NBER WORKING PAPER SERIES

FIREWOOD IN THE AMERICAN ECONOMY: 1700 TO 2010.

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Working Paper 33974
http://www.nber.org/papers/w33974

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2025

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NBER Working Paper No. 33974
June 2025
JEL No. N11, N12, N51, N52, N71, N72, Q23

ABSTRACT

Despite the central role of firewood in the development of the early American economy, prices for this energy fuel are absent from official government statistics and the scholarly literature. This paper presents the most comprehensive dataset of firewood prices in the United States compiled to date, encompassing over 6,000 price quotes from 1700 to 2010. Between 1700 and 2010, real firewood prices increased by between 0.2% and 0.4%, annually, and from 1800 to the Civil War, real prices increased especially rapidly, between 0.7% and 1% per year. Rising firewood prices and falling coal prices led to the transition to coal as the primary energy fuel. Between 1860 and 1890, the income elasticity for firewood switched from 0.5 to -0.5. Beginning in the last decade of the 18th century, firewood output increased from about 18% of GDP to just under 30% of GDP in the 1830s. The value of firewood fell to less than 5% of GDP by the 1880s. Prior estimates of firewood output in the 19th century significantly underestimated its value. Finally, incorporating the new estimates of firewood output into agricultural production leads to higher estimates of agricultural productivity growth prior to 1860 than previously reported in the literature.

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A Replication kit available here is available at http://www.nber.org/data-appendix/w33974

I. Introduction.

This paper fills an important gap in the study of American economic history by presenting the first reasonably comprehensive series of firewood prices for the United States (U.S.) economy. The data extend from before the American Revolution to the present era. This new database contains over 6,000 price quotes gathered from newspaper archives, public, industrial, and commercial records, and a collection of existing price data.

Prior to the 20th century, the U.S. economy, both firms and households, was powered almost exclusively by firewood. Large scale coal production didn't begin until the 1830s (Chandler, 1972). When the Civil War began in 1860 estimates suggest that energy consumed from wood comprised 85 percent of total energy used in the U.S. (Census, 1975). Despite its central role as an energy source, prices for firewood remain largely missing from the historical record. Extant sources of historical commodity prices either omit firewood prices entirely, or they rely on tenuous imputations. For example, official price indices focusing on fuel and light include coal prices, not firewood (Warren and Pearson, 1932;1935; U.S. Census, 1949; 1975). In the description of their fuel and light price index, Warren and Pearson (1932) state:

> "…[c]onsiderable wood is used for fuel. This was an important fuel material a century ago. It is not included in the fuel-and-lighting group because no prices were available."
>
> Warren and Pearson (1932, p. 81)

And, referring to the 18th century:

> "No quotations for firewood were available. This [firewood] was cheap in earlier years."
>
> Warren and Pearson (1932, p. 132)

Reflecting the abundance of firewood in the 18th and 19th centuries, the implications of its bountiful nature for prices, and the central role firewood played in the U.S. economy, Reynolds and Pierson (1942) write:

> "Cordwood was about as plentiful as air. But nobody wrote about air – why write about firewood, or even record statistics about it? Hence, there is now as little written evidence as there is public appreciation of the past importance of wood fuel in the development of this country."
>
> Reynolds and Pierson, 1942 (p. 2)

Arthur Cole (1970) describes the role of firewood in the U.S. economy prior to the Civil War, and in doing so, offers an explanation for the lack of firewood prices even when wood was the dominant energy source. In the agrarian society of the 17th, 18th and early 19th centuries in

America[1], households felled and processed trees located on their property for internal consumption.

> "Most houses in the country maintained a modest woodlot, probably in a part of the property least favored for agricultural or dwelling purposes. Here aging trees were felled, usually at slack times in the routines of the farm[.]"
>
> Cole (1970, p. 343)

So, when firewood contributed the vast majority of energy to the American economy, it was bountiful, *and* much production and consumption of this fuel occurred outside the market boundary. Both forces contributed to the lack of a coherent historical price record.

Prominent scholars of the early American economy note that the paucity of firewood pricing data is especially problematic because of the heavy reliance on fuel wood. William Howard Shaw (1947) reported estimates of the value of commodity output beginning in 1869. Because of a lack of data, he reports just two estimates of the value of firewood consumed (one for 1880 and one for 1908). He states that:

> "Our failure to include firewood thus means a fairly serious deficiency in the fuel estimates, which the user should not forget."
>
> Shaw (1947, p. 103)

Harold Barger (1955), using Shaw's figures, reports just seven annual estimates of the total value of firewood consumption between 1869 and 1929 in his study of wholesale and retail distribution of goods and services. Towne and Rasmussen (1960) report decadal firewood output estimates from 1800-1900. Their price series is an imputation from an 1879 benchmark price using a price series from Vermont[2]. Simon Kuznets and Elizabeth Jenks (1961) did not include the value of firewood in their analysis of capital formation in the early American economy, citing the fragmentary nature of the existing estimates from Shaw (1947) and Barger (1955). Kuznets and Jenks conclude that, given the declining trajectory of reliance on firewood after the Civil War, proper inclusion of firewood in their national output series would have reduced estimates of growth (Kuznets and Jenks, 1961). Robert Gallman (1966) discusses the flaws in Shaw's (1947) and Barger's (1955) estimates and ultimately includes the value of fuelwood consumption in his estimates of Gross National Product (GNP). Gallman (1966) relied on the price estimates in Brady (1966), who documented (indexed) firewood prices for five years between 1809 and 1899[3]. These data were subsequently used by David (1967) and David and Solar (1977). Clearly,

[1] Only a small share of the population lived in cities: in 1800 under 10 percent of the population lived in cities, by 1840 this share increased to just over 20 percent (Census, https://www.census.gov/dataviz/visualizations/005/).
[2] Note that the Vermont price series in Muller (2016), included in the Northeastern regional price series in the present paper, is the 1800 – 1900 price series used by Towne and Rasmussen (1960) to impute changes from the 1879 benchmark year.
[3] These data are not cited in the federal historical price indices (Census, 1975).

seminal analyses of the early American economy lack a suitably comprehensive price series needed to value what was the dominant energy fuel used by both firms and households.

As Cole (1970) argues, early price records for firewood were missing because this abundant fuel source was primarily grown, harvested, and used by households in rural, agrarian communities. The nature of early firewood production and use raises an important question: how should firewood that was primarily not traded in markets be valued? The valuation of goods and services produced and consumed outside of the market boundary is a familiar problem, addressed by economists seeking to expand the National Income and Product Accounts (NIPAs) to include home production. The recommended approach for valuing home production is adopted here: quantities of goods and services produced in the home should be valued according to their market prices (Fitzgerald, Swenson, Wicks, 1996; Landefeld and McCulla, 2000). Reflecting this guidance, the 2008 revision of the System of National Accounts (SNA) stipulates that agricultural products that are produced and consumed by the same household are valued according to the current market-equivalent price, or the price that the good produced would bear if sold in markets. Further, the SNA specifies that agricultural output produced by unincorporated households, inclusive of that consumed by the household, is considered economic production and is valued and included in the NIPAs (SNA, §6.32; §6.87).

The SNAs' treatment of agricultural products made by households also raises the issue of whether firewood output should be added to existing estimates of output, as would home production, or if it is already included as intermediate inputs. Hence, a key question is what share of firewood was transacted in markets. It is conceivable that firewood produced and consumed by households, as described by Cole (1970), may have been entirely outside of formal markets. The share consumed by firms would have been more likely to be transacted in markets. The evidence provided in Schurr et al., (1960) suggests that the majority of firewood consumption occurred in the household. In 1850, 90 percent of the estimated 100 million cords used in the U.S. was employed by households, with three-quarters households situated in rural areas (Schurr et al., 1960 p. 49). These facts point to a large share of home production of firewood.

This discussion raises the question of where to find records of market transactions of firewood with which to value firewood that was largely produced and used outside of the market. Despite the apparent dominance of home production, the historical record indicates that markets for fuel wood existed early in the colonial economy. Appendix A.3 provides evidence that as early as the late 17th century, towns in the New England colonies attempted to manage firewood harvest from common lands, and especially to curtail extraction for subsequent commercial sale. Further, Lemon (1972 p. 199) documents that during the 18th century, firewood produced on rural woodlots was transported into cities to meet the "urgent need of city dwellers for wood,"[4]. Hence, urban demand for energy was met by rural producers and farmers who hauled firewood

[4] James T. Lemon (1972 p. 168) states that "By 1775 firewood was brought down the Delaware [River] to the city [Philadelphia]." And "firewood production…would occur near the market because of high transport cost." (Lemon, 1972 p. 184). That firewood producers endeavored to harvest and transport firewood among towns suggests significant price differentials given the weight and bulky nature of firewood.

to towns and cities for commercial distribution. Such transactions, and hence, recorded prices, would have been more likely to occur in towns and cities, where fuel could not be procured via home production.

Indeed, the firewood prices and valuation data gathered for the present paper are largely found in early American newspapers, some of which reported price quotes in their classified advertisement "marketplaces". To assemble these pricing data, this paper makes use of technological improvements in both the quality of document (newspaper) images and in text extraction software. Additional valuation data are collected from colonial town and court records, commercial and industrial records, and other assorted sources. The end product of this data gathering strategy are firewood price series that span more than three centuries, from 1645 to 2010, in multiple U.S. cities and regions.

The present analysis estimates two firewood price indices spanning the years 1700 to 2010[5]. An eight-city index includes historical and contemporary prices for Philadelphia, Pennsylvania, Boston, Massachusetts (and surrounding areas), New York City, Richmond, Virginia, New Orleans, Louisiana, Detroit, Michigan, Portland, Oregon, and Washington, D.C. The cities were targeted both because of the availability of data, and to obtain a nationally representative sample of prices. The earliest price quotes, not surprisingly, are for the cities on the east coast that were settled during the colonial era: Boston, Philadelphia, New York, and the Richmond area in Virginia. The price series begin much later for Detroit and Portland because these cities were established well after the early colonial settlements that became Boston, New York, and Richmond. A four-region index is developed as a complement to the metropolitan index. The regional indices, defined over the Northeast, Southeast, Midwest, and Western areas of the U.S., include the cities listed above and price quotes for many other locations matched by region[6].

Leveraging these new data, the present paper characterizes real price changes over the entire 310-year time series and the following sub-periods: 1700 – 1800, 1800 – 1860, 1860 – 1917, and 1917 – 2010. The firewood prices are then used to explore three topics that are of central importance to the study of the 19th century American economy. First, the real value of firewood output, tabulated by multiplying prices and consumption quantities, is compared to extant estimates of Gross Domestic Product (GDP), Gross National product (GNP), and perishable commodity output. Prior to the Civil War, the American economy was almost entirely powered by firewood. And, because of the dearth of price data, the literature has provided little insight as to the value of this commodity even when it comprised the dominant energy source.

Second, firewood was produced on farms. Thus, from a productivity accounting perspective, proper attribution of the value of output is to the agricultural sector. Coupled with existing agricultural workforce estimates (Lebergott, 1966) the paper analyzes how the new output estimates compare to existing agricultural productivity calculations in the 19th century. The

[5] Data prior to 1700 are presented in Appendix 4. These data are not included in the main body of the paper because none of the valuation estimates are market prices, and currency conversions in the 17th century to a contiguous U.S. dollar series are especially tenuous.

[6] All of the price quotes and original source information is provided in a series of digitized databases that accompany this paper.

productivity of this sector during the first half of the 19th century was mis-measured largely because of *very limited* firewood price data in the existing literature.

Third, the energy transition from firewood to coal in the late 1800s occurred with stunning speed and it launched a reliance on fossil fuels that continues to persist in the American (and global) economy. The firewood price data gathered here facilitates a detailed analysis of the role that the relative prices for wood and coal played in this transition.

The central results presented in this paper are as follows. First, using the newly constructed price series and extant historical price deflators (McCusker, 1991) the paper estimates real growth rates in firewood prices. Over the entire sample, real firewood prices increased by between 0.2% and 0.4%, annually, according to the eight-city and the regional price indices, respectively. Between 1800 and the Civil War, real prices increased especially rapidly, between 0.7% and 1% per year. From 1860 to 1917, real firewood prices do not exhibit a clear intertemporal pattern. From 1917 to 2010 real firewood prices increased by 0.1% to 0.4%, according to the eight-city and the regional indices, respectively. In the early 19th century, prices increased especially rapidly in Boston, Massachusetts and in Philadelphia. Over the entire period of analysis, prices increased at the greatest rate in Boston, Massachusetts and Portland, Oregon.

The rapid appreciation of firewood prices prior to the Civil War led to the transition away from firewood toward coal as the economy's primary energy fuel. Between 1860 and 1890, the income elasticity for firewood switched from 0.5 to -0.5. Hence, firewood transitioned from being a normal to an inferior good. This change in the income elasticity estimates mirrored changes in the relative prices of coal and wood.

