). It averaged 11.9 cents a pound in 1930, but subsequently dropped to a low of 3.4 cents in 1932, prior to recartelization in 1934, when the International Rubber Regulation Agreement continued what the Stevenson Plan had attempted between 1922 and 1928. The price per pound of rubber was 12.9 cents in 1934, rising to 19.4 cents in 1937 before falling back during the U.S. recession of 1938 to 14.7 cents. With the advent of war in Europe in 1939 it increased to 17.7 cents, then to 20.1 in 1940 and 22.4 in 1941.

Visiting Torréon in Mexico, Eisenhower noted that there were four guayule processing plants in the vicinity capable of producing annually about 5,360 long tons of rubber. The facility's manager told him the operation could be self-sustaining with rubber at 20 cents a pound. After touring the facilities of the IRC in Salinas, Eisenhower wrote in his diary that "we feel certain that with the return of normal prices in crude rubber, the production of guayule rubber will be started in many parts of the U.S." He was impressed with the capital-intensive processing technology, viewing it as reliable and effective.

In his report, however, despite his earlier diary observations, he was no longer optimistic that market forces by themselves would bring forth a large supply of irrigated guayule from independent farmers. Moreover, the market risks faced by the IRC made it unlikely that the company would undertake a major expansion on its own account, nor were there other companies in the U.S. with the experience in cultivation and processing that would likely do so in its stead. And he concluded that the United States could not rely on revival of a substantial supply of rubber from Mexican guayule due to the insecurity of property rights in that country and uncertainty about the success of efforts to reseed wild guayule.

These considered judgments lead him to propose government subsidization of guayule cultivation in the United States, listing seven reasons why this might benefit the nation. The first of course was that it would reduce dependence on Southeast Asian supplies that could be interrupted by war or restricted by cartelization. He

considered the employment benefits during a Depression of providing additional jobs for farmers, workers, and mechanics, and noted that in 1930 the U.S. was spending 200-300 million dollars annually to pay for rubber imports (more than on any other imported commodity). He commented on the benefits of shifting acreage away from crops like cotton, corn, and small grains that produced more than the U.S. needed toward the production of an input for which the country was almost entirely dependent on imports. And he noted that the IRC had several decades of experience harvesting and processing guayule, that the plant had been studied extensively, and that the semiarid regions most suited to its cultivation were not well suited to the cultivation of other crops. Finally, suggesting a relatively sophisticated understanding of economics, he observed that adding even 10 percent to the world supply of rubber would drive down the price of *hevea*, which would benefit the United States to the degree it continued to import.

He therefore proposed that the government subsidize 400,000 acres (about 25 miles square if in one block) of cultivated guayule. This would enable the annual production of about 71,400 long tons, some of which could be consumed immediately, with the remainder added to and sustaining a strategic reserve. He suggested four mechanisms by which the government might foster such cultivation. First, have the government plant and cultivate guayule directly. Second, impose a tariff on imported rubber, which then entered duty free. Third, offer public lands for guayule cultivation at a nominal fee. Fourth, provide a 15-year government commitment to buy all the natural rubber produced and milled in the United States, suggesting a price for standard smoked sheets of .30 a pound, with the government paying to the cultivator any amount by which the market price fell short of that guarantee. Different grades of rubber would be priced accordingly and Eisenhower had no objection if it turned out that other plants containing latex could be profitably cultivated on these terms.

Eisenhower's report vanished into oblivion, its journey to a final resting place speeded on its course by the collapse of rubber prices in the worst years of the Depression.

After Singapore was overrun in February 1942, however, the government had second thoughts, and three weeks later Congress passed the Emergency Rubber Act (March 5, 1942), sometimes known as the Guayule Act. The legislation authorized buyout of the IRC facilities, intellectual property, and acreage in Salinas, and a total of 50,000 acres in guayule on government owned or leased land, an authorization increased in panic to 500,000 acres in October 1942, following the release of the Baruch (Rubber Survey) Committee report. This would permit an estimated annual harvest of 80,000 LT a year.

These parameters are very close to those suggested in the original Eisenhower report. But it was too late. Guayule plants took four years to mature. Farmers pressured into Emergency Rubber Project contracts to grow guayule soon wanted out, so they could grow more profitable cash crops. Most of the acreage planted was eventually plowed under before it could yield much rubber (U.S. Department of Agriculture, 1946).

Thomas Edison, who spent the last four years of his life researching plant-based alternatives to *hevea*, was never a fan of guayule as an emergency rubber source for the same reason: the plant took too long to reach maturity. Had some version of Eisenhower's plan been implemented earlier, however, mature plants in large numbers might have been available in 1942. How much of a difference could that have made? Suppose 400,000 acres had been planted starting in 1935 and then harvested sustainably, with a fourth of the acreage processed and replanted every year, the rubber going into a stockpile rather than current consumption. Between 1939, when serious government stockpiling began, and the end of the war in 1945, this could have yielded an annual flow over a six-year period of 71,400 long tons a year, making unnecessary the production of 428,400 long tons of synthetic rubber. This could easily have complemented a more aggressive pre-Singapore program of importation, yielding a stockpile that would have obviated the need for *any* synthetic, again with the advantage that guayule, unlike GR-S, did not entail the time and labor milling penalty. It was close to a perfect substitute for *hevea* in most uses, and superior in some.

