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ABSTRACT

Carbon intensity from fossil fuel use in the United States economy peaked in 1917. World War I ended, and the Spanish Flu pandemic broke out one year later in 1918. This paper contends that these events, coupled with associated turmoil in the domestic coal industry, were largely responsible for the turning point in carbon intensity. It is instructive to consider that geopolitics, labor markets, and public health at the time of peak carbon intensity bear relevance to the global economy from 2019 to the present. Interventions in markets intended to mitigate detrimental consequences of pandemic and war may induce ancillary impacts for long-run climate change and environmental quality.

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The carbon intensity of the United States (U.S.) economy[1] exhibits a sharp and unambiguous peak in 1917. (See figure 1.) This was a time in world history that is notable for at least two reasons: World War I (WWI) ended, and the Spanish Flu broke out one year later in 1918. This paper contends that these events, coupled with (not unrelated) turmoil in the domestic coal industry, were largely responsible for the turning point in carbon intensity. The paper gathers the data necessary to characterize fossil-carbon intensity as well as real wages and Gross Domestic Product (GDP) from 1800 to 2020. The empirical analysis documents and explores potential causes for notable structural breaks in these series. Additionally, differential patterns in wage and GDP data in the years immediately following 1918 are examined at some length. Trends during this period bear direct relevance to labor conditions in the mining sector, the output from which drives top-line carbon intensity. The paper concludes by drawing parallels to the current geopolitical, labor, and public health contexts that exhibit striking similarities to those at the time when U.S. carbon intensity peaked.

The primary data inputs for this analysis are the nominal GDP series from 1800 to 2020 (Williamson, 2022), a GDP deflator (Williamson, 2022), and hourly wages of production workers (Officer and Williamson, 2022). Detailed data on wages in the mining and manufacturing sectors are obtained from the Federal Reserve (BLS, 1934; 1946; FRED, 1960; 2022).

The carbon emission series is spliced together from a variety of sources. From 1800 to 1950, carbon emissions are derived from annual energy use statistics (by major fuel source – coal, crude oil, and gas) provided by Schurr et al., 1960. Energy use data, again by fossil fuel, from 1970 to 2010 is provided by the U.S. Department of Energy SEDS databases (USDOE, 2022). From 1950 through 1970, emissions data are provided by the USDOE's Annual Energy Review (USDOE, 2012). The final decade of data is drawn from the U.S. Environmental Protection Agency's (USEPA) emissions inventories (EPA, 2022). For the years 1800 through 1950, and from 1970 through 2010, emission factors for the major fossil fuels

[1] Because of data constraints in the 19th century, carbon intensity is defined as total carbon dioxide (CO_2) emitted from fossil fuel combustion divided by Gross Domestic Product (GDP).

are used to convert energy consumption to emissions[2]. Carbon intensity is then calculated at the ratio of tonnage to the dollar value of real GDP as shown in (1).

$$I_t = \left(CO_{2,t} \middle/ \left(GDP_t \middle/ D_t \right) \right) \tag{1}$$

where $CO_{2,t}$ denotes tonnage from fossil fuel combustion in period (t) and GDP_t is nominal GDP (expressed in millions of USD). The GDP deflator is denoted D_t.

Growth rates reported in table 1 are estimated by regressing the natural log of GDP, wages, and carbon dioxide-equivalent emissions on year as shown in (2).

$$ln(GDP_t) = \beta_0 + \beta_1 Y_t + \varepsilon_t \tag{2}$$

where: Y_t = year, ε_t is a stochastic error term, and β_1, β_0 are statistically estimated using ordinary least squares with heteroskedasticity and autocorrelation-robust standard errors.

Table 1 reports that between 1800 and 2020, real U.S. GDP grew at an annual rate of 3.6%. CO_2 emissions grew at 4.4%. The U.S. economy became more carbon-intensive at a rate of about 0.8% per year. This masks a dramatic rise and then fall in U.S. carbon intensity. From the Civil War era to 1917, carbon intensity of U.S. GDP tripled. By 1950, CO_2 per unit GDP fell back to levels observed during the Civil War[3].