Next, the analysis turns to the aggregate value of economy-wide firewood output, which amounted to an appreciable share of GDP and GNP prior to the Civil War. Beginning in the last decade of the 18th century, firewood output increased from about 18% of GDP to just under 30% of GDP in the 1830s. Following this peak share of output, the value of firewood fell to less than 5% of GDP by the 1880s. These results are robust to different measures of GDP and GNP in the literature (Johnston and Williamson, 2023; Romer, 1989; Gallman and Rhode 2019). In a set of provisional calculations, this analysis replaces estimates of firewood output in historical GDP series with that produced in this paper. Then, growth in this adjusted GDP measure is compared to the existing series between 1790 and 1890. This exercise suggests an upward revision of real growth between 1800 and 1840 followed by a significant downward adjustment to growth between 1840 and 1870. The driver of these differences appears to be the new firewood price series presented in this paper.

Finally, the firewood output series is analyzed in the context of agricultural labor productivity in the first half of the 19th century. This exercise reports that firewood output per agricultural worker increased at a rate of 1.6% from 1800 to 1860. This new calculation is used in a revision of Weiss' (1993) estimates of agricultural labor productivity. These productivity gains appear to be driven by the Northeastern states.

The remainder of this paper is structured as follows. Section II. covers the data sources and econometric methods. Section III. presents the empirical results. Section IV. concludes.

II. Methods and Data.

This section consists of a description of the sources of data and of the processes used to assemble the various price data into a coherent national database. This section is structured according to the geographic regions for which the price data are assembled. Lastly, the sources for the aggregate output and agricultural sector data are discussed.

A. Firewood Price Data.

Because the sources of firewood pricing data are disparate in nature, the description of sources is organized according to geography. The discussion proceeds through the major cities that comprise the metropolitan wood price index. Next it covers state and regional data that comprise the regional price indices. For each city below, the price series terminate around 1970. In order to extend these series to 2010, the data are spliced with matching state average prices from the U.S. Department of Energy's State Energy Data System (USDOE, 2019). Though the indices are expressed in terms of annual prices, for cities with monthly price quotes, Figures A7 and A8 in the appendix show results from models that test whether there are seasonal differences in both the prices and the number of price quotes. Further, the price series for some cities include information on wood type. Figure A9 in the appendix shows results from models that test whether there are systematic differences in prices according to wood type.

1. Philadelphia.

The pricing data for Philadelphia begin in the pre-Revolution economy. The first dataset (Muller, 2019a) consists of a collection of firewood prices spanning 1691 to 1835. The specific source for each price quote is given in the supporting databases (Muller, 2019a). Prices spanning 1733 to 1744 were obtained from Benjamin Franklin's diary (Muller, 2019a, University of Delaware, http://udspace.udel.edu/handle/19716/2357). The next batch of Philadelphia prices were obtained from classified advertisements in historical newspapers (Muller, 2019b). These data encompass price quotes from 1783 to 1840. This database also includes prices from 1841 through 1965 from the *Philadelphia Public Ledger,* a newspaper. An additional series, also gathered from classified advertisements in historical newspapers includes prices from 1861 to 1870 (Muller, 2019c). Thus, the Philadelphia series spans 1691 to 1965. Note that the 1691 price quote is dropped because the McCusker Consumer Price Index used to convert nominal values to real begins in 1700.

2. New York.

The New York price series begins with price quotes in 1741 (Muller, 2019a). This database includes price quotes from New York until 1795. As above, the specific sources for each price quote are reported in the supporting database (Muller, 2019a). Muller (2019b) also contains price quotes from New York newspapers. These price quotes encompass the years from 1776 to 1836. A collection of prices from an assortment of entrepreneurs' logbooks spanning 1757 to 1791 is featured in Muller (2019d). A small collection of prices from the *New York Times* from 1860 to 1908 are reported in Muller (2019e). A statewide series obtained from (Mass. BSL, 1901; Muller, 2019f) spans 1851 to 1889.

3. Richmond and Virginia.

Muller (2019a) contains prices for Virginia including years between 1740 and 1807. These data are drawn from a case study of early American towns in the Chesapeake Region (see Muller, 2019a). Prices specifically for Richmond, Virginia from 1852 to 1967 are cataloged in Muller (2019g).

4. Washington, D.C. and Baltimore, Maryland.

The price series for Washington and Baltimore features price quotes from Washington, D.C. newspapers from 1853 to 1973 (Muller, 2019h). The next batch of prices include quotes from around Baltimore and Washington, D.C. and these were obtained from classified advertisements in historical newspapers (Muller, 2019b). These prices include the years from 1792 to 1840. Muller (2019a) includes prices for Baltimore from 1785 to 1831.

5. New Orleans.

For New Orleans, Louisiana, prices for firewood span 1838 to 1950. These data are all assembled from classified advertisements (see Muller, 2019i). The specific dates and sources are reported in Muller (2019i).

6. Detroit.

For Detroit, Michigan, prices for firewood span 1839 to 1970. These data are all assembled from classified advertisements (see Muller, 2019j). The specific dates and sources are reported in Muller (2019j).

7. Portland, Oregon.

Prices from 1862 to 1965 from Portland, Oregon are included (Muller, 2019n). These price quotes were gathered from the *Portland Oregonian* archives.

8. Massachusetts.

Firewood price data is relatively abundant for Massachusetts. Though many of the price quotes and valuations are in Boston, numerous data points are from other towns and cities in Massachusetts. These include Salem, Ipswich, Barnstable, and others. The Massachusetts Bureau of the Statistics of Labor reports prices for Massachusetts from 1799 to 1858 (Mass. BSL, 1885). Muller (2019b) includes a short time series from Boston spanning a few years between 1779 to 1834. Muller (2019l) reports a short series of prices from 1660 to 1757 in Massachusetts; prices prior to 1700 are included only in the analysis found in appendix 4. The database in Muller (2019o) includes prices from 1860 to 1883, Muller (2019p) encompasses prices from the period 1851 to 1891, and Muller (2019q) features firewood prices from 1891 through 1963. Muller (2019r) includes prices from 1701 to 1834. Firewood valuation estimates from the 17th century, specifically from 1645 to 1702, are reported in Muller (2019t). These data are gathered from colonial town and court records. It is important to note that the firewood values reported in Muller (2019t) are not clearly attributable to market exchanges. This, coupled with the difficulty

in converting the colonial currencies to U.S. dollars, prohibits their inclusion in the price indices that are the primary subject of analysis in this paper.

9. Regional and Assorted State Data.

In order to expand the geographic coverage of the price databases data from a collection of state and regional sources are also assembled. Except for the state of Massachusetts, none of these assorted sources span the same long time horizon as the six primary cities discussed above.

a. Regional Data.

The Midwest series consists of data for Detroit from Muller (2019j). Muller (2019b) contains a short series from 1824 to 1840 for Midwestern cities. The Massachusetts Bureau of the Statistics of Labor reports prices from nine Midwestern states from 1851 to 1913 (Mass. BSL, 1885). Muller (2019k) reports prices for St. Louis, Missouri from 1875 to 1900. Finally, the U.S. Department of Energy's State Energy Data System provides state average firewood prices from 1970 to 2010 to complete the Midwestern price series (USDOE, 2019).

The Northeastern series consists of the city series for Philadelphia, Washington D.C (and Baltimore), Boston, and New York described above. In addition, the Vermont state series developed in Muller (2016) is included. The Massachusetts Bureau of the Statistics of Labor reports prices from seven Northeastern states from 1851 to 1913 (Mass. BSL, 1885). Muller (2019b) contains a series from 1779 to 1840 for Northeastern cities. A short series of prices from New Hampshire spanning 1748 to 1770 is also in the Northeastern index (Muller, 2019a). Finally, the U.S. Department of Energy's State Energy Data System provides state average firewood prices from 1970 to 2010 to complete the Northeastern price series (USDOE, 2019).

The Southeastern series is comprised of the city series for New Orleans and Richmond discussed above. In addition, prices in Southeastern cities from 1822 to 1840 in Muller (2019b) are included. The Massachusetts Bureau of the Statistics of Labor reports prices from seven Southeastern states from 1851 to 1913 (Mass. BSL, 1885). Prices for the city of Atlanta, Georgia from 1869 to 1922 are reported in Muller (2019m). And the U.S. Department of Energy's State Energy Data System provides state average firewood prices from 1970 to 2010 to complete the Southeastern price series (USDOE, 2019).

The Western regional price series contains the least geographic coverage. The data consist of prices for Portland discussed above, and California from the Massachusetts Bureau of the Statistics of Labor over just a few years from 1884 to 1913 (Mass. BSL, 1885). And the U.S. Department of Energy's State Energy Data System provides state average firewood prices from 1970 to 2010 to complete the Western price series (USDOE, 2019).

B. Other Data.

Coal price data are assembled from two sources. Cole (1938) and CIPR (2019) contain historical coal prices for Philadelphia, New York, and New Orleans. These price series span 1784 to 1861. The Massachusetts Bureau of the Statistics of Labor reports state prices for both bituminous (1851 – 1891) and anthracite (1825 – 1891) coal of varying grades from 1851 to 1913 (Mass.

BSL, 1885). Population data are provided by Manson et al., (2019). Consumption of fuel wood and coal as a share of total energy consumption in the U.S. economy from 1630 to 1955 was obtained from Reynolds and Pierson (1942) and Schurr et al. (1960). National conversions of cords of fuel wood into btus relies on conversion factors from the U.S. Census (1975). GDP estimated by Johnston and Williamson (2023) from 1790 to the present is used in sections III.D and III.E., as are the GNP series from Romer (1989) and Rhode and Gallman (2019). Gallman's (1960) perishable commodity output series is also used in section III.D.

C. Calculations and Estimation.

Deflation from nominal to real values relies on the McCusker Consumer Price Index (McCusker, 1991) which spans 1700 to 1991. This index is spliced with the Bureau of Labor Statistics all-goods CPI, as used in Muller (2016). The base year for the composite CPI is 1860. Some price quotes prior to 1776 are expressed in colonial currencies (Massachusetts pound, for example). We convert these to dollar equivalents by first converting to the U.K. pound using colony-specific conversions (McCusker, 1991) and then converting between the U.K. pound and dollars (McCusker, 1991).

While the regional index is an unweighted average, the population-weighted eight-city firewood price index assumes the following form.

$$P_t = \sum_{i=1}^{8} \omega_{i,t} P_{i,t} \quad (1)$$

where: $P_{i,t}$ = real price of firewood in city (i), time (t).

$$\omega_{i,t} = {Pop_{i,t}}\Big/{\sum_{i=1}^{8} Pop_{i,t}}$$

Growth rates are estimated using equation (2), which features firewood prices for illustrative purposes. The same form is used to estimate growth rates in output, consumption, agricultural workers and output per worker.

$$ln(P_{i,t}) = \beta_0 + \beta_1 Y_t + \gamma_c + \varepsilon_{i,t} \quad (2)$$

where: β_0, β_1 = statistically estimated parameters.
$\varepsilon_{i,t}$ = stochastic error term
γ_c = city (or region) fixed effects
Y_t = year.

Regression models of the form shown in (3) are used to assess the share of firewood output relative to total economic output and commodity output.

$$ln\left(\frac{O_t}{GDP_t}\right) = \beta_0 + \sum_{d=1}^{D} \beta_d I_d + \varepsilon_{i,t} \quad (3)$$

where: O_t = real firewood output, at time (t).
GDP_t = real GDP time (t).

I_d = indicator variable for decade (d).
$\varepsilon_{i,t}$ = stochastic error term
β_0, β_d = statistically estimated parameters.

Seasonality in firewood prices and the count of price quotes is examined using the model in (4) which is fit to monthly pricing data (*m*), by wood type (*k*), for the cities included in the city index.

$$ln(P_{i,t}) = \beta_0 + \beta_1 Y_t + \sum_{m=2}^{12} \theta_m I_m + \sum_{k=1}^{K} \alpha_k I_k + \gamma_c + \varepsilon_{i,t} \quad (4)$$

where: $\beta_0, \beta_1, \theta_{m,}, \alpha_k$ = statistically estimated parameters.
I_m, I_k = indicator variables for month-of-year (*m*) and wood type (*k*).
γ_c = city fixed effects
$\varepsilon_{i,t}$ = stochastic error term
Y_t = year.

Model (4) is also used to test whether there are systematically different prices for different types (species) of firewood.

Model (5) is employed to characterize decadal differences in agricultural productivity, on a per worker basis.

$$ln\left(\frac{AO_t}{Ag_t}\right) = \beta_0 + \sum_{d=1}^{D} \beta_d I_d + \varepsilon_{i,t} \quad (5)$$

where: AO_t = real agricultural sector output, at time (t).
Ag_t = number of agricultural workers at time (t).
I_d = indicator variable for decade (d).
$\varepsilon_{i,t}$ = stochastic error term

Using the specification in (5) comparisons are made between output defined using the original series published in Towne and Rasmussen (1960), and the livestock and crop series published in Towne and Rasmussen (1960) together with the firewood output series reported herein.

Model (6) estimates the empirical correlation between personal income (Inc_t) and gross firewood consumption (C_t). That both variables are in natural log forms suggests an interpretation of the parameter estimate of interest (β_1) as an income elasticity.

$$ln(C_t) = \beta_0 + \beta_1 ln(Inc_t) \quad + \varepsilon_{i,t} \quad (6)$$

Model (6) is applied to 20-year time periods to allow for time-variant estimates of the income elasticity. Each 20-year period is constructed with 10 lagging and leading years. The earliest period spans 1780 through 1800, centered at 1790. The next period is centered on the year 1791 and so on until 1930.