Synthetic Rubber

In 1939, when war broke out in Europe, it was not too late for stockpiling but almost too late for guayule. By March 1942 it was too late for either. Under these circumstances, a synthetic rubber program was unavoidable if the country was to survive the war. Such a program was under discussion by the Army-Navy Munitions Board beginning in early 1939. Representatives of Standard Oil (NJ) met with the Board repeatedly during that year, and sketched out a program that, with some modifications, reflected the design ultimately embarked upon.[24] The design and execution of that program has, like so much about the U.S. economic mobilization effort, been uncritically lionized. The underlying science was not new. As Whaley wrote in 1944, "The point to be understood is that synthetic rubber is no eleventh-hour miracle developed in response to the war emergency" (Whaley, 1944, p. 18). That said, there was very limited experience with some of the processes that stood at the center of Standard's blueprint, which relied exclusively on petroleum as the source for butadiene.

Decisions about the initiative had to be made in the face of uncertainty, and it is easy to criticize the evolution of policy after the fact, when one knows how history unfolded. There was, however, consensus ex ante that the risks of war with Japan were high, and, conditional on a state of war, that the probability of losing access to Southeast Asian rubber was even higher. For the synthetic rubber program a number of decisions look bad both in prospect and in retrospect.

This section of the paper will focus on two: first, the decision to design the program so heavily around the use of petroleum rather than alcohol as the precursor for the butadiene that would be copolymerized with styrene to

[24] For details, see testimony of F. A. Farish, President of Standard Oil (N.J.) to the Truman Committee (U.S. Senate, 1942, p. 4396).

make GR-S. Butadiene had no other commercial uses so there was little experience manufacturing it and no option of diverting existing production flows from less essential uses. The second is the more than a full year delay in beginning to build the butadiene plants after the basic design of the program had been set in November 1940. Supplying butadiene in large quantities was widely understood to be the most problematic part of the synthetic program, of far more concern than the copolymerization plants. At the time of Pearl Harbor, construction had begun on none of the butadiene plants.[25]

In 1939 Standard Oil of New Jersey began to press the government to consider a synthetic rubber program. The company deserves credit for having done so, because the government itself had no program, nor did it have the in-house technical expertise to design or evaluate one (Howard, 1947, p. 73). Many, including Jones and to some degree the President, were not persuaded that one was necessary or, if it was, whether it should receive government funding. That said, the design of the initiative was strongly influenced by the interests of oil companies, particularly Standard, in having the government lay the foundations for a synthetic rubber program that might or might not be profitable in the postwar period, but if it were, would provide a market for byproducts of crude oil refining. The emphasis on petroleum as the exclusive precursor for butadiene reflected that interest, but it did so at the cost of jeopardizing the more pressing national objective of winning the war. The design decisions, in the event, did not cause the war to be lost – but they made matters much dicier than they needed to be, even after March 1942, when the necessity of some synthetic rubber program became a given (Solo 1959, pp. 80-82).

Goodrich and Goodyear had experimented with synthetic rubber before the war, trademarking their products as Ameripol and Chemigum respectively. Standard viewed these as versions of Buna-N – a synthetic based on the copolymerization of butadiene with acrylonitrile rather than styrene.[26] Standard claimed that, through its patent exchange agreements with IG Farben, it had U.S. rights to this product, as well as GR-S – the U.S. nomenclature for what the Germans called Buna-S. Through legal pressure prior to Pearl Harbor Standard forced a wartime standardization on GR-S, a general-purpose rubber suitable for tire treads and carcasses, the end use for 70 percent of rubber. To make GR-S, one needed styrene, which was manufactured commercially, and butadiene, which was not, because it had no other commercial uses.

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[25] Solo (1959, p. 24) states unequivocally that in December 1941, "construction had started on not a single one of the essential butadiene plants." In September 1941, Rubber Reserve (in other words, Jones) ordered Standard Oil to stop engineering work on a planned government funded butadiene plant in Baton Rouge, LA. (Standard continued the engineering expense at its own expense) (Farish testimony, U.S. Senate, 1942, p. 4465). This is another instance of Jones's efforts to delay or stop the development of a synthetic rubber program. Fenberg misleads about pre-1942 progress on synthetic when he writes "After the Korean War, the synthetic rubber plants built before Pearl Harbor were finally put up for sale…" (2011, p. 584).

[26] Aside from styrene and acrylonitrile, no other copolymers for butadiene have been found suitable for making synthetic rubber.

Butadiene was a gas that could be obtained in multiple ways. The process preferred by Standard worked from isobutylene, a byproduct of its refineries. It could also be made from butane, or from naphtha, all of which could be byproducts of the distillation and refinement of crude oil. Butane is also abundant in natural gas. And finally, butadiene could be produced from industrial alcohol (ethanol) which could be obtained either from fermentation of plant material or synthesized from petroleum. The butadiene would then be copolymerized with styrene in a 3:1 ratio to make GR-S.[27]

Neither copolymerization nor additional manufacture of styrene was anticipated to pose serious problems, and they did not. The big question was butadiene, particularly because the process favored by Standard was untested. Yet the original design of the program was built entirely around the use of petroleum rather than ethanol as the feedstock. Once the program had been designed along this route, however, and in the absence of an alternative, its execution was unconscionably delayed, and once again, Jones' skepticism about the severity of the threat posed by the possibility of rubber cutoff played a big role.

Timeline of the Synthetic Rubber Program in the United States

1/12/1939 Representatives of Standard Oil (N.J.) begin meetings and correspondence with the Army Navy Munitions Board (ANMB) about the possibility of a synthetic rubber program (U.S. Senate, 1942, pp. 4384, 4396).

10/9/1939 Standard Oil reps meet with ANMB, argue that a synthetic industry capable of producing a general-purpose rubber was essential for U.S. national security, and that they were prepared, with government support, to lead an industry effort to create one (Solo, 1959, p. 6).

11/19/1939 Standard meets again with ANMB, describes "cooperative plan" to develop synthetic rubber (the Big 4 rubber companies along with Standard would participate together in developing a copolymerization plant; Standard would supply the butadiene). Standard wants either some subsidy or a guaranteed buyer for synthetic rubber products. ANMB says no government funds would be offered, but they would provide a letter of support, thus giving SONJ some protection against the antitrust laws.