Prior to peak intensity shown in figure 1, from 1800 to 1918, GDP grew at about 4% while CO_2 emissions rapidly increased at 7.8%. As the U.S. economy grew and industrialized from the colonial period to WWI,

[2] Biomass consumption for energy use is not included in the analysis because whether such consumption contributed to net emissions depends on rates of deforestation and afforestation. Assembling information on these latter two objects is beyond the scope of this paper.
[3] Figure 1 in Ausubel (2007) plots global carbon intensity, defined in terms of energy rather than output from 1850 to the early 21st century. Ausubel's plot depicts very gradual, nearly monotonic, decarbonization.

carbon intensity increased by nearly 4% per year. This pattern of concomitant growth and carbonization stopped in 1918. The reversal in trend of carbonization coincides with a break in what had been steady, exponential growth in the U.S. economy's production and consumption of coal. After growing at nearly 8% per year from 1800 to 1918, energy consumed from coal flat-lined until the late 1940s. What lead to this structural change?

Both WWI and the Spanish Flu comprised large, negative labor supply shocks among prime working-aged men[4] (Garrett, 2007; Clay, Lewis, Severnini, 2019). To frame the analysis of the joint influences of WWI and the Flu, this paper adopts an approach employed in the context of the Bubonic Plague; previous scholars discuss Malthusian and Smithian effects of significant, negative labor supply shocks (Jedwab, Johnson, and Koyama, 2022). According to the Malthusian perspective, real wages rise following events like WWI and the Spanish Flu (Hansen and Prescott, 2002). Because the Malthusian framework defines income in terms of the ratios of land and capital to labor, the large population losses from the war and the pandemic should cause real wages to subsequently rise. In contrast, the Smithian perspective argues that real economic growth is due to the division of labor, exploitation of comparative advantage, and trade. This implies a *positive* correlation between population growth and development and a decline in output following negative labor supply shocks. The results in table 1 and figure 2 provide a means to test the Malthusian and Smithian points of view for the joint shocks of WWI and the Spanish Flu.

The left panel of figure 2 plots real wages and per-capita GDP over the entire 220-year time series. Although plotted on different scale, wages and GDP covary quite closely from 1800 to 1917. After 1918, the series diverge, with real wage growth initially rapidly exceeding that of GDP. The right-hand panel of figure 2 plots per-capita GDP and wage indices with 1916 levels as the base year. After 1918 real wages increased rapidly: rising by 50% in the middle 1920s and then doubling by 1935. In contrast, real per-capita GDP oscillates without trend until the late 1930s. Table 1 also supports the differential trends in

[4] U.S. participation in WWI was limited to April 1917 to November, 2018. The second, especially disruptive wave of the Spanish Flu broke out in the U.S. in the fall of 2018.

wages and GDP from 1918 to 1940; it was the following year in 1941 when the Lend-Lease programs started during which U.S. manufacturing production ramped up to supply the Allies. Prior to 1918, real per capita GDP increased at an annual rate of 4%. Wages grew by just over 1%. And again after 1940, GDP increased by more than 3% while wages climbed at 1.4%. However, between 1919 and 1940 wage growth was 3% and real GDP grew at just 1.6%. A close inspection of the data, evident in the right panel of figure 2, indicates that it was the period between 1918 and 1922 during which wages and real GDP diverged. Wages of production workers jumped by between 5% and 20% in 1918 through 1920 (Officer and Williamson, 2022). From 1922 to 1929, and then again following the most disruptive years of the Great Depression, the wage and GDP series were roughly parallel.

This spurt of rapid real wage growth, following the negative labor supply shock of WWI and the Spanish Flu, is strongly suggestive of a Malthusian response. That real GDP didn't keep track with wages suggests adverse macroeconomic conditions[5], pointing to a Smithian response. Concurrent evidence of Malthusian and Smithian mechanisms is not unprecedented. Conditions in England following the Black Death exhibit these conflicting forces (Jedwab, Johnson, Koyama, 2022). Economic historians have argued that the Black Death was sufficiently disruptive to cause structural changes to medieval society that ultimately led to the Great Divergence (see Jedwab, Johnson, Koyama, 2022). Was the end of WWI and the multiple waves of the Spanish Flu sufficiently disruptive to stop a century's worth of growth in coal production and reverse the rising trend in U.S. carbon intensity?