III. Results

The results section begins with an analysis of national firewood consumption. Then, the behavior of firewood prices in each of the eight cities included in the multi-city index is covered. Next, section C compares wood and coal prices. Section D compares total firewood output to estimates of economy-wide output. Section E focuses on agricultural productivity.

A. Firewood Consumption.

Figure 1 indicates that firewood comprised the dominant source of energy from the early 18th century until the late 19th century. Total firewood consumption peaked in 1870, and the firewood share of total energy consumed in the United States fell precipitously from nearly 100% in 1800 to about 20% in 1900. By World War I energy derived from firewood amounted to just 10% of economy-wide energy consumption. As a share of total energy consumed, coal surpassed firewood in the middle 1880s (see figure A1 in the appendix).

Figure 1 also shows per capita firewood energy consumption, which peaked in the middle 1700s. Per capita consumption, expressed in million British Thermal Units (MMBTU) then fell through the early 1800s, before rising again in the 1820s and 1830s. Beginning in the 1840s, per capita consumption of energy from wood fell very rapidly. Subsequent sections of this analysis will show that between 1800 and the Civil War, wood prices were rising more rapidly than the general price level. Concurrently, real coal prices were falling. The change in relative prices of these fuels appears to have played a fundamental role in the transition from wood to coal.

B. Price Indices.

Table 1 reports growth rates in firewood prices for the eight-city index and the regional index. In addition to the full sample, growth rates are calculated for the following periods: 1700 – 1800, 1800 – 1860, 1860 – 1917, and 1917 - 2010. Figure 2 plots the price data. Each observation corresponds to a city or region-year. To account for systematic geographic difference in prices, the regression models used to estimate growth include city or region fixed effects. Beginning with the full 310-year span of the analysis, the city index indicates that real firewood prices climbed by just over 0.2% per year. The regional index increased at a rate just over 0.3%. Between 1700 and 1800, neither index provides evidence that firewood prices exhibited real growth during this time. (Figure A2 in the appendix shows the indices from 1700 to 1800.) In contrast, from 1800 to the onset of the Civil War, real prices increased at an annual rate of 0.7% according to the city price index and 1% according to the regional index. Within this period, real growth exhibits different timing and rates according to whether measured using the regional or the city indices. Annual increases in the city price index were 1.2% from 1800 to 1840 and regional prices grew by 1.9% year-over-year from 1800 and 1840.

Macroeconomic conditions provide some insight as to why firewood prices appreciated especially rapidly during this time. Gallman and Rhode (2019) provide evidence of swift growth in the domestic capital stock prior to the Civil War. Capital accumulation was especially brisk from 1840 to 1860. (See tables 4.4 and 4.6 in chapter 4 of Gallman and Rhode, 2019.) The GDP series provided by Johnston and Williamson (2023) also provides evidence of rapid growth from

1800 to 1860. Within this period, real GDP growth averaged over 5% between 1820 and 1860. And, firewood was the primary source of energy, accounting for 95% of energy consumption economy-wide from 1800 to 1860, and 91% between 1840 to 1860 (Schurr et al., 1960). Thus, firewood fueled broad-based economic growth, and prices for this source of energy appreciated accordingly.

Between 1860 and 1917, when the U.S. entered World War I (WWI), table 1 shows evidence that firewood prices fell, though the growth rates are imprecisely estimated. Though figure 1 reports falling per capita consumption after 1830, total consumption of firewood continued to increase until 1870. After 1870, demand for this fuel fell precipitously as the economy's reliance on coal grew. The flat or falling real prices for firewood after 1860 evidently reflect a demand-side effect, rather than new supplies flooding the markets.

After 1917, both city and regional prices increased at relatively low rates. During and after WWI, coal prices increased, and coal use began to decline as the economy began to transition to oil and natural gas as the primary energy sources (Muller, 2022). Firewood prices were quite stable through the 20th century until the oil price shocks of the 1970s and the financial crisis in 2008, when real firewood prices increased rapidly. (See figure A3.)

As stated in the introduction, existing empirical estimates of firewood prices in the 19th century are limited. It is instructive to compare the historical estimates from the literature with the new series gathered here. Figure A4 in the appendix plots individual price quotes from the city and regional series from 1835 to 1845. The horizontal lines correspond to three firewood price estimates from Seaman (1868) which informed Gallman's estimates of commodity output from 1839 to 1899 (Gallman, 1960). The figure indicates that Seaman's estimates are significantly lower than the price estimates gathered here[7]. In 1840, the average price in the data reported in this paper is \$4/cord. This is roughly a factor of two larger than Seaman's estimates. A mean comparison test of all prices shown in figure A4 and just those in 1840 reject equivalence to all three of Seaman's price quotes ($p < 0.01$).

A second comparison is demonstrated in figure A5. This is between the firewood price index compiled by Brady (1966) and the annually matched prices compiled in the present analysis. To convert Brady's index to monetary units Seaman's central estimate of \$2/cord for 1840 is used. This imputation yields the red circles in figure A5. The average real price from the Brady series is just over \$2.25/cord. The average of the 48 individual prices quotes matched to the years of the Brady index is \$4.74/cord. This factor of two difference is statistically significant ($p < 0.01$).

These two comparisons suggest that estimates of commodity output and gross national (and domestic) product that include firewood output would be revised upward (by a potentially substantial margin) if the sparse series in Seaman (1868) and Brady (1966) were replaced with the estimates presented here. This revision would be especially marked for the period between 1800 and 1860 when firewood was the dominant energy fuel in the American economy. This paper explores these issues in sections E. and F. below.

[7] Seaman's estimates are converted from 1840 dollars to 1860 dollars for the purposes of this comparison.

1. Firewood Prices by City and Region.

Table A1 in the appendix reports real growth rates in firewood prices for the eight cities in the multi-city index. The first column indicates that prices in Richmond, Washington, New York, Detroit, and New Orleans exhibited positive real growth rates of less than 0.2%. Prices in Philadelphia show no significant trend. In Boston and Portland, Oregon prices increased at 0.46% and 0.48%, respectively. Between 1700 and 1800 prices were essentially flat in the cities with more than just a few price quotes. Between 1800 and 1860 table A1 shows evidence of rapid price increases in Philadelphia (0.8%) and Boston (1.7%). Prices in Detroit (4.4%) and Richmond also increased over this period (0.3%), though the number of price quotes was very small. These relatively rapid rates of change in real firewood prices support the results in table 1 for the same period. Between 1860 and 1917 there is not a significant trend in firewood prices in seven of the eight cities. Only firewood prices in Washington D.C. exhibit evidence of annual growth (0.6%). In the modern era, from 1917 to 2010 the growth rates in firewood prices show considerable heterogeneity across cities. In Washington, D.C., Philadelphia, and Boston, real firewood prices fell at rates between 0.5% and 1%, annually. However, in New York, Detroit, New Orleans, and Portland, real prices increased annually at rates from 0.5% to 1.7%.

Table A2 reports the growth rates of regional firewood prices. These results are largely in accord with those presented in table A1. Over the full sample period, real firewood prices increased, with prices in all regions exhibiting significant growth rates between 0.2% and 0.5%. And, between, 1700 and 1800 regional prices do not show a significant trend. For 1800 to 1860, prices in the Northeastern states show real increases (1.6%). This comports with table A1 which showed that prices in Philadelphia and Boston significantly increased over this period. From 1860 to 1917 there is no statistically significant trend in the price series for any of the four regions. And, from 1917 to 2010, there is evidence of increasing real firewood prices in all regions except for the Northeastern states. The significant price increases in the Southeast, Midwest, and West align with the price increases reported in table A1 for New Orleans, Detroit, and Portland. The negative (though insignificant) coefficient for prices in the Northeast supports the conflicting price trends in Boston, Philadelphia, and New York in table A1.

Summarizing the results from tables A1 and A2, whether analyzed regionally or by individual cities, real firewood prices increased over the 300 years covered in this study. Price increases were concentrated in two periods: from 1800 to 1860 when the U.S. economy was critically dependent on biomass for energy, and after WWI, when households reverted to firewood use especially during the energy crises of the 1970s and during the Great Recession of 2008 (see figure 2). While the latter period of rising prices was widely spread across the U.S., during the period from 1800 to 1860, prices were rising especially in the Northeast.

One explanation for rising prices in the Northeastern states, from 1800 to 1860, is the following. Population levels from the late 1700s through the Civil War era were higher in the Northeast (see figure A6). And European settlement occurred relatively early in this region. Both factors imply greater cumulative demand for fuelwood through the late 18^{th} and early 19^{th} centuries. Given long regrowth periods for mature trees, cumulative consumption over a multi-decade period would have been an important driver of scarcity in fuelwood. Further, population growth in the

Northeast surpassed that of the South from 1840 to 1860 (see figure A6). The associated growth in demand for energy fuels would have pushed suppliers to harvest firewood farther from emergent urban areas. Longer transportation routes would have raised costs and retail prices.

2. Seasonality and Pricing by Wood Type.

While the preceding discussion focused on aggregate price movements as depicted by the city and regional indices, undergirding the indices are more nuanced determinants of market prices. This section examines two important characteristics of firewood markets: seasonality and price differences by type of wood.

The microdata that comprises the city and regional indices facilitates a novel analysis of whether there are predictable fluctuations in the firewood prices and market activity that occur at regular intervals within a year, as one would expect given recurring patterns in supply and demand. The analysis of seasonality may be instructive as to the composition of demand for fuelwood. Predominant use of firewood for space heating suggests seasonally higher prices during the winter heating months, and lower prices during warmer times of the year. In contrast, if firewood were used for industrial process heat, as in early iron foundries, then seasonality may be less pronounced[8].

Figure A7 reports the monthly firewood prices expressed as percentage differences from prices in January. The coefficients are month-of-year fixed effects in a model that also includes firewood type, city, and year fixed effects. The figure indicates that firewood prices exhibit strong seasonality with significantly lower prices from May through September. The discount ranges between 5 and 10 percent relative to January. Another means to test for seasonality in firewood markets is to explore whether the count of suppliers' price quotes fluctuate predictably throughout the year. Figure A8 displays the month-of-year fixed effects expressed as a percentage difference in the number of price quotes from January. As depicted in figure A7, evidence of seasonality is present in the price quotes. Specifically, the number of price quotations during the summer months tends to be between 10-20% lower than in January. Both figures A7 and A8 demonstrate that firewood markets exhibited pronounced seasonality which is indicative of demand for this fuel being primarily to provide space heating services.

Figure A9 presents the results from a regression model that includes wood type fixed effects along with month-of-year, city, and year fixed effects. Specifically, the figure shows the fitted regression coefficients for the wood type fixed effects plotted against the actual energy content per cord of wood, relative to white pine[9]. This comparison suggests that market prices reflect the energy content of the firewood types. Prices for hickory, ash, and oak exhibit 20 percent or greater premiums relative to pine. The ranking of fitted coefficients does not exhibit perfect agreement with energy content. This is to be expected given that firewood consumers may also

[8] James T. Lemon (1987) states that "Large tracts of seemingly endless forest were also kept for charcoaling in the gradually increasing iron industry." And Lemon (1972) points out that "the forests contributed building materials and fuel to farmers and to ironmakers, who used enormous quantities of hardwood charcoal for reducing ore."

[9] White Pine is the excluded wood type in the regression models.

have preferences over burn duration, seasoning time, and ease of splitting. Each of these attributes inherent to the tree species would be captured by the wood type fixed effects.

C. Firewood Income Elasticities and the Comparison of Wood and Coal Prices.

Figure 3 displays the income elasticity estimates produced by model (6). The model is run on 20-year time periods beginning with the period from 1780 to 1800. The most compelling result evident in figure 3 is that the estimated income elasticities switch from being positive prior to the Civil War to negative thereafter until the 1930s. Thus, firewood was a normal good prior to the Civil War and an inferior good thereafter. Prior to the Civil War the estimated elasticities oscillate around a value of about 0.5. The estimates then decline through the remainder of the 19th century to -0.5. After this steep decline, the estimates stabilize around -0.2 from 1915 through the 1930s.

The red line in figure 3 provides one reason for this reversal. It plots the relative prices of firewood to anthracite coal. From 1825, when the anthracite price series began, firewood grew more expensive relative to coal; the average cost of a cord doubled relative to a ton of coal from 1830 to 1861[10]. At this time, the price of a cord of wood, when adjusted for relative energy content, had surpassed the price of a ton of anthracite coal.

During the period when firewood switched from being a normal good to an inferior good, the U.S. economy transitioned from firewood to coal as the primary energy fuel. In 1860, wood comprised 85% of energy consumption (Schurr et al., 1960). By 1900 the coal share of economy-wide energy use was 71% (Schurr et al., 1960). Reflecting the relative price of these fuels, and the energy transition, Clark (1990 p. 263) states "As woodland was cleared and the price of firewood increased, some families started to use imported coal for cooking and heating." In this case, Clark was referring to conditions in Western Massachusetts in the 1840s to 1850s,

The rise of anthracite mining in Northeastern Pennsylvania rapidly expanded coal use in U.S. cities. For example, Chandler reports that in 1824, just 10% of coal consumed in East Coast cities was from anthracite, whereas, in 1835, this share had risen to 80% (Chandler, 1972). Subsequent improvements to the inland transportation networks, canals and then railroads, also resulted in greater market access for coal, and hence, lower prices. Such transportation networks likely also shipped firewood into urban demand centers. Why then were firewood prices on the rise at this time? It is likely that depletion of the forests required longer shipping distances to access timber and bring fuel to urban markets.