1/1940 Full plan presented; discarded three months later because of fears it would not survive antitrust challenge. SONJ then proposes a cross licensing scheme between the rubber companies and SONJ in which royalties would have been shared by all parties with most going to SONJ. Although a government-run program, in a sense it would have been a sort of producers' cooperative, sponsored and funded by the government. Plan discarded in April due to fears it would also not survive antitrust challenge.

5/28/1940 National Defense Advisory Committee (NDAC) established. Edward R. Stettinius Jr. head of its Raw Materials Division, assisted by William Batt. forms Francis Committee to develop rubber policy.

7/17/1940 Francis committee recommends a synthetic rubber program capable of producing 100,000 tons/yr. This number is obtained by polling companies and asking how much they would be interested in producing.

[27] Synthetic rubber is a bit of misnomer, since the chemical composition differs from natural rubber. It can be more accurately be described as a synthetic elastomer.

9/12/1940 Letter from Stettinius to FDR outlines severity of the threat of rubber cutoff, emphasizing lead times of 18 months to build synthetic rubber plants.

9/1940 Francis committee members Edward Stettinius and William Batt (his assistant) approach Jesse Jones (National Loan Coordinator/RFC) to discuss possible funding, based on their letter to the President. Batt testified in 1942 that there was a "difference of opinion" between Stettinius and Batt, on the one hand, and Jones, and that Jones found their proposal "reckless". Jones responded that he was skeptical of the need for (that) much synthetic rubber capacity, that the President shared his view, and if there was to be any federal support, the oil and rubber companies should deal directly with Jones. (U.S. Senate, 1942, pp. 4285, 4287).

11/25/1940 Stettinius memorializes that responsibility for development of synthetic rubber, given the "unsatisfactory" earlier meeting, had, at Jones' request, been transferred from NDAC to the RFC. He also notes that "There has been some question raised as to the speed with which the arrangements for the production of synthetic rubber are progressing" (U.S. Senate, 1942, p. 4358).

11/1940 The NDAC proposal for a 100,000 ton program is formally submitted to Jones. Jones rejects it, instead asking what might be done with $25 million, which would fund perhaps a 40,000-ton program.

1/15/1941 SONJ proposes to build a plant to produce butadiene from oil, financed 75 percent by RFC, 25 percent by Standard. "Nothing came of this proposal" (U.S. Senate, 1942, p. 4463).

1/1941. Roosevelt replaces NDAC with the Office of Production Management.

2/1941 *Jones cancels the entire synthetic rubber program*.

3/28/1941 In response to protests, the RFC proposes that each of the big four rubber product manufacturing companies build a 2,500 ton (annual) capacity copolymerization plant for demonstration purposes, to get experience with the processes. But there is no provision for the construction of butadiene plants, although it is understood that butadiene is the big question mark in the program.

5/9/1941 William Knudsen (Director of the Office of Production Management) writes to Jones telling him (ordering him?) to proceed with a 40,000-ton program, saying that that might ultimately be increased to 100,000 or 200,000 tons. Jones agrees to a 40,000 LT program.

9/16/1941 Jones, working through Stanley Crossland at the RFC, orders Standard Oil (NJ) to cease engineering work on a planned government funded butadiene plant in Baton Rouge. SONJ continues planning at its own expense. W. A. Farish, President of SONJ, testified in 1942 that he did not know the reason for the cancellation At the same hearings Jones testified they ordered cancellation because "we found we could buy the raw material without building the plant, that we didn't need the plant." He offered no details on the alternate source (U.S. Senate, 1942, pp. 4478, 4540, 4621).

12/7/1941 Pearl Harbor attacked.

1/2/1942 War Production Board (WPB) created, supplants Office of Production Management

1/7/1942 WPB orders whiskey distilling industry to shift 60 percent of capacity to production of industrial alcohol.

1/12/1942 WPB announces target of 400,000 tons/yr synthetic rubber program, a ten-fold increase.

3/1942 WPB increases program again, with 700,000 tons/yr GR-S now targeted; almost all butadiene to come from petroleum; 40,000 tons from alcohol, but most of the alcohol to be synthetically produced from petroleum.

3/1942 Gillette Committee hearings begin. Agricultural interests and farm state senators press to shift from petroleum to plant-based ethanol (alcohol) as the butadiene precursor.

5/24/1942 WPB raises alcohol portion of GR-S to 220,000 tons/yr, at expense of planned butane to butadiene plants, due to claimed discovery of previously overlooked alcohol distilling capacity.

7/22/1941 Rubber Supply Act passed by both houses of Congress; calls for synthetic rubber from alcohol produced from "agricultural or forest products."

8/6/1942 Roosevelt vetoes Rubber Supply Act, sets up Rubber Survey (Baruch) Committee

9/1942 Baruch Committee Report recommends GR-S target of 845,000 tons of capacity, appointment of rubber 'czar', nationwide gas rationing, 35 MPH speed limit.

9/26/1942 Jeffers, the rubber 'czar', imposes by executive order 35 MPH nationwide speed limit, based on study showing tires last four times longer at that speed than at 65 MPH (Flamm, 2006, p. 79).

12/1/1942 By executive order Roosevelt imposes nationwide gas rationing to save rubber.

2/1943 First alcohol butadiene plant online. Capacity: 80,000 tons/yr. Output through 6/1944: 151,190.

4/1943 First petroleum butadiene plant online. Capacity: 30,000 tons/yr. Output through 6/1944: 22,210

5/1943 Petroleum butadiene plant online. Capacity: 15,000 tons/yr. Output through 6/1944: 20,600

7/1943 Alcohol butadiene plant online. Capacity: 80,000 tons/yr. Output through 6/1944: 95,380.