There are two key points in support of this position: one Malthusian, one Smithian. First, while workers in many industries enjoyed rapid real wage growth, coal miners did not. Wage growth in the manufacturing sector accelerated in the decade following WWI and the pandemic (Garrett, 2007). In contrast, miners' wages fell. Between 1922 and 1929, nominal mining wages fell by 25% whereas annual earnings and hourly wages in the manufacturing sector increased by about 15% (BLS, 1946; FRED, 1960;

[5] The U.S. economy experienced two short recessions between 1919 and 1922.

2022). The price level increased by just 2% (Williamson, 2022). Velde (2020) notes that there were adverse shocks to the demand for coal during the pandemic years reflecting reduced economic activity both from the pandemic and curtailment of government demand following Armistice. This period of falling demand and real wages in the mining sector featured labor shortages and unrest at coal mines including the strike of 1919 and the Battle at Blair Mountain. The latter, an armed confrontation between miners, anti-union forces including local law enforcement, and federal troops, was a particularly disruptive event. Thus, the pandemic, the war, and subsequent conditions in labor markets conspired to suppress output from the mines beginning in 1918.

Second, the Smithian response to the pandemic and WWI (evident in figure 2) may have also attenuated carbon intensity. The argument is that particularly targeted or specific disruptions to the coal industry (stemming from acutely different rates of wage growth documented above) would have raised costs of this fuel relative to increasingly abundant substitutes: namely, oil and gas. With coal production stalled, households and firms turned to much less carbon-dense oil and natural gas.

Figure 3, which plots the energy intensity of GDP from use of coal, oil, and gas demonstrates that after 1918, reliance on coal plummeted while oil and gas use were on the rise. The right panel of figure 3, which focuses on the interwar years, clearly documents an economy transitioning away from coal toward oil and gas. After the disruptive events of the Flu and WWI, energy derived from oil rapidly increased as a share of GDP. *Both* coal and gas energy intensities fell until 1921. Then, after the recessions following the pandemic and the war, energy from gas climbed quickly while reliance on coal continued to fall. Reduced reliance on coal, coupled with real GDP growth, though at a modest 1.6% pace until the U.S. began to participate in WWII, resulted in precipitous reductions in carbon intensity. In fact, between 1918 and 1940 CO_2 emissions *fell* at an annual rate of 1.3%

In the 1950s, when coal production began to grow (for use as thermal coal in power plants), the rate of decline in carbon intensity attenuated. However, by this time, the widespread reliance on oil and gas for transportation, industrial process heating, as well as home heating and cooking, meant that the levels of carbon intensity observed from the Civil War to WWI would never be reached again.

After 1940 until the modern era, GDP grew at 3.2% while CO_2 emissions began to grow again, but at just 1.7%, annually. As a result, decarbonization continued at about 1.5% per year. Figure 3 captures a second crucial change in U.S. carbon intensity. Around the years of 1973 and 1974, energy from oil and gas (expressed relative to real GDP) peaked. In the years preceding the Energy Crises (as this period is colloquially known), carbon intensity appeared to be rising again. The oil price shocks, subsequent recession, changes to regulation (the Clean Air Act and vehicle fuel economy standards, for example), and consumer behavior clearly led to a reversal of the rise in energy intensity (from oil and gas). The decarbonization trend again picked up and has held through 2020.

The factors leading to the striking pattern of growth and reduction in carbon intensity shown in figure 1 can be summarized as follows. WWI and the Spanish Flu both contributed to disrupt a trend of carbon-rich growth due to heavy reliance on coal in the U.S. Both factors reduced labor supply and components of demand for coal. Rapid wage growth followed. Coal miners did not experience real wage growth in the years following these disruptions. Not surprisingly, strikes and general labor unrest ensued with the result being little to no growth in coal output. In lieu of coal, oil and gas use increased. Given the differences in carbon content of these fuels, carbon intensity fell as the U.S. economy grew from WWI onward.