Figure 4 provides a more detailed depiction of coal and firewood prices. It compares firewood and coal prices from 1825 to 1900. Figure 4 supports the earlier results in Tables 1, A1, and A2 in that it shows real firewood prices increasing sharply (by 75%) from 1825 to 1860. In contrast, anthracite prices fell by one-half over this period, remaining low through the late 1800s. Similarly, bituminous coal prices fell by 25% between 1850 and 1860.

[10] The red line in figure 4 is a lowess smooth of the ratio of firewood to coal prices.

Table A3 further compares firewood and coal prices (Cole, 1938; CIPR, 2016). The coal prices are reported for Philadelphia, New York, and New Orleans, and are thus matched to the firewood prices for those cities. The general pattern evident in table A3 is that coal prices tended to fall relative to firewood prices over the first half of the 19th century. Across all three of these cities, from 1785 to 1861, firewood prices grew at about 0.8% annually, and coal prices were flat. Philadelphia incurred rapidly rising firewood prices (1.3%, $p < 0.01$), whereas real coal prices exhibited no trend. In New York, firewood prices increased slowly (0.1%, $p < 0.01$) while coal prices did not exhibit a trend. In New Orleans, firewood prices did not exhibit a statistically significant trend. However, coal prices fell by 0.8%, annually ($p < 0.05$).

The preceding analysis, coupled with figures 1, A1, and A10, document a pattern of rising prices and falling consumption for fuel wood, and falling prices and rising consumption for coal. The former suggests an inward shift in supply and demand for wood. The latter points to a rapidly expanding supply of coal that, despite exponentially increasing per capita consumption from 1850 to 1917, resulted in significant real price reductions. These contrasting patterns are evidence of the transition from an economy fueled by wood to one based on coal.

D. Firewood and 19th Century Economic Output.

To estimate the value of firewood output, the cross-sectional average from the regional price series is multiplied by national consumption estimates from Schurr et al., (1960) and USDOE (2017). This valuation strategy reflects the conceptual framework found in the literature (Landefeld and McCulla, 2000) and stipulated in the SNA (SNA, 2008, §6.32; §6.87).

The firewood output estimates are compared to the GDP series provided by Johnston and Williamson (2023), and the GNP series reported by Romer (1989) and Gallman and Rhode (2019) to gauge the magnitude of output relative to total economic activity. To the extent that historical harvest and use of firewood reflected home production and consumption, the value of firewood output should be added to estimates of GDP and GNP that cover market activity (SNA, 2008 §6.32). In contrast, if firewood was used as intermediate goods by firms, or was bought by urban households in organized markets, then the firewood output series estimated here should not be added to the historical GDP and GNP estimates since these are based on the value of final goods, which reflect the embodied value of intermediate goods (presumably including firewood) in final sales. Can one gauge the share of firewood output that passed through the marketplace?

The evidence provided in Schurr et al., (1960) suggests that the majority of firewood consumption occurred in the household. Specifically, in 1850, 90 percent of the estimated 100 million cords used in the U.S. was employed by households, with three-quarters of that total devoted to providing space heating (Schurr et al., 1960 p. 49). In 1879, a more detailed decomposition of firewood use indicates that 96 percent went to domestic use. Of the industrial uses, one-third each powered locomotives and manufacturing activities, and another 12 percent powered steamboats (Schurr et al., 1960 p. 53). While it is clear that firewood use occurred predominantly in the household, it is not at all clear what share passed through markets. If urban consumers relied on the rural agricultural sector for fuel, and such transactions occurred in

organized markets, then firewood consumed by households in cities would already be accounted for in the existing output series. Accordingly, the fact that in 1850 90 percent of wood was consumed by households, and 30 percent of people lived in cities, suggests that roughly one-third of firewood consumed was transacted in markets.

Because of the difficulty in precisely ascertaining the extent to which firewood was traded in markets, to begin, the firewood output series is simply compared to existing the economy-wide output series to gauge the magnitude of firewood output in an economically meaningful way. In a set of provisional calculations, the impact on growth of including the new firewood output series in an augmented measure of GDP is characterized below. In section III.E., the firewood output series is used to analyze agricultural labor productivity.

The results reported in table 2 are estimated coefficients that represent decadal average output shares. Thus, in column (1) for the decade from 1790 – 1800, firewood output estimated in the present study amounts to just under 18% of GDP as estimated by Johnston and Williamson (2023)[11]. As the coefficients in column (1) indicate, from the late 18th century through the first half of the 19th century firewood output increased as a share of GDP, reaching over one-quarter of GDP in the 1830s. After 1840, the firewood share of GDP fell precipitously to under 10% of GDP in the 1870s, and under 1% in the 1910s. This stark reduction in the gross value of firewood consumption relative to overall economic activity is indicative of the transition from fuelwood to coal after the Civil War.

Using Romer's (1989) GNP estimates as the basis for comparison, see column (2), reveals a similar pattern of falling firewood output as a share of total economic activity from 1860 (about 7% of GNP) through 1920 (less than 1% of GNP). Column (3) compares firewood output with Gallman's GNP series (Gallman and Rhode, 2019). The coefficients suggest the value of total firewood consumption amounted to just under one-quarter of GNP in the 1830s and that this share declined rapidly throughout the remainder of the 19th century.

Column (4) compares firewood output to perishable commodity output as estimated by Gallman (1960). This comparison reinforces the findings in columns (1) through (3); firewood output amounted to a large share of the value of commodity production in the early-to-middle decades of the 19th century (nearly 50% in the 1830s) before declining as the U.S. economy transitioned to coal as its primary source of energy in the late 19th and early 20th century.

How do the firewood output estimates reported in this paper compare to the few estimates reported in the literature? Barger (1955) estimates the gross value of firewood from 1869 to 1929 on a decadal basis. Figure A11 in the appendix documents this comparison. In 1869, the gross value of firewood consumption estimated in the present paper is 50% larger than Barger's estimates, which are shown by the solid red line[12]. By the 1890s the estimates in this paper are more than twice that of Barger. Then from the late 1800s to 1930, the output estimates from Barger (1955) and the present study converge. The dashed red line computes firewood output using Barger's prices and the consumption estimates utilized here. The differences between

[11] This share is found by adding the coefficient 0.167 and the constant term 0.007.

[12] This difference is somewhat larger when using the eight-city firewood price index.

Barger's series and the those from the present study are largely unchanged. Hence, the main driver of the divergence between the output series are the respective price series.

Towne and Rasmussen (1960) provide rough imputations for the value of firewood production in the agricultural sector every ten years from 1800 to 1900. An assumed annual consumption rate of one cord per capita is maintained throughout their series, and a nominal firewood price series from Vermont is used to impute changes from an 1879 benchmark price value from the U.S. Census. How does Towne and Rasmussen's output series compare to the present analysis?

In 1800, consumption reported here exceeds that in Towne and Rasmussen by a factor of five. The national average price (from the regional price index) in 1800 exceeds the 1800 price in Towne and Rasmussen by a factor of 4.5 and real output reported in the present study is over twenty-times greater than estimated in Towne and Rasmussen (1960), as shown in figure A12. In 1840, these differences are basically unchanged. In 1900, consumption reported in the present paper is 30% larger than in Towne and Rasmussen, prices are about three-times higher, and output is between three and four times larger. So, while the consumption series converge, because the price series reported here is robustly higher than the imputed series in Towne and Rasmussen (1960), the total value of firewood output reported in the present paper is consistently larger than the estimates in Towne and Rasmussen (1960). The red dashed line in figure A12 employs the new (regional) price series from this paper along with the consumption estimates from Town and Rasmussen. Using the price series from this paper results in convergence of the two output series toward the end of the 19th century.

The analysis in this section yields two important conclusions. First, firewood output comprised a large share of various measures of the total value of economic activity in the U.S. before the Civil War. Second, the new price series presented in this paper play an important role in the difference between existing estimates of the gross value of firewood output and those calculated here. Finally, while some existing estimates of GDP and GNP in the 19th century embodied estimates of firewood output, the novel price series reported in the present paper suggests that existing estimates are biased downward, because of their reliance on very rough imputations of firewood prices.

A final set of provisional calculations examine how GDP growth estimates would change using the firewood output series developed in this paper. First, an estimate of the value of firewood output *already included in GDP* as reported by Johnston and Williamson (2023) is deducted from that series (see appendix A.2 for details). Then the value of firewood output developed in this paper is added back to real GDP in two ways. First, the full value of firewood output is added to GDP, which assumes that all firewood was produced outside of the market boundary. In a second scenario, two-thirds[13] of firewood output is added to GDP, thereby assuming that this share of firewood was produced outside of markets with the remaining one-third already implicitly included in GDP as an intermediate input. The difference in growth rates between real

[13] In 1850, 90 percent of firewood was consumed in the home. Further, roughly 70 to 75 percent of the population lived in rural communities. If one assumes all rural households produced their own firewood, this implies a home production share of about two-thirds: 0.90 x 0.725 = 0.65.

GDP reported by Johnston and Williamson (2023) and the adjusted GDP series is shown in figure A.2.1. (See appendix A.2.)

This figure conveys two findings. First, from the late 18th century through 1840, the adjusted GDP series that embody the firewood output series estimated in this paper appears to have grown more rapidly than the series in Johnston and Williamson (2023). Though the estimates are noisy, the growth rate differences are significant ($p < 0.10$) just prior to the War of 1812, during the mid-1820s and the late 1830s. On an annual basis, the growth differences amount to between 25 and 75 basis points. Second, from the 1840s through 1870, the adjusted GDP series grew less rapidly than the Johnston and Williamson (2023) series. This includes a period between 1853 and 1870 during which the differences were both large (up to 100 basis points, annually) and statistically significant ($p < 0.01$). The firewood price series drive these differences.

First, as appendix A.2 documents, following Gallman (1966) the reconstructed firewood output series deducted from GDP employs the same firewood consumption data as used in the present paper (Reynolds and Pierson, 1942). Further, during the period from 1800 to 1840, real firewood prices gathered in this paper grew especially rapidly (see the discussion of table 1 above). In contrast, the firewood prices in the Johnston and Williamson series (which were interpolated from 1809 to the 1830s) were essentially unchanged. Then during the 1840s through the 1850s, the interpolated prices comprising the Brady firewood price index (1966) increased at 2 percent annually (See figure A5.) Over this same period the real firewood prices gathered here exhibit a downward trend.

Though implications of the new firewood price data for GDP growth estimates are provocative, it is important to note caveats associated with these conclusions. First, the year-over-year volatility in the firewood prices series and the output estimates produced in this paper is substantial. This permeates the adjusted GDP series and renders many of the comparisons in figure A.2.1 not statistically significant. Second, the attempt to deduct existing firewood output from the Johnston and Williamson (2023) GDP series is surely imperfect. Though it adheres to the explanation given by Gallman (1966), invariably the actual procedure adopted here differs from Gallman's estimates. Third, the appropriate share of firewood output to be added to GDP is uncertain. The range from two-thirds to all of output reflects reasonable assumptions regarding market transactions of firewood. Though these are essentially back-of-the-envelope calculations, they illustrate the impact that the firewood output series reported herein may have on existing estimates of economic growth in the 19th century.

E. Productivity in the Agricultural Sector.

Next, the paper investigates the implications of the new firewood output series for measures of agricultural productivity. In the 18th and 19th centuries, firewood was largely produced on farms (Cole, 1970). As noted by Lebergott (1966) and Ball and Watson (1976), in the early American economy, a very large share of the labor force was engaged in agriculture. As such, especially during the first half of the 19th century, productivity and output per capita for the entire economy were largely driven by the agricultural sector.

Table 3, which begins with a national analysis, presents the analysis of productivity in the agricultural sector from 1800 to 1860. The bottom panels report the results from the analysis using the regional firewood price series, coupled with regional consumption data, to conduct a novel comparison of agricultural productivity in the Northeastern and Southern states between 1800 and 1860.

Table 3 reports growth in total firewood output, agricultural workers, output per worker, consumption (cords of wood) and real firewood prices. The top panel covers the period from 1800 to 1860, inclusive of all regions. Firewood output increased at a rate of 3.8% annually, in real terms. Column (4) indicates that consumption in physical units was rising by over 2.5% annually, and as previously reported, column (5) shows that real prices were also rising between 1 and 2%. Nationally, the agricultural workforce increased by 2.2% annually. Thus, output per worker increased by 1.6%. Weiss (1993) provides estimates of growth in agricultural output per worker from 1800 to 1860 ranging from 0.61 to 0.70%.