8/1943 Alcohol butadiene plant online. Capacity: 60,000 tons/yr. Output through 6/1944: 74,800

2/1944 Petroleum butadiene plant online. Capacity: 100,000 tons. Output through 6/1944: 18,180

4/1944 Petroleum butadiene plant online. Capacity: 50,000 tons. Output through 6/1944: 3,580

8/1944 Petroleum butadiene plant online. Capacity: 55,000 tons. Output through 6/1944:

Sources: 1939-42: U.S. Senate (1942), Solo (1959); 1943-44: United States War Production Board (1944, Table II, p. 4).

The first part of this timeline documents the role that Jones and the RFC played in delaying the development of plants to produce butadiene from petroleum and in general acting to block or slow down the development of a synthetic rubber program, until overruled by Knudsen at the Office of Production Management. We also see the frantic increases in the targeted size of the program starting in early 1942, as the full scope of the impending disaster became apparent. The timeline also documents the belated willingness, under the WPB, to allow some of the butadiene production to come from plants using ethanol. The first butadiene plant was not completed until April 1943. All three of the big alcohol plants opened that year, and they produced far more than their rated annual capacity. Of the five petroleum-based butadiene plants, the three largest did not begin production until 1944, and consistently produced below their rated capacity.

Of the total 425,360 LT of butadiene produced up through and including June 1944, the month of the D-Day invasion, the lion's share, 321,370 LT was produced by the alcohol-based plants, which were completely absent

in the initial program design. The four butylene-based petroleum plants listed on the timeline provided just 64,570 LT. The enumeration does not include butadiene from nine other generally smaller government owned plants making butadiene from naphtha and gas oil, from naphtha and butylene, or from butane. They contributed the balance of 39,430 LT (United States War Production Board, 1944, Table II, p. 4).

Given earlier inaction or inadequate action on stockpiling or guayule, the delays in butadiene production are responsible for making near impossible the execution of a successful cross channel invasion in 1943, as originally planned. And without alcohol- based butadiene, it's hard to see how D-Day could have gone forward in June 1944. In retrospect, it's not clear that petroleum-based butadiene was needed at all to win the war. To be sure, butadiene from butylene was cheaper in the long run because, even though plants using this process were much more expensive to construct, required much more complex engineering, and relied on untested processes, the feedstock (petroleum) was ultimately cheaper. Due to huge agricultural surpluses accumulated during the Depression, however, the opportunity cost of ethanol was far lower during the war years, an advantage augmented by the much lower capital requirements of the process using it to produce butadiene, and its lack of competition with the aviation fuel program.

The U.S. government ended up stablishing the foundations for a commercially successful synthetic rubber industry in the postwar period, one using petroleum as the principal feedstock, as Standard intended. Given that synthetic rubber was needed during the war, it would have been cheaper and faster to have focused from the outset on ethanol as the feedstock. That this did not happen is largely on Standard. Whether petroleum or ethanol was to be the feedstock, however, construction on the butadiene plants should have started much earlier. The delays in doing so are largely on Jones.

The Economic Effects of the Rubber Famine

On May 28, 1939, Cordell Hull, U.S. Secretary of State, gave a concise explanation of the economic effects of losing access to strategic and critical raw materials. Aside from the option of stockpiling, Hull covered almost all the basics:

> Some of the things we now purchase in other countries we can perhaps produce domestically, but at a much higher cost in terms of economic effort than is required for the production of exports with which we now buy these foreign products. For others we can develop substitutes of inferior quality, and again at a relatively higher cost. Still others we cannot produce at all, and if we did not import them, we would have to do without them altogether. In each case, the net result would be a decline of our national efficiency and consequently an inexorable lowering in the level of satisfaction of our people's wants. (Hull, cited in Marshall, 1985, p. 1).

The rubber famine's negative impact on productivity (efficiency) operated through multiple channels, both within the manufacture of rubber products and in the expanding industry producing inputs domestically. Synthetic rubber (GR-S) was an imperfect substitute for natural, lacking its plasticity and tack. When flexed and allowed to return to its original shape it generates much more heat than natural (Whaley, 1944, pp. 18, 28). The manufacture of almost all products, especially airplane and heavy truck tires, required blending synthetic with natural, or in some cases could use no synthetic at all, which is why the stockpile of natural rubber remained so critical. In the final stage of fabrication (where natural and synthetic was blended and then vulcanized), mixtures of synthetic and natural rubber took longer to mill and required up to a third more labor time as compared with all natural.[28] The Baruch report made this point, and as a consequence anticipated a shortage of milling capacity in 1943 and 1944, which is precisely what happened. The constraint began to bind in January 1944 and continued through August, placing a hard cap on the total amount of rubber, synthetic and natural, that could be processed into final products. In the remainder of 1944, shortages of labor limited rubber product manufacture, as did a critical shortage of carbon black in the first half of 1945 that forced a cutback from seven to six days of weekly production (Wendt, 1947, p. 222-3). Any uptick in production intermittency reduced total factor productivity by reducing capital productivity, since the capital service flows continued mostly uninterrupted, independently of the intensity of utilization.[29]

Even after the changes made in 1942, the design of the synthetic program still heavily favored petroleum rather than alcohol as the feedstock for the butadiene that would be copolymerized with styrene to make GR-S. Priority claims on boilers, valves, pumps, heat exchangers, metals (particularly stainless steel, which needed chromium and nickel to manufacture), and other construction material and manpower were far in excess of what would have been necessary had alcohol been more prominently featured as a butadiene precursor. There was another problem of pursuing the petroleum route to butadiene: it conflicted with the aviation fuel program, which needed toluene to raise octane. Isobutylene (sometimes called butene) from refinery operations could be used to make either butadiene or toluene.