This paper argues that geopolitics, labor markets, and public health were central to patterns in energy use, fuel procurement, and CO_2 emissions intensity. It is potentially instructive to consider that these forces bear direct relevance to the global economy today. The COVID pandemic disrupted both production and consumption patterns in ways that are pivotal to energy use and carbon intensity (Cicala et al., 2021). Labor markets have fundamentally changed, post-COVID. Wage growth accelerated following the pandemic, but not uniformly across sectors of the economy. The war in eastern Europe shifted global flows of energy fuels and other commodities. Each of these factors has a clear parallel to the period studied in this paper, during which trends in carbon intensity in the U.S. reversed course.

The historical record indicates that business cycles and periods of social change are often associated with significant shifts in environmental outcomes (Muller, 2020). This paper adds evidence to this record. Whether and how the U.S. experience in the 1920s informs outcomes in the 2020s and beyond remains to be seen. Nonetheless, this paper makes the case that disruptive social events may exert lasting effects on environmental conditions. Interventions in markets intended to mitigate detrimental consequences of pandemic and war may induce ancillary impacts for long-run climate change and environmental quality.

References.

1) Ausubel, J.H. 2007. Renewable and Nuclear Heresies. *International Journal of Nuclear Governance, Economy, and Ecology*. 1(3):229 – 243.
2) Cicala, S., S.P. Holland, E.T. Mansur, N.Z. Muller, A.J. Yates. 2021. "Expected Health Effects of Reduced Air Pollution from COVID-19 Social Distancing." Atmosphere 2021, 12, 951. https://doi.org/10.3390/atmos12080951.
3) Clay, K. J. Lewis, E. Severnini. "What Explains Cross-City Variation in Mortality during the 1918 Influenza Pandemic? Evidence from 438 U.S. Cities" *Economics and Human Biology*, 35 (2019): 42-50.
4) Federal Reserve Bank of St. Louis. FRED. 2022. "Average Absolute Annual Earnings of Employees or Wage Earners in All Manufacturing Industries for the United States, Dollars per Year, Monthly, Not Seasonally Adjusted 1915 – 1928." https://fred.stlouisfed.org/series/M08040USM302NNBR
5) Federal Reserve Bank of St. Louis. FRED. 1960. https://fraser.stlouisfed.org/title/employment-earnings-60/august-1960-20153/gross-hours-earnings-production-workers-manufacturing-340949
6) Garrett, T.A. 2007; War and Pestilence as Labor Market Shocks: Manufacturing Wage Growth 1914-1919, Federal Reserve Bank of St. Louis Working Paper 2006-018. https://doi.org/10.20955/wp.2006.018
7) Hansen, G.D., E.C. Prescott. 2002. "Malthus to Solow." *American Economic Review*. 92(4): 1205 – 1217.
8) Jedwab, R., N.D. Johnson, M. Koyama. 2022. "The Economic Impact of the Black Death." *Journal of Economic Literature*. 60(1): 132 – 178.
9) Muller, N.Z. 2020. "Long-Run Environmental Accounting in the United States Economy." Environmental and Energy Policy in the Economy, Vol. 1: 158 - 191. National Bureau of Economic Research, Cambridge, MA, USA.
10) Officer, L.H. and S.H. Williamson, 2022. 'Annual Wages in the United States, 1774-Present,' MeasuringWorth.
11) Schurr, S. B.C. Netschert, V.F. Eliasberg. 1960. *Energy in the American Economy, 1850 – 1975*. Johns Hopkins Press, Baltimore, MD, USA.
12) Williamson, S.H. 2022. 'What Was the U.S. GDP Then?' MeasuringWorth, 2022.
13) United States Department of Energy. Energy Information Administration. 2012. *Annual Energy Review 2011*. Office of Energy Statistics. Washington, D.C. 20585.
14) United States Department of Energy. Energy Information Administration. 2022. State Energy Data System. Office of Energy Statistics. Washington, D.C. 20585. https://www.eia.gov/state/seds/
15) United States Department of Labor. Bureau of Labor Statistics. 1934. "Wages and Hours of Labor in Bituminous Coal Mining: 1933." Bulletin No. 601. Washington D.C., U.S.A.
16) United States Department of Labor. Bureau of Labor Statistics. 1946. "War and Post War Wages, Prices, and Hours. 1914-1923 and 1939 - 1944" Bulletin No. 852. Washington D.C., U.S.A. https://fraser.stlouisfed.org/files/docs/publications/bls/bls_0852_1946.pdf?utm_source=direct_download
17) United States Environmental Protection Agency (EPA). 2022. Greenhouse Gas Reporting Program. https://www.epa.gov/ghgreporting