How would including the new estimates of firewood output affect productivity estimates? First, it is important to note that Weiss' estimates include the rough imputations for firewood production in the agricultural sector reported by Towne and Rasmussen (1960). Accordingly, how the new output series would affect agricultural productivity estimates depends on both the levels and the rates of change in firewood output reported by Towne and Rasmussen (1960) and in the present paper. The previous section documented the difference in levels; this comparison suggests that firewood output would have comprised a much larger share of agricultural output than what is included in Weiss' (1993) estimates. Specifically, from 1800 to 1860, firewood output as estimated by Towne and Rasmussen (1960) amounts to no more than 2.5% of total agricultural output. In marked contrast, the firewood output estimates produced and reported in the present paper comprise between 20% and 35% of total agricultural output[14]. Thus, inclusion of the new output series, which suggest more rapid productivity growth, would likely appreciably increase the productivity growth estimates in Weiss (1993).

To characterize the implications of these estimates for agricultural productivity growth, the (log form) output per agricultural worker is regressed on decadal fixed effects from 1800 to 1860, using the regression specification in (5). One regression uses Towne and Rasmussen's (1960) estimates, a second regression substitutes the measure of firewood output estimated in the present study along with output from crops and livestock in Towne and Rasmussen (1960). The coefficients from these regressions are reported in figure A13. There are noticeable differences from the 1820s to the 1840s. This period coincides with especially rapid real price increases in the new price series reported in this paper.

In each decade, the results suggest that agricultural productivity growth was higher using the firewood output estimates reported here. Specifically, output per worker during the 1820s was estimated to be equivalent to the 1800 – 1810 period using the Towne and Rasmussen firewood output series, and 10% higher than during the 1800 – 1810 period using the output series from

[14] These are comparisons to the total agricultural output estimates reported in Towne and Rasmussen (1960) inclusive of crops and livestock.

the present study. During the 1830s productivity was estimated to be about 32% higher than during the 1800 – 1810 period using the Towne and Rasmussen output series, and nearly 40% higher using the output series from this analysis.

The upshot of this comparison is that the firewood output series estimated in the present study makes a non-trivial adjustment to earlier calculations of productivity in the agricultural sector of the U.S. economy from 1800 to 1860. This stems from two factors. First, the price series reported here improves upon the incomplete and geographically limited price data in the literature. Second, the magnitude of firewood output computed with this new price series is large relative to total agricultural output.

The middle panel of table 2 analyzes agricultural productivity in the Northeastern states. In this region, firewood output increased by 3.4% per year and the agricultural workforce increased by just about 1.5% annually. Thus, year-over-year, output per worker grew at nearly 2%. In contrast, in the Southern states, while firewood output also increased (2.5%) the agricultural labor force grew more rapidly. Hence, output per worker actually fell over this period; the fitted coefficient suggests a decrease of about 0.2% annually, though it is imprecisely estimated. Columns (4) and (5) shed additional light on the comparison between the Northeastern and Southern states. In the Northeast, consumption grew at 1.8% while in the South, consumption nearly reached 2.5% annually. However, real prices appreciated at 1.6% in the Northeastern states, while prices did not exhibit a clear trend in the Southern states. Thus, two factors appear to drive the differences in estimated labor productivity between 1800 and 1860: more rapid growth in the number of agricultural workers in the South, and real firewood price increases in the Northeast.

IV. Conclusions and Discussion

This paper presents the most comprehensive dataset of firewood prices in the U.S. compiled to date. The series encompasses over 6,000 price quotes over three centuries from 1700 to 2010. Though little-used in the modern era, firewood and its derivative products powered the early American economy. At the time when the Civil War began in 1860, energy consumed from wood amounted to 85% of total energy used in the U.S. (Census, 1975). Despite its significant role in the development of the early American economy, pricing data is conspicuously absent from official government statistics and the scholarly literature.

Cole (1970) argues that firewood prices were not systematically recorded because, during the 18th and early 19th centuries, firewood was harvested and consumed on farms, in a de facto informal sector. Urbanization increased fuel demand among consumers that could not grow their own fuel (Lemon, 1972). Hence, more formal firewood markets emerged, and pricing information began to appear in print. This study makes use of text recognition software, digital, archived advertisements, public, industrial and commercial records, and a collection of existing price quotes to compile the new price series.

The newly assembled firewood prices enable analyses of three topics that are of foremost importance to the study of the 19th century American economy: the role of relative prices in the energy transition from firewood to coal, the real value of firewood output relative to GDP, and

the implications of new firewood output estimates for GDP growth and productivity of the agricultural sector. This study attempts to fill these gaps.

The central results from these analyses are as follows. First, real firewood prices increased over the 1700 to 2010 period. The increases were concentrated between 1800 and 1860, and after 1917, especially from 1970 to 2010. Between 1860 and 1917 firewood prices kept pace with inflation. The period of rising firewood prices from 1800 to 1860 preceded the U.S. economy transitioning from firewood to coal as the primary energy fuel. In 1860, coal just comprised 15% of energy consumption and by 1900 the coal share of economy-wide energy use was 71% (Schurr et al., 1960). This analysis provides new evidence of a fundamental change in the relationship between firewood consumption and per capita income that occurred during the transition from an economy fueled by wood to one based on coal.

Second, the gross value of firewood output amounted to a large share of existing estimates of GDP, GNP, and perishable commodity output. The peak share of GDP and GNP was about 25%, that for commodity output was almost 50%. These peak shares occurred during the 1830s. The values reported here suggest that, when used as a source of energy, American forests contributed significantly to national economic output.

In a set of provisional calculations, this analysis replaces estimates of firewood output in historical GDP series with that produced in this paper. Then, growth in this adjusted GDP measure is compared to the existing series between 1790 and 1890. The results of this exercise indicate a substantial upward revision of real growth between 1800 and 1840 followed by a significant downward adjustment to growth between 1840 and 1870. The driver of the differences in estimated growth rates appears to be the new firewood price series presented in this paper.

The analysis of early American GDP highlights the importance of recognizing the inherent difficulty in valuing home production or that occurring in informal markets. Existing literature and the SNA clearly suggest that the value of firewood output should be included in measures such as GNP or GDP (Landefeld and McCulla, 2000; SNA, 2008 §6.32). However, while it is reasonably clear that most firewood was produced on farms and consumed by households (Schurr et al., 1960), the share of firewood that passed through organized markets is not. Thus, incorporation of the value of firewood into the GDP series as is done in this study yields results that must be viewed as suggestive or provisional.

Third, this study leverages evidence that firewood was largely produced on farms (Cole, 1970) to revisit agricultural productivity measurement in the 18th and 19th centuries using the novel firewood output estimates reported here. As noted by Lebergott (1966) and Ball and Watson (1976), the labor force in the early American economy was largely comprised of agricultural workers. Accordingly, an assessment of productivity growth in the agricultural sector during this time likely informs inferences about economy-wide productivity growth. This study finds that real firewood output per agricultural worker rapidly increased from 1800 to 1860 at about 1.6 percent per year. These productivity gains were concentrated in the Northeastern states. In the

Southern states, rapid increases in the agricultural labor force essentially kept pace with the growth in firewood output – nullifying any productivity gains.

Including firewood productivity into the agricultural sector output estimates reported in Towne and Rasmussen (1960) significantly revises agricultural productivity growth in the 1820s and 1830s. Thus, what had been viewed as a period of middling productivity growth (Towne and Rasmussen,1960) appears to have exhibited relatively rapid growth. This analysis shows that while consumption of firewood was increasing at a rate very close to the overall population, and only slightly faster than the agricultural labor force, real price appreciation meant that growth in firewood *output* exceeded both population growth and that of agricultural workers. The apparent mischaracterization of productivity in the literature was due to missing prices for firewood which have been gathered and made available in the present study.

The data gathered and employed in this study may inform future research. Two areas for future research are highlighted here. One clear application is to the study of the cost-of-living in colonial and pre-Civil War America. Households were reliant on firewood for heating and cooking and the new price series constitutes a significant upward revision over existing firewood price series in the literature (Brady, 1966). A second application is the recalculation of consumer price indices. Early fuel and light indices encompass coal; the price data reported here enable inclusion of firewood for cities, regions, and the country as a whole. Revised consumer price indices may influence estimates of real growth in the early American economy. Beyond these two topics, other researchers in economic history can use the data assembled and reported in this study to explore a host of related topics that had been out of reach.

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Tables

Table 1: Growth Rates in Real Firewood Prices.

	(1)	(2)	(3)	(4)	(5)
	1700 - 2010	**1700 - 1800**	**1800 - 1860**	**1860 - 1917**	**1917 - 2010**
Multi-Region	0.00325***[A]	0.0000118	0.00997***	-0.000749	0.00451***
Index	(0.000265)	(0.00284)	(0.00220)	(0.00179)	(0.000689)
Constant	-4.837***	0.891	-17.03***	2.736	-7.388***
	(0.510)	(5.004)	(4.029)	(3.416)	(1.350)
adj. R^2	0.255	0.014	0.158	0.024	0.138
N	729	80	118	215	316
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	1700 - 2010	**1700 - 1800**	**1800 - 1860**	**1860 - 1917**	**1917 - 2010**
Multi-City	0.00224***	0.000563	0.00741***	-0.00320	0.00129**
Index	(0.000235)	(0.00264)	(0.00186)	(0.00194)	(0.000640)
Constant	-2.859***	-0.0827	-12.23***	7.566**	-1.055
	(0.457)	(4.654)	(3.403)	(3.719)	(1.256)
adj. R^2	0.153	0.161	0.147	0.214	0.094
N	1131	109	168	325	529

A = OLS regression coefficient of natural log of real firewood price on year. Robust standard errors in parentheses.

The multi-city index regression models include city fixed effects. The multi-region index regression models include region fixed effects.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Table 2: Firewood Output and Gross National Product.

	(1)	(2)	(3)	(4)
	GDP	**GNP**	**GNP**	**Perishable Commodity Output**
	Johnston and Williamson	**Romer**	**Gallman**	**Gallman**
1774 – 1790	0.280***[A]			
	(0.0639)			
1790 – 1800	0.167***			
	(0.0262)			
1800 - 1810	0.192***			
	(0.0171)			
1810 - 1820	0.168***			
	(0.0296)			
1820 - 1830	0.220***			
	(0.0259)			
1830 - 1840	0.267***		0.212***	0.238***
	(0.0327)		(0.0308)	(0.0647)
1840 - 1850	0.156***		0.148***	0.112***
	(0.0129)		(0.0116)	(0.0233)
1850 - 1860	0.103***		0.101***	0.0544***
	(0.00435)		(0.00477)	(0.0115)
1860 - 1870	0.125***	0.0658***	0.0700***	
	(0.0261)	(0.000452)	(0.00111)	
1870 - 1880	0.0732***	0.0540***	0.0588***	-0.0258*
	(0.00566)	(0.00491)	(0.00614)	(0.0151)
1880 - 1890	0.0440***	0.0341***	0.0318***	-0.0915***
	(0.00342)	(0.00224)	(0.00313)	(0.00595)
1890 - 1900	0.0199***	0.0173***	0.0111***	-0.138***
	(0.00156)	(0.00118)	(0.00174)	(0.00366)
1900 - 1910	0.00827***	0.00858***		-0.167***
	(0.00113)	(0.000999)		(0.00288)
1910 - 1920	0.00244***	0.00274***		
	(0.000765)	(0.000677)		
1920 - 1930				
Constant	0.00678***	0.00560***	0.0175***	0.216***
	(0.000533)	(0.000452)	(0.00111)	(4.49e-09)
adj. R^2	0.483	0.885	0.842	0.807
N	155	61	67	67

A = OLS regression coefficient of firewood output as a share of GDP, GNP, or the value of perishable commodities on decadal indicators. Robust standard errors in parentheses.
*** p < 0.01; ** p < 0.05; * p < 0.10.

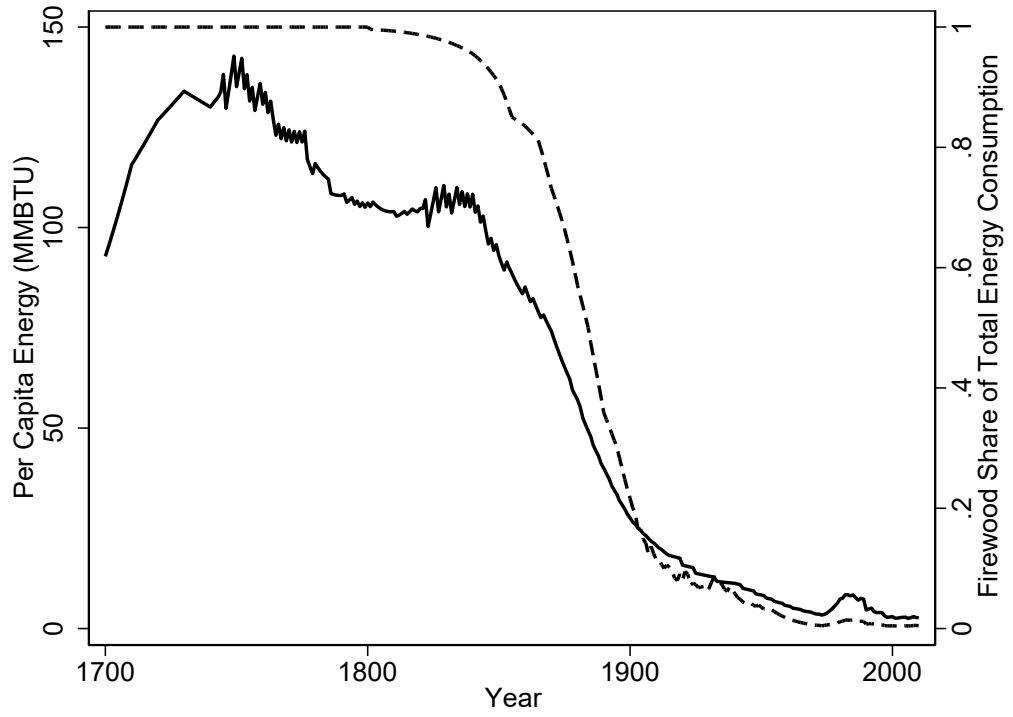
Table 3: Productivity Growth in the Agricultural Sector from 1800 - 1900.