In most cases the rubber program, widely acknowledged as the number one production problem during the war, had priority access to subassemblies and materials, a preference which the petroleum administrator for war (Harold Ickes) bitterly resented and sometimes overcame (Wendt, 1947, p. 212). The more timely completion of the alcohol based plants likely reflected the reality that capital requirements were lower and the engineering less

[28] Wendt suggests that the milling penalty for working with blended GR-S/natural might be as low as 10 percent (Wendt, 1947, p. 222). This is probably based on the supposedly expert technical advice given to the Rubber Survey Committee in 1942 that just 10 percent of total rubber requirements for final products would need to be natural. This was far too optimistic. At the end of the war, according to Solo, the actual percentage was about thirty percent, and for truck and airplane tires it was one hundred percent (Solo, 1959, p. 84). After the war, according to Solo, it was forty percent. See also Garvey (1941, p. 51) on the milling penalty associated with both Buna S and Buna N.

[29] See Field (2022, ch. 2) for discussion.

complex, placing less strain on supplies of construction materials, subassemblies, and specialized materials. Conflict with the aviation fuel program also probably played a role in prioritizing delivery of the more limited capital requirements for the alcohol plants and delaying completion of the petroleum-based butadiene plants.

If the rubber program obtained access to materials or construction labor it could have done without, for example by focusing more on ethanol, it starved other sectors of inputs. If it failed to get the inputs it needed, conditional on the design of the program, synthetic rubber supplies were delayed. In either case the result could be production intermittency, an affliction which dragged down productivity and product completion rates throughout the economy. The rubber famine also led directly to the imposition of a 35-mph speed limit and nationwide gas rationing in a country which, in the aggregate, was awash in petroleum. This made it more difficult for people to get to work, contributing to absenteeism, and impacted the distribution of products by truck.

Prior to the war the country enjoyed cheap and reliable delivery to its shores of hundreds of thousands of tons annually of Southeast Asian natural rubber. In response to the cutoff, the production of synthetic required building 51 plants at a cost of about $700,000,000. At the peak of the program in 1944 and 1945, operating costs for materials, utilities, labor, and other expenses were approximately $2 million a day, meaning an annual outlay for operation almost equal to the plant construction costs (Jones, 1951, p. 415). Synthetic rubber yielded, at great expense, an imperfect substitute for natural that required additional labor in final product fabrication.

The Rubber Survey (Baruch) Report (September 1942) repeatedly stressed the severe threat posed by the rubber famine. It emphasized how critical the availability of synthetic rubber would be in 1943, and planned/promised 400,000 long tons of GR-S. Because of the delayed completion and poor initial performance of the petroleum-based butadiene plants (the processes, unlike those for alcohol, were largely untested), less than half that amount was actually delivered. The Soviet victories at Stalingrad and Kursk gave the Allies breathing space, allowing delay of the cross-channel invasion, which irked the Soviets but was welcomed by the British. In the event, rubber shortages that year probably made a successful cross channel invasion impossible. During the following year (1944) synthetic production began to approach the expanded GR-S targets set during the panicked months of 1942. Now the complementarity between natural and synthetic began to bind, and as the natural rubber stockpile shrank to dangerously low levels, unusable stocks of synthetic accumulated.[30] From the standpoint of national security, the program both overbuilt and underdelivered during the war.

We can put some statistical flesh on the economic scaffolding contained in Secretary of State Hull's remarks. A rough estimate of the impact on labor productivity in rubber manufacturing can be obtained by dividing U.S.

total rubber consumption in long tons (synthetic and natural) by the number of FTEs in the subsector. This physical productivity statistic moves from 4,133.7 in 1941 to 2,087.0 in 1942, 2,180.9 in 1943, 2,974.0 in 1944 and 3,660.1 in 1945 (U.S. Department of Commerce, 1966, table 6.4, line 22, p. 103; U.S. War Production Board (1945b, p. 95).[31] 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 a 35 mph speed limit, as well as the component and raw material shortages imposed on other sectors by the construction and materials requirements resulting from the design of the program, meant that the negative productivity impacts were not limited to the rubber subsector. The widespread perception of the development of the synthetic rubber program as miraculous and almost effortless should be rejected.

The extent to which rubber dominated U.S. resource concerns during the first half of the twentieth century is, for many, hard to fathom from the vantage point of the first half of the twenty first century. Just as oil has exercised an outsized influence on American diplomacy and foreign policy in recent decades, such was the case earlier with rubber. President Harding, for example, encouraged by his good friend Harvey Firestone, and working through his Secretary of Commerce Herbert Hoover, pushed back in the 1920s against the Stevenson Plan that aimed to cartelize world rubber (Mittman, 2021, pp. 23-25).[32] Growers in the Dutch East Indies failed to participate, in part due to American pressure.

Finally, for those still skeptical that the rubber shortage really was that serious, the degree to which the famine permeated and affected life in the United States during the war is vividly illustrated in notes that British journalist Alistair Cooke recorded during a cross country trip he took in 1942. Beginning in Washington, D.C., and proceeding to the West Coast via a southern route, and then moving north along the West Coast, he returned via a more northerly route ending up in New England, having traversed 35 states. The record of his journey was published in 2006, two years after his death, as *The American Home Front, 1941-1942*. Rubber shortage is a leitmotiv in the book, referenced multiple times in his narrative.

After obtaining his press credentials, Cooke is told to apply to the Office of Price Administration for access to tires and appears before his newly formed local ration board: "All that remained… was to convince a board of fellow citizens that I had a better right than they to four new tires… The ration board in New York was

[31] The intent here is to get a rough measure of physical labor productivity in rubber products manufacturing. We are assuming that data on rubber consumption reflects rubber (synthetic or natural) ultimately embodied in final products. Rubber products manufacturing would likely not include either the plants producing butadiene or styrene or the plants copolymerizing the two to make GR-S. Most likely these would be included under Chemicals and Allied Products. Some of the decline in physical productivity likely reflects product mix effects but, some would also reflect the milling penalty imposed by having to work with blended synthetic and natural rubber inputs.