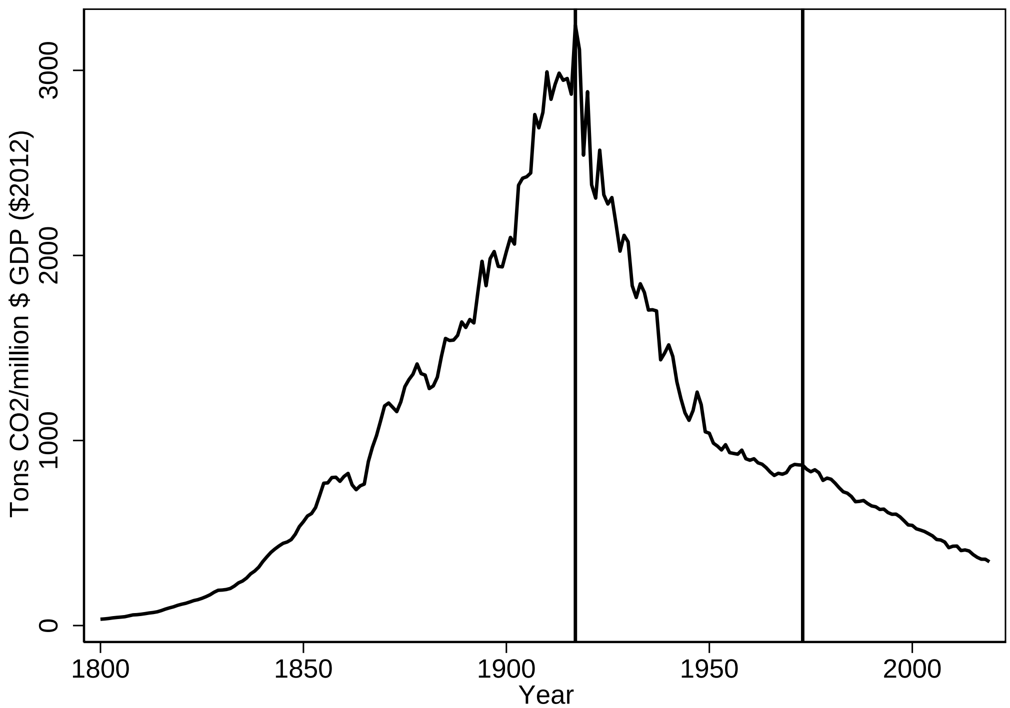
18) Velde, F.R. 2020. “What Happened to the US Economy During the 1918 Influenza Pandemic? A View Through High-Frequency Data.” Federal Reserve Bank of Chicago. WP 2020-11. https://doi.org/10.21033/wp-2020-11.

Table 1. Output, Wages, and Carbon Growth Rates.

	1800-2019	1800-1918	1919-1939	1940-2019
GDP	0.0362***[A]	0.0405***	0.0160***	0.0318***
	(0.000171)[B]	(0.000270)	(0.00293)	(0.000530)
	0.995[C]	0.996	0.452	0.988
	220[D]	119	21	80
Wages	0.0187***	0.0136***	0.0305***	0.0139***
	(0.000192)	(0.000286)	(0.00149)	(0.000512)
	0.972	0.936	0.951	0.929
	220	119	21	80
Carbon	0.0438***	0.0782***	-0.0129***	0.0166***
	(0.00133)	(0.000921)	(0.00390)	(0.000692)
	0.870	0.988	0.253	0.904
	220	119	21	80