	(1) Firewood Output	(2) Agricultural Workers	(3) Firewood Output/ Worker	(4) Consumption (cords)	(5) Real Price
			1800 – 1860		
Year	0.0380***	0.0221***	0.0160***	0.0266***	0.0114***
	(0.00199)	(0.000265)	(0.00209)	(0.000366)	(0.00193)
Constant	-50.55***	-25.48***	-11.25***	-30.78***	-19.77***
	(3.661)	(0.487)	(3.845)	(0.666)	(3.539)
adj. R^2	0.779	0.994	0.365	0.991	0.245
N	60	60	60	60	60
			Northeastern States: 1800-1860		
Year	0.0342***	0.0144***	0.0198***	0.0179***	0.0164***
	(0.00236)	(0.000336)	(0.00244)	(0.000437)	(0.00238)
Constant	-51.39***	-7.941***	-36.57***	-22.47***	-28.92***
	(4.335)	(0.616)	(4.476)	(0.800)	(4.380)
adj. R^2	0.728	0.976	0.463	0.966	0.383
N	60	61	60	60	60
			Southern States: 1800 - 1860		
Year	0.0248***	0.0272***	-0.0019	0.0248***	-0.0001
	(0.00185)	(0.000268)	(0.00184)	(0.000571)	(0.00157)
Constant	-34.31***	-31.01***	2.579	-35.77***	1.453
	(3.387)	(0.492)	(3.369)	(1.045)	(2.878)
adj. R^2	0.550	0.995	-0.023	0.978	-0.030
N	35	61	35	35	35

A = OLS regression coefficient of natural log of the value of firewood output (1), agricultural workers (2), output per worker (3), consumption (4), and firewood prices (5) on year.
Robust standard errors in parentheses.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

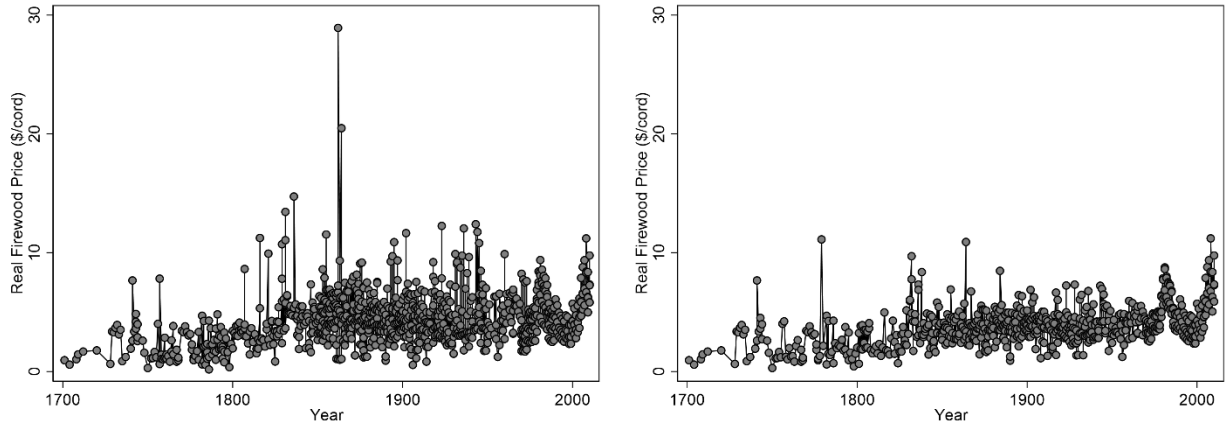
Figures.

Figure 1: Consumption of Fuelwood.



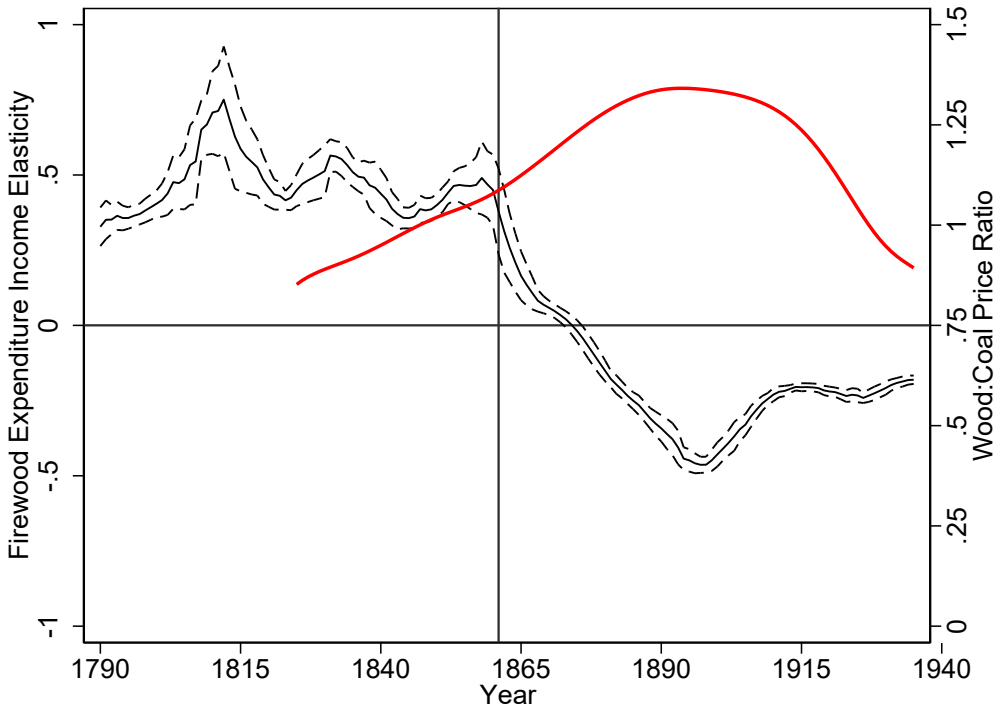
Solid = per-capita consumption from firewood.
Dash = firewood share of total energy consumed in the U.S.
Source: Schurr et al., (1960), USDOE (2019) and author's calculations.

Figure 2: Firewood Prices.



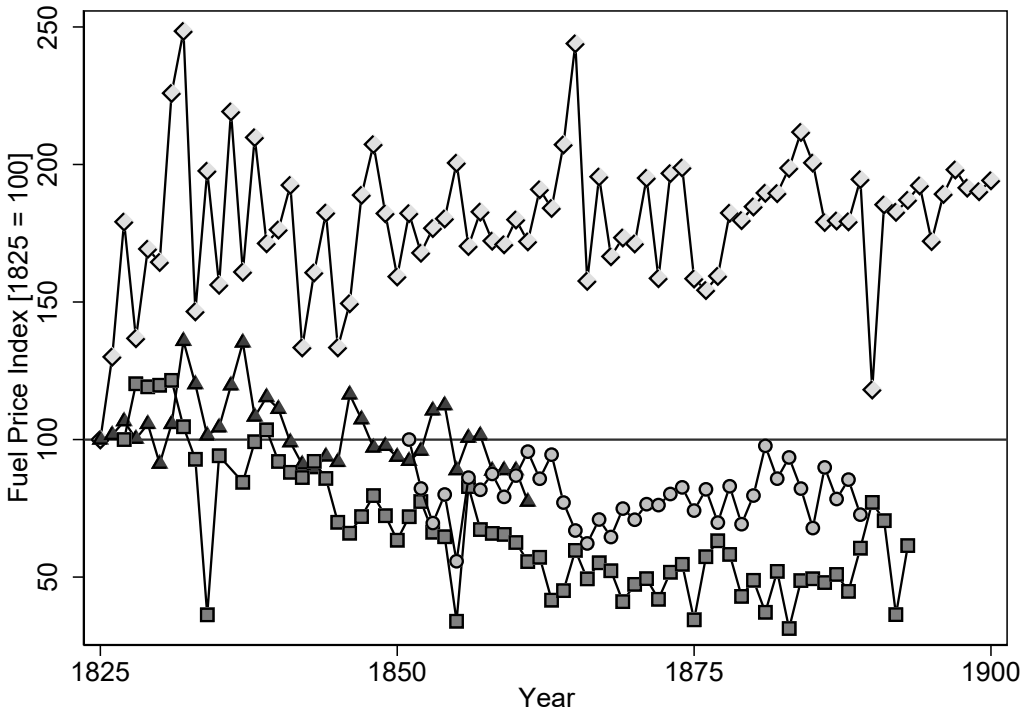
All prices in real 1860 USD.
Left panel: prices in eight cities. Each observation is an annual average by city-year.
Right panel: prices in four regions. Each observation is an annual average by region-year.

Figure 3: Firewood Income Elasticity Estimates.



Solid line: parameter estimates from regression model (6) using total firewood consumption and total personal income.
Dashed lines: 95% confidence intervals.
Red line: Lowess smooth of wood price ($/cord) divided by anthracite coal price ($/ton).
Firewood price is adjusted for average energy content of wood relative to anthracite coal (20 mmbtu/25 mmbtu).
Vertical line at 1861 which marks the beginning of the U.S. Civil War.

Figure 4: Real Firewood and Coal Prices in the 19th Century.



Diamond: Regional firewood price.
Circle: Bituminous coal price (Mass BSL, 1885), index base year is 1851.
Triangle: Coal price (Cole, 1938).
Square: Anthracite coal price (Mass BSL, 1885).

Firewood in the American Economy: 1700 to 2010.

Appendix

Appendix A.1: Tables and Figures.

Table A1: Growth Rates of Real Firewood Prices in Eight Major Cities.

	1700 – 2010	1700 – 1800	1800 – 1860	1860 – 1917	1917 – 2010
Richmond, VA	0.00180***[A]	0.00213	0.00268**	-0.0116	0.00162
	(0.000583)	(0.00552)	(0.000937)	(0.00817)	(0.00109)
	0.067	-0.078	0.295	0.072	0.015
	159	14	15	42	88
Washington, DC	0.00107*	0.0809*	0.00375	0.00600***	-0.00507***
	(0.000552)	(0.00940)	(0.00687)	(0.00169)	(0.00140)
	0.039	0.947	-0.023	0.227	0.122
	133	3	19	48	63
Philadelphia, PA	0.000674	0.000746	0.00796***	-0.00436	-0.00892***
	(0.000478)	(0.00361)	(0.00225)	(0.00418)	(0.00206)
	0.007	-0.037	0.132	-0.000	0.252
	157	27	34	35	61
New York, NY	0.00182**	0.00581	-0.0176	0.0214	0.0174***
	(0.000728)	(0.0132)	(0.0109)	(0.0126)	(0.00347)
	0.052	-0.026	0.092	0.051	0.376
	98	23	17	17	41
Detroit, MI	0.00120*		0.0444*	-0.00318	0.00554***
	(0.000644)		(0.0231)	(0.00359)	(0.00141)
	0.018	No Data	0.137	-0.003	0.185
	128		15	53	60
New Orleans, LA	0.00112**		-0.000991	-0.00546	0.00451***
	(0.000551)		(0.00907)	(0.00449)	(0.00124)
	0.014	No Data	-0.062	0.013	0.127
	141		18	49	74
Boston, MA	0.00456***	-0.00117	0.0166***	-0.00348	-0.00630***
	(0.000554)	(0.00423)	(0.00229)	(0.00258)	(0.00173)
	0.267	-0.023	0.492	0.046	0.161
	196	42	50	34	70
Portland, OR	0.00479***			-0.00555	0.0107***
	(0.00106)			(0.00704)	(0.000936)
	0.224	No Data	No Data	0.011	0.623
	119			47	72

A = OLS regression coefficient of natural log of price on year.
Robust standard errors in parentheses.
*** p < 0.01; ** p < 0.05; * p < 0.10.

Table A2: Regional Growth Rates of Real Firewood Prices.