[32] Other rubber barons, more heavily indebted to New York banks who were relying on higher rubber prices to enable Britain to pay off its WWI war debts to them, were more sanguine about the plan, even if it meant higher prices for American consumers.

sympathetic but could find no privileged category to fit me in. I went on trying to get some tires by every legal means…" In the end he "managed to pick up some secondhand tires and, after a great deal of wrangling with a tire inspector, had them retreaded" (Cooke, 2006, p. 26).

He next mentions rubber, or the lack of it, as he proceeds through the South. Cooke describes driving past automobile junkyards, where "[t]here are hundreds of rusty and decrepit automobiles looking, as usual, like an anthology of old accidents…. But you notice that not one of them has an inch of rubber… every single car is naked of its tires" (Cooke, 2006, p. 60).

Moving through oil country in Texas, he embarks on a sophisticated discussion of the design of the synthetic rubber program and its impact: "the rationing of rubber for civilians has greatly cut the amount of gasoline that the nation can fairly use. What the government demands from the industry is certain refined products, especially toluene for aviation gasoline and butadiene for synthetic rubber. These were formerly minor special products. None of them calls for much crude oil… Yet… these special products come from the gases produced in normal distillation processes, and to secure them you have to refine ordinary crude oil. So the government's needs…call for even more motor fuel gasoline than usual, which the normal consumer is to be denied. Consequently, the oil tanks are full to overflowing… Neither the consumer nor the bewildered gas station operator can quite understand the connection between this abundance and this rationing." Keep in mind that almost the entirety of Cooke's trip takes place before Roosevelt, by executive order, required nationwide gas rationing and a nationwide 35 mph speed limit aimed at reducing tire wear on the nation's existing stock of vehicles came into force. Rationing on the Eastern Seaboard (PAW District 1) came earlier, the result of German U-Boat warfare along the Atlantic and Caribbean Coasts.[33]

In Houston Cooke mentions the sudden overcrowding of buses. "This is uncomfortable anywhere, but in the South means an irritating crowding of the Jim Crow customs" (Cooke, 2006, pp. 97-98).

He interrupts his car travel and proceeds by train through Arizona and the Imperial Valley to Los Angeles. A few mornings later, he buys a second car in Pasadena. "The salesman who finally sold me was in a state of high excitement for 48 hours after hearing that a visitor wanted to buy a car for no other reason than to drive around the country. Throughout his subsequent negotiations, he regarded me as an amiable madman. His storeroom was a funeral parlor. The cars lined up there like so many coffins…. About once a month, somebody would come in on the pretense of wanting to buy a car and then sneak around prodding the tires and not even bother to look at the engine. These were pestiferous middlemen looking for cars with good rubber and making heavy profits on the immediate resale. I was obliged to share this obsession for good rubber, and in the end settled for a make I did

[33] Those shortages represented a regional distribution problem, one that was quite serious, but it did reflect a shortfall in overall production (see Field, 2022, ch. 4).

not want that had four solid retreaded tires with about 15,000 miles of rubber still left on them" (Cooke, 2006, pp. 125-126).

In California, Cooke takes a side trip from Los Angeles to visit the internment camp at Manzanar. He observes and comments on the work of Japanese internees grafting and improving the drought resistance of guayule, describing how they have already built a lathe house and planted 25,000 cuttings of guayule. Cooke notes that to the degree these efforts are successful they will benefit U.S. soldiers fighting the internees' Japanese cousins (Cooke, 2006, p. 147).

Finally, he visits Salinas, where the government has taken over the former operations of the Intercontinental Rubber Company. and finds optimism about the wartime Emergency Rubber Program: "Salinas is proud of its lettuces, but prouder for the duration of its guayule rubber, which is bouncing from its small government owned mill at the modest rate of 40 tons a week. The man sitting at the counter with me sneered at the marvels of synthetic. "Sure, they can produce barrels of it from grain alcohol, but it falls into shreds if you run it over 30 miles a year. The Germans have been plugging away for decades, but the only place they can use it is on supply trucks. Give us a year or two and you're going to hear plenty about this town. The whole southwest will be growing guayule" (p. 156). Or not.

Conclusion

A study of the origins and consequences of the U.S. rubber famine provides additional insights into the causes of U.S. wartime productivity decline and has broader relevance. A repeated theme in the political and bureaucratic history of the Second World War are calls for an all-powerful czar to take charge of some portion of or the entirety of the war planning process. Jones never became or claimed to be that czar, but because of his close ties to Roosevelt and influential Congressmen, and the multiple positions he occupied, he became in essence the head of the federal government's development bank for the war effort, with more immediate control over the power of the purse than Congress.

Jones was experienced in business and finance, and politically astute. But he lacked the technical background to make decisions with far reaching implications for the U.S. ability to wage war. Ultimately, Roosevelt had to bring in Baruch, Conant, and Compton to try and clean up the rubber mess for which Jones and Roosevelt himself were in part responsible. From the vantage point of September 1942, Baruch, Conant, and Compton identified rubber as the number one production problem for U.S. war mobilization. The members of the Rubber Survey Committee stated clearly in their report that mistakes had been made. But at that point the basic structure of the program had been set, and although the committee made a number of recommendations, mostly implemented, they concluded that it was too late to change the basic design. Their description of the severity of the challenge reflected a mood bordering on panic.