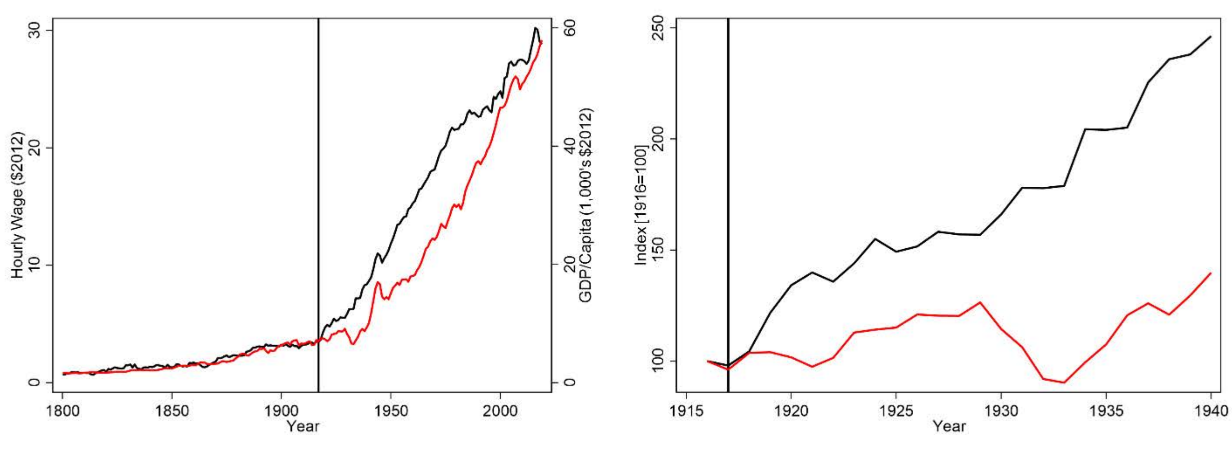
A = OLS regression coefficient, 0.0362 = 3.62% annual growth rate.
B = Standard error.
C = R^2
D = Observations.
*** = $p < 0.01$; ** = $p < 0.05$; * = $p < 0.10$.

Figure 1: Carbon Intensity of the U.S. Economy 1800 – 2019.



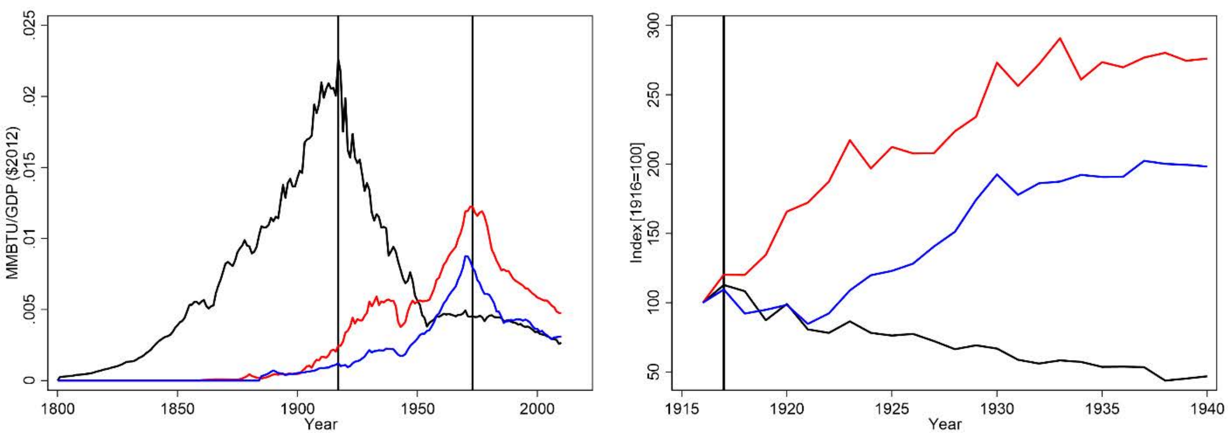
Left-hand vertical line at 1917, right-hand line at 1973.

Figure 2: Wages and Per-Capita GDP.



Left panel: Real hourly wages (black) and real per-capita GDP (red). Vertical line at 1917.
Right panel: Wage (black) and per-capita GDP indices (red). Vertical line at 1917. Base year = 1916.

Figure 3: Energy Intensity of the U.S. Economy 1800 – 2019.



Black = coal; Red = oil; Blue = natural gas.
Left panel: Left-hand vertical line at 1917, right-hand line at 1973.
Right panel: Vertical line at 1917.