Era	Multi-Region	Southeast	Northeast	Midwest	West
Full Sample	0.00325***[A]	0.00220***	0.00378***	0.00211***	0.00495***
	(0.000265)	(0.000476)	(0.000388)	(0.000626)	(0.000788)
R^2	0.255	0.123	0.302	0.081	0.297
N	729	197	277	136	119
1700 - 1800	0.00001	0.00213	-0.00026	No Data	No Data
	(0.00284)	(0.00552)	(0.00313)		
R^2	0.014	-0.078	-0.016		
N	80	14	66		
1800 – 1860	0.00997***	-0.0000978	0.0164***	0.0104	No Data
	(0.00220)	(0.00157)	(0.00238)	(0.0166)	
R^2	0.158	-0.030	0.383	-0.007	
N	118	35	60	23	
1860 – 1917	-0.000749	-0.00060	-0.00279	0.00041	0.00075
	(0.00179)	(0.00442)	(0.00251)	(0.00318)	(0.00384)
R^2	0.024	-0.018	0.015	-0.019	-0.021
N	215	57	57	54	47
1917 – 2010	0.00451***	0.00318***	-0.00063	0.00567***	0.0104***
	(0.000689)	(0.00108)	(0.00161)	(0.00139)	(0.000935)
R^2	0.138	0.081	-0.008	0.195	0.623
N	316	91	94	59	72

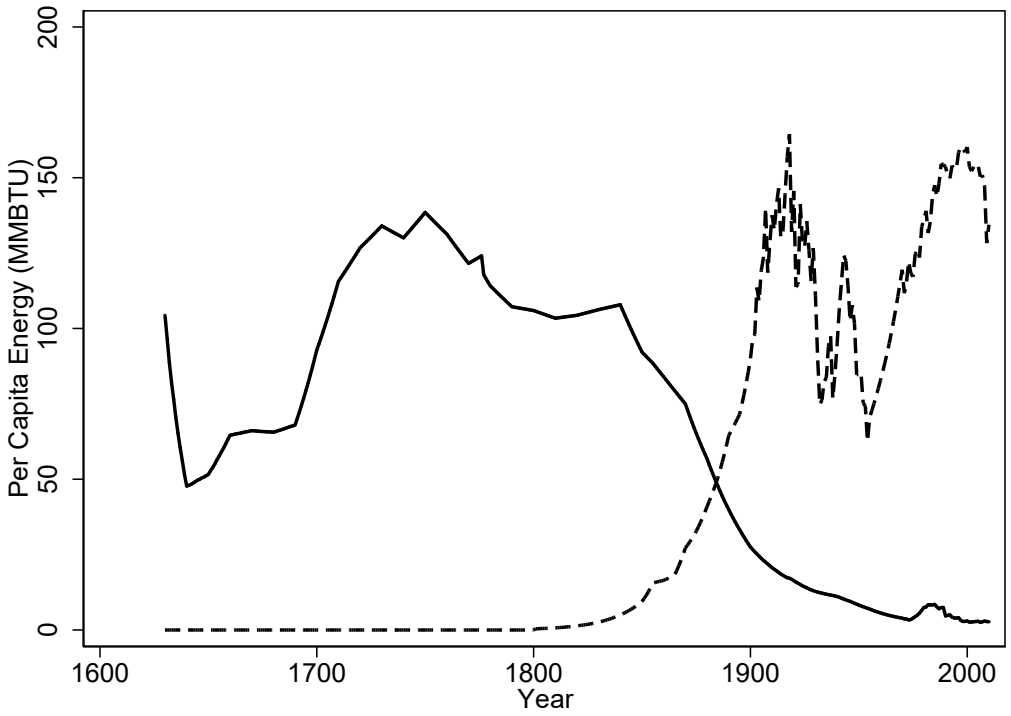
A = OLS regression coefficient of natural log of price on year.
Robust standard errors in parentheses.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Table A3: Comparison of Growth Rates in Real Firewood and Coal Prices.

Region	Multi-City Unweighted Average	Philadelphia	New York	New Orleans
Firewood	0.0126***[A]	0.0131***	0.0010***	0.0037
	(0.0014)	(0.0023)	(0.0034)	(0.0086)
Coal	0.0001	0.0008	-0.0123	-0.0075**
	(0.0008)	(0.0009)	(0.0013)	(0.0034)
Years	1785 - 1861	1785 - 1861	1741 – 1861[B]	1838 - 1861

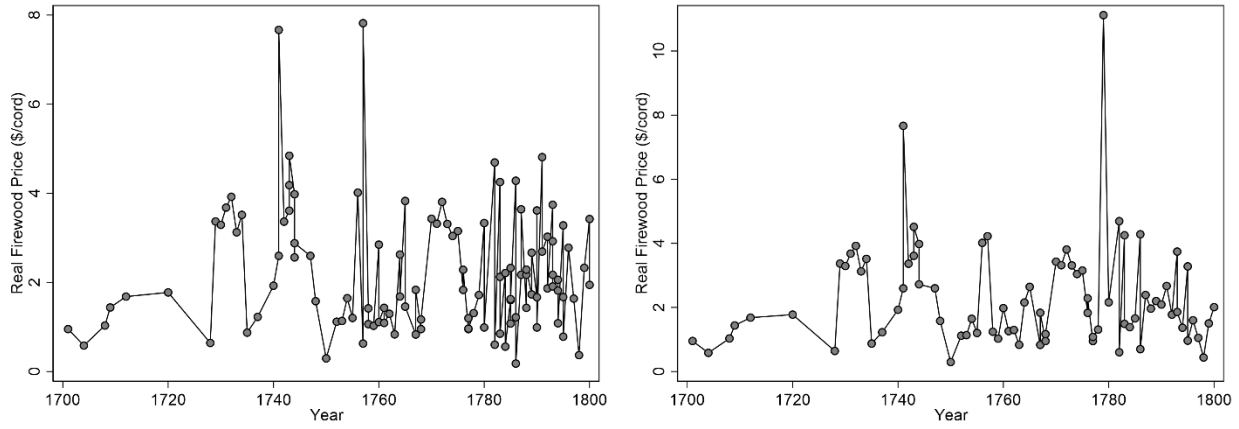
A = OLS regression coefficient of natural log of price on year.
B = New York City wood prices inclusive of 1741 – 1861, New York City coal prices 1797 – 1861.
Robust standard errors in parentheses.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Figure A1: Per Capita Coal and Wood Energy Consumption: 1630 – 2010.



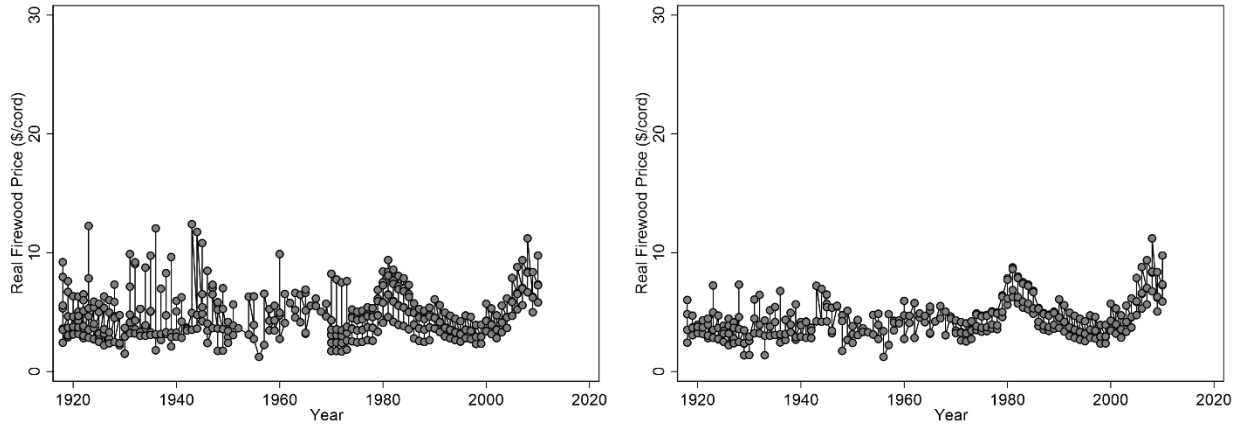
Solid = fuel wood; dash = coal.
Source: Schurr et al., 1960, USDOE (2019) and author's calculations.

Figure A2: Firewood Prices in the 18th Century.



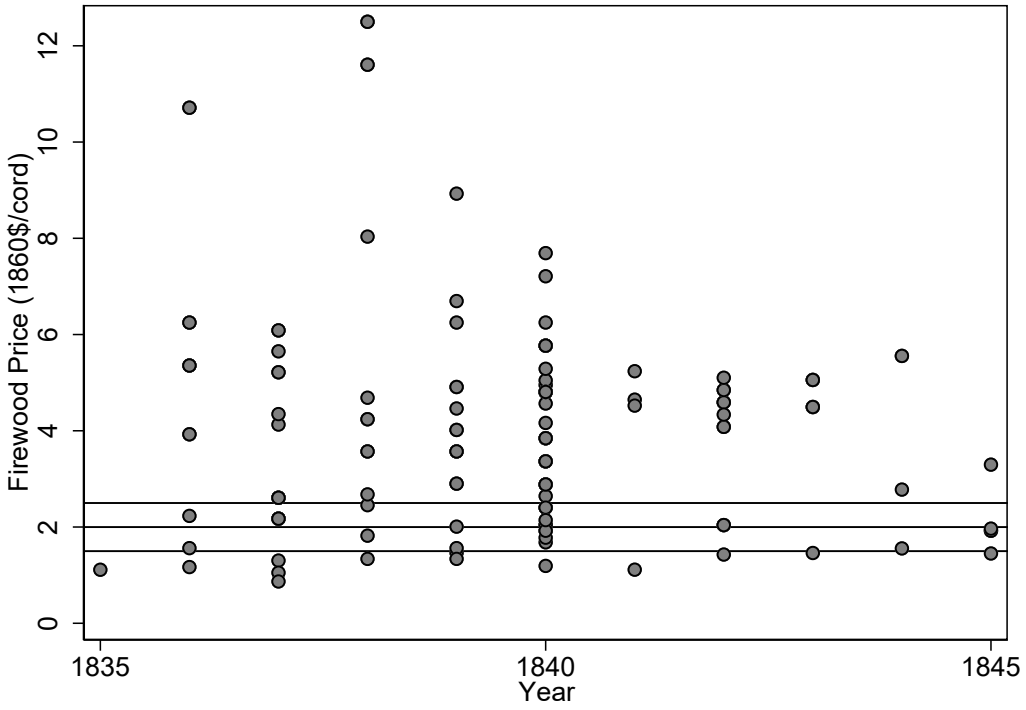
All prices in real 1860 USD.
Left panel: prices in eight cities. Each observation is an annual average by city-year.
Right panel: prices in four regions. Each observation is an annual average by region-year.

Figure A3: Firewood Prices in the 20th Century.



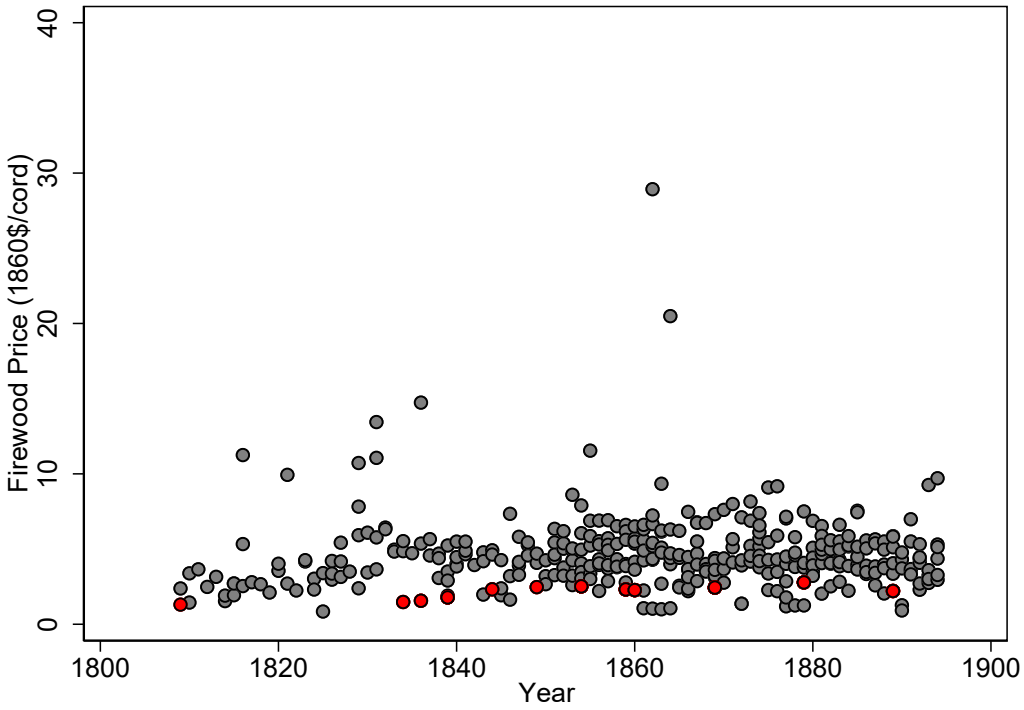
All prices in real 1860 USD.
Left panel: prices in eight cities. Each observation is an annual average by city-year.
Right panel: prices in four regions. Each observation is an annual average by region-year.

Figure A4: Comparison with Seaman (1868) Prices.