This claim may seem surprising. A celebratory imperative emerging out of the evident victory of the United States and its allies has dulled our critical sensibilities in thinking about the economic history of the war, and this aspect of it is no exception. The rubber famine has largely faded from U.S. consciousness, and some may not even be aware that the wartime rubber shortage really was a very serious thing. For those who know more of the history, skepticism persists because of two related beliefs, both false: first, that the synthetic rubber program was almost effortlessly willed into existence -- the terms miracle and miraculous often feature in discussions of it -- and second, that once it was available, synthetic was an almost perfect substitute for natural. Both claims are simply wrong. Synthetic rubber had to be blended with natural in the manufacture of almost all products – imposing a time and labor cost milling penalty – and for some products like airplane tires, only natural could be used.

By 1944 GR-S was finally available in quantity, but at that point the rapidly dwindling stockpile of natural rubber become the binding constraint on overall rubber product manufacture. The frantic increases during 1942 in GR-S program targets combined with the reliance on petroleum-based butadiene and the delays in building the plants to produce the gas led to a program that underdelivered in 1943 and, in terms of the absorptive capacity of the economy, overdelivered in 1944. In the process of overbuilding capacity using an unnecessarily expensive process, the program sat on or consumed valuable resources needed by other war programs.

The 1944 report of the Rubber Development Corporation emphasized that the increased availability of synthetic in that year did not by any means alleviate the rubber famine: "the need for natural rubber under these circumstances remains as acute as ever, and every effort must be continued to assure that every possible ton will be secured from the sources available to us" (1944, p. 22). In 1945 the War Production Board forecast that in the event of an invasion of Japan, the U.S. would simply run out of natural rubber in 1946 (U.S. War Production Board, 1945b, p. 94).

The frenzied buying and stockpiling of natural rubber by the United States at the outbreak of the Korean War provides additional testimony to the imperfect substitutability of synthetic for natural rubber and underlies again how critical was the size of the natural rubber stockpile in April 1942. At the start of the Korean conflict, the Preparedness Subcommittee of the Senate Committee on Armed Forces, chaired by Lyndon Baines Johnson, stated that "we must stockpile and conserve rubber as if our very lives depended upon it because that may be the reality" (Langdon, 1952, p. 146). Johnson made this statement despite the fact that the U.S. government then possessed a large synthetic capability, with abundant access to the necessary feedstocks, all still entirely under its own control.

Taking a broader view, the history of rubber before and during the war highlights the benefits and risks for the United States of reliance on global supply chains. The basic tradeoff – one evident during the pandemic in

choices involving vaccine manufacturing supplies and personal protective equipment (PPE) and immediately after it in the supply shortages due to scarcity of computer chips -- was between the risks of depending on cheap foreign sourcing that might not always be available and the expense and efficiency penalties of stockpiling or developing or retaining standby or operational raw material or manufacturing capacity via subsidies or protection.

It is also an object lesson in what happens when powerful leaders in (or outside of) government rely excessively on their own judgement to make decisions with far-reaching implications.

U.S. vulnerability to rubber cutoff during the war was unavoidable. Both before and after U.S. entry, however, that vulnerability could have been addressed in ways less damaging to both economic efficiency and national security.

References

Alchian, Armen. 1963. "Reliability of Progress Curves in Airframe Production." *Econometrica* 30 (October): 679-693.

American Chemical Society. 1998. "United States Synthetic Rubber Program, 1939-1945."

Army Navy Munitions Board, 1940. *The Strategic and Critical Materials*. Washington: Army Navy Munitions Board, 1940.

Arrow, Kenneth. 1962. "The Economic Implications of Learning by Doing." *Review of Economic Studies* 29 (June): 155–73.

Ball, J.M. 1947. *Reclaimed Rubber: The Story of an American Industry*. New York: Rubber Reclaimers Association, Inc.

Caldwell, Bill. 1942. "Rubber on the Rebound." *Esquire* (August): 46, 112-13.

Cooke, Alistair. 2006. *The American Home Front, 1941-42.* New York: Atlantic Monthly Press.

Fenberg, Steven. 2011. *Unprecedented Power: Jesse Jones, Capitalism, and the Common Good.* College Station: Texas A&M Press.

Field, Alexander J. 2003. "The Most Technologically Progressive Decade of the Century," *American Economic Review* 93 (September): 1399-1414.

_____. 2011. *A Great Leap Forward: 1930s Depression and U.S. Economic Growth*. New Haven: Yale University Press.

_____. 2022. *The Economic Consequences of U.S. Mobilization for the Second World War*. New Haven: Yale University Press.

_____. 2023. "The Decline of U.S. Manufacturing Productivity between 1941 and 1948." *Economic History Review*. https://onlinelibrary.wiley.com/doi/10.1111/ehr.13239.

Finlay, Mark R. 2009. *Growing American Rubber: Strategic Plants and the Politics of National Security*. New Brunswick: Rutgers University Press.

Flamm, Bradley, J. 2006. "Putting the Brakes on 'Non-Essential' Travel: 1940s Wartime Mobility, Prosperity, and the US Office of Defense Transportation." *Journal of Transport History* 27 (March): 71-92.

Garvey, B.S. 1941. "Synthetic Rubber." *The Scientific Monthly* 52 (January): 48-55.

Gemery, Henry A. and Jan S. Hogendorn. 1993. "The Microeconomic Bases of Short-Run Learning Curves: Destroyer Production in World War II." In Geoffrey T. Mills and Hugh Rockoff, eds., *The Sinews of War: Essays on the Economic History of World War II*. Ames: Iowa State University Press, pp. 150-165.

Harp, Stephen L. 2016. *A World History of Rubber: Empire, Industry, and the Everyday*. Chichester:

Wiley/Blackwell.

Herbert, Vernon and Attilio Bisio. 1985. *Synthetic Rubber: A Project that Had to Succeed*. Westport, CT: Greenwood Press.

Holt, Daniel D. and James L. Leyerzapf, eds. 1998. *Eisenhower: The Prewar Diaries and Selected Papers.* Baltimore: The Johns Hopkins University Press.

Howard, Frank. 1947. *Buna Rubber: The Birth of an Industry.* New York: Van Nostrand.

Ilzetzki, Ethan. 2023. "Learning by Necessity: Government Demands, Capacity Constraints, and Productivity Growth." Working Paper, dated January 9.

Janeway, Eliot. 1939. "The Americans and the New Pacific." *Asia* 39 (February): 109-113.

Jones, Jesses. 1951. *Fifty Billion Dollars: My Thirteen Years with the RFC (1932-1945).* Written with Edward Angly. New York: Macmillan.

Lafond, F., Greenwald, D. & Farmer, J.D. (2022). 'Can Stimulating Demand Drive Costs Down? World War II as a Natural Experiment'. *The Journal of Economic History* 82 (September): 727-764

Langdon, William R. 1952. "Malaya's Rubber and Tin." *Current History* 23 (September): 144-149.

Marshall, Jonathan. 1995. *To Have and Have Not: Southeast Asian Raw Materials and the Origins of the Pacific War*. Berkeley: University of California Press.

Mittman, Gregg. 2021 *Empire of Rubber: Firestone's Scramble for Land and Power in Liberia.* New York: The New Press.

Neeleman, Gary and Rose Neeleman. 2017. *Rubber Soldiers: The Forgotten Army that Saved the Allies in WWII.* Atlglen, PA: Schiffer Military History.

Neer, Robert M. 2013. *Napalm: An American Biography*. Cambridge: Harvard University Press.

Nelson, Donald M. 1946. *Arsenal of Democracy: The Story of American War Production*. New York: Harcourt Brace Jovanovich.

Olson, James S. 1988. *Saving Capitalism: The Reconstruction Finance Corporation and the New Deal, 1933-1940.* Princeton: Princeton University Press.

Rockoff, Hugh. 2000. "Getting in the Scrap: The Salvage Drives of World War II." Working Paper, March 15.

Roth, Frank L. and William L. Holt. 1944. "Measuring the Rate of Wear of Tire Treads." *Journal of Research of the National Bureau of Standards* 32 (February): 61-65.

Scott Kemmis, Don and Martin Bell. 2010. "The Mythology of Learning-by-Doing in World War II Airframe and Ship Production." *International Journal of Technological Learning, Innovation, and Development* 3 (1): 1-35.

Solo, Robert A. 1959. *Synthetic Rubber: A Case Study in Technological Development under Government Direction*. United States Congress: Senate. Committee on the Judiciary. Subcommittee on

Patents, Trademarks, and Copyright. Washington: Government Printing Office.

Thornton, Rebecca and Peter Thompson. 2001. "Learning from Experience and Learning from Others: An Exploration of Learning and Spillovers in Wartime Shipbuilding." *American Economic Review* 91 (December): 1350-1368.

Timmons. Bascom N. 1956. *Jesse H. Jones: The Man and the Statesman.* New York: Henry Holt.

Tuttle, William M. Jr. 1981. "The Synthetic Rubber "Mess" in World War II." *Technology and Culture* 22 (January): 35-67.

United States Army Service Forces, 1945. *Annual Report of the Director*. Washington: Government Printing Office.

United States Department of Agriculture. 1946. *Emergency Rubber Project: A Report on our Wartime Guayule Rubber Program.* Los Angeles, CA. Typescript dated December 1946.

United States Department of Commerce. 1952. *Materials Survey: Rubber*. Compiled for the National Security Resources Board. December. Washington, D.C.: Government Printing Office.

_____. 1966. *The National Income and Product Accounts of the United States, 1929-65*. Washington: Government Printing Office.

United States Rubber Development Corporation. 1944. "Report of the Operations of Rubber Development Corporation, February 23, 1943 to August 31, 1944." Typescript dated September 20. Washington, Rubber Development Corporation.

United States Rubber Reserve Company. 1945. *Report on the Rubber Program, 1940-1945*. Washington: Rubber Reserve Company.

United States Senate. 1942. *Hearings before a Special Committee Investigating the National Defense Program*. *Part II. March 5, 24, 26, 27, 31, April 1, 2 3, 7, 1942. Rubber.* Seventy-Seventh Congress. Washington: Government Printing Office.

United States Special Committee to Study the Rubber Situation. 1942. *Report of the Rubber Survey Committee*. Washington, D.C.

United States Tariff Commission. 1940 *Crude Rubber: A Brief Summary of the Current Situation with Special Reference to the Effects of War Conditions on United States Imports*. Washington, D.C.

United States War Production Board. 1944. *Special Report of Office of the Rubber Director on the Synthetic Rubber Program: Plant Investment and Production Costs*. Bradley Dewey director. Washington, D.C. Dated August 31.

_____. 1945a. *Report of the Special Director of Rubber Programs to the War Production Board*. Dated June 25. Washington: Government Printing Office.

_____. 1945b. *Wartime Production Achievements and the Reconversion Outlook: Report of the Chairman*. Washington: Government Printing Office.

Van Harmelen, Jonathan. 2021. “The Scientists and the Shrub: Manzanar’s Guayule Project and Incarcerated Japanese American Scientists.” *Southern California Quarterly* 103 (Spring): 61-98.

Whaley, W. Gordon. 1944. “Western Hemisphere Natural Rubber.” *Torreya* 44: 17-29.

_____. 1948. “Rubber: The Primary Sources for American Production.” *Economic Botany* 2 (Apr – Jun): 198-216.

White, Gerald T. 1980. *Billions for Defense: Government Financing by the Defense Plant Corporation during World War II.* University of Alabama Press.