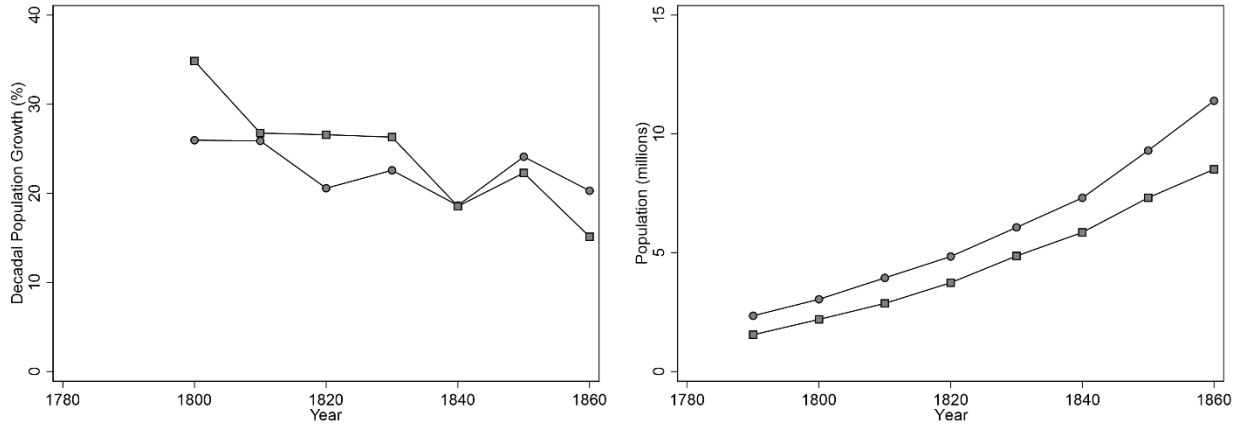
Price data shown drawn from the city price series for Philadelphia, New Orleans, Boston, and Washington D.C., and from the regional series, excluding the western region because there are no price data for the 1835 to 1840 period (Muller, 2019a; 2019b; 2019i). The horizontal lines represent Seaman's (1868) stated and imputed prices for 1840 (converted to $1860).

Figure A5: Comparison with Brady (1966) Index.



Grey circles = eight-city firewood price index.
Red circles = Seaman (1868) price ($2/cord $1840) imputed using Brady Index (1966).

Figure A6: Regional Population 1790 – 1860.



Left panel: population growth rates in Northeastern states (circles) and Southern states (squares). Right panel: population levels in Northeastern states (circles) and Southern states (squares).

Figure A7: Seasonality in Firewood Prices.

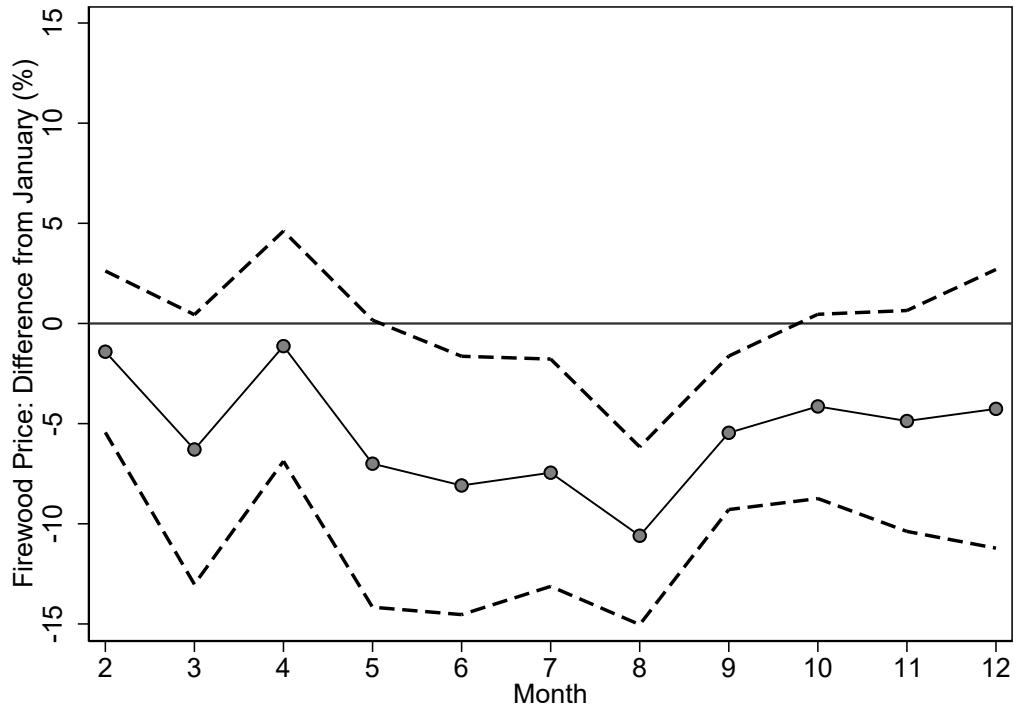


Figure A7 shows the coefficients for month-of-year fixed effects from a regression of ln(price) on year, month, wood type and city fixed effects. The coefficients have been transformed to account for the log approximation: (exp(β)-1) x 100. Dashed lines are 95% confidence intervals.

Figure A8: Seasonality in Firewood Price Counts.

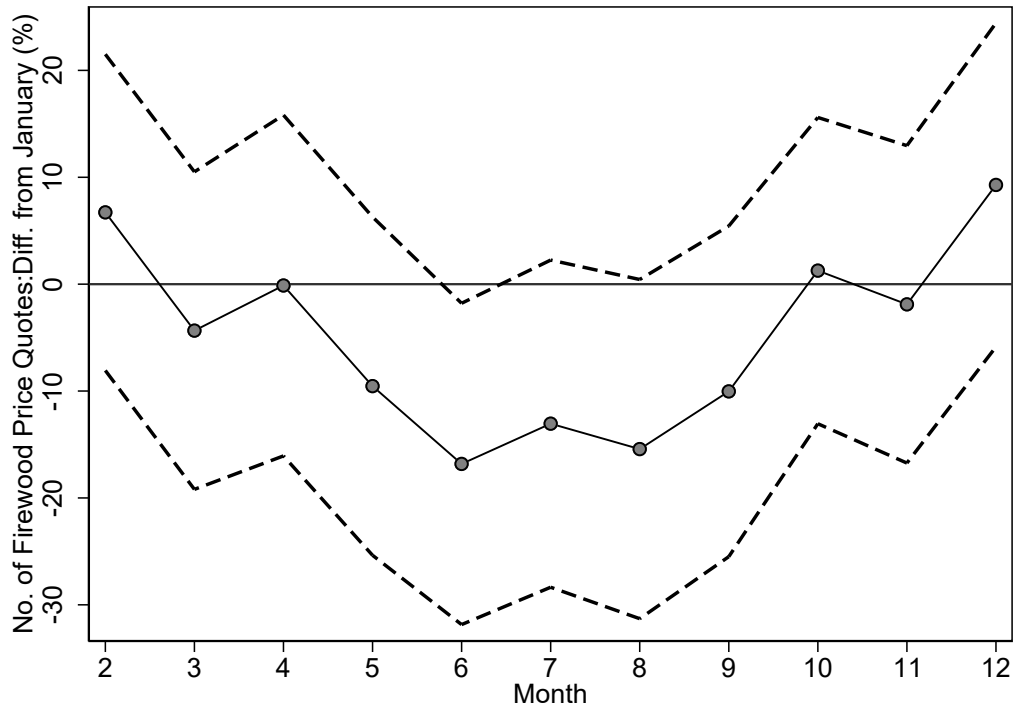


Figure A8 shows the coefficients for month-of-year fixed effects from a regression of ln(# of price quotes) on year, month, and city fixed effects. The coefficients have been transformed to account for the log approximation: (exp(β)-1) x 100. Dashed lines are 95% confidence intervals.

Figure A9: Firewood Prices by Wood Type.

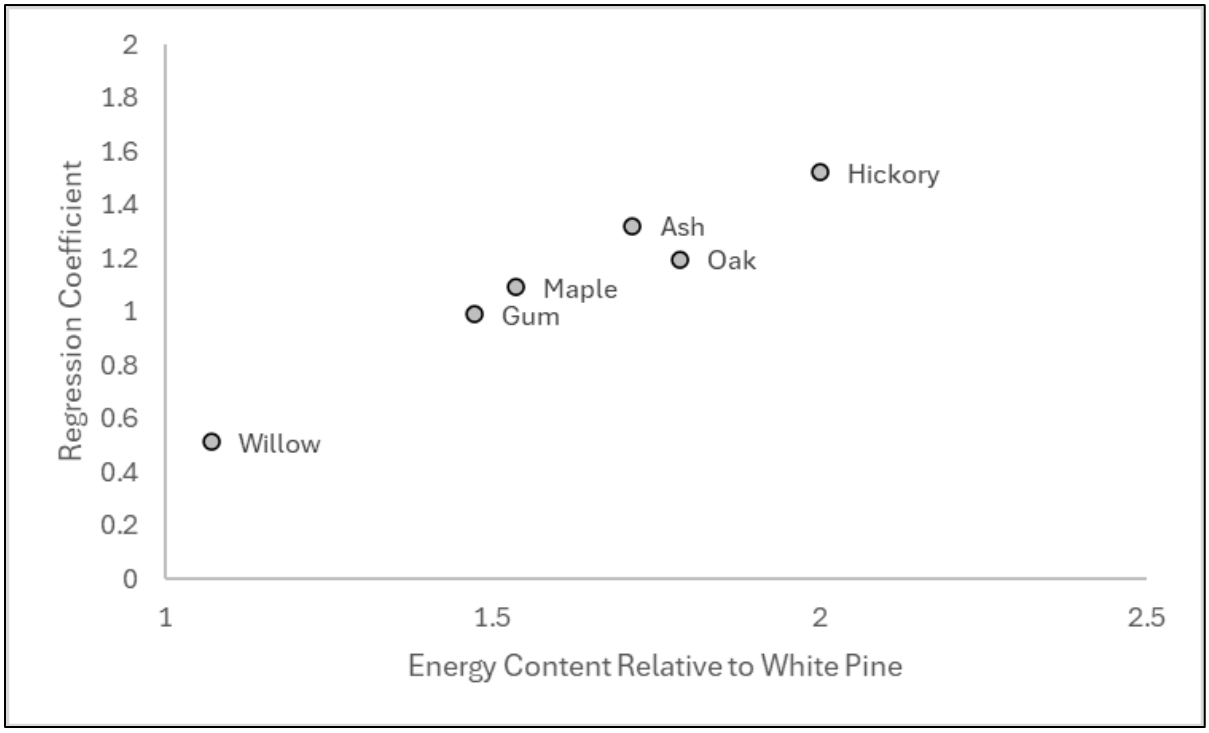
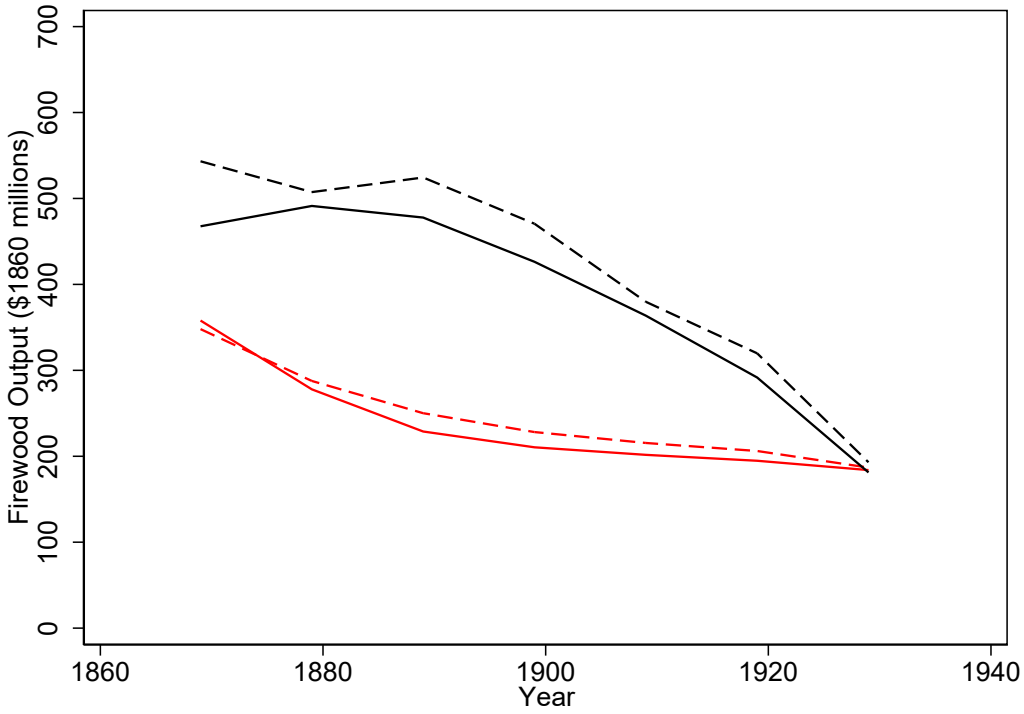


Figure A9 shows the coefficients for wood type fixed effects from a regression of ln(price) on year, month, wood type, and city fixed effects with White Pine as the excluded type. The coefficients have been transformed to account for the log approximation: exp(β).

Figure A10: Combined Coal and Wood Share of Total Energy Consumption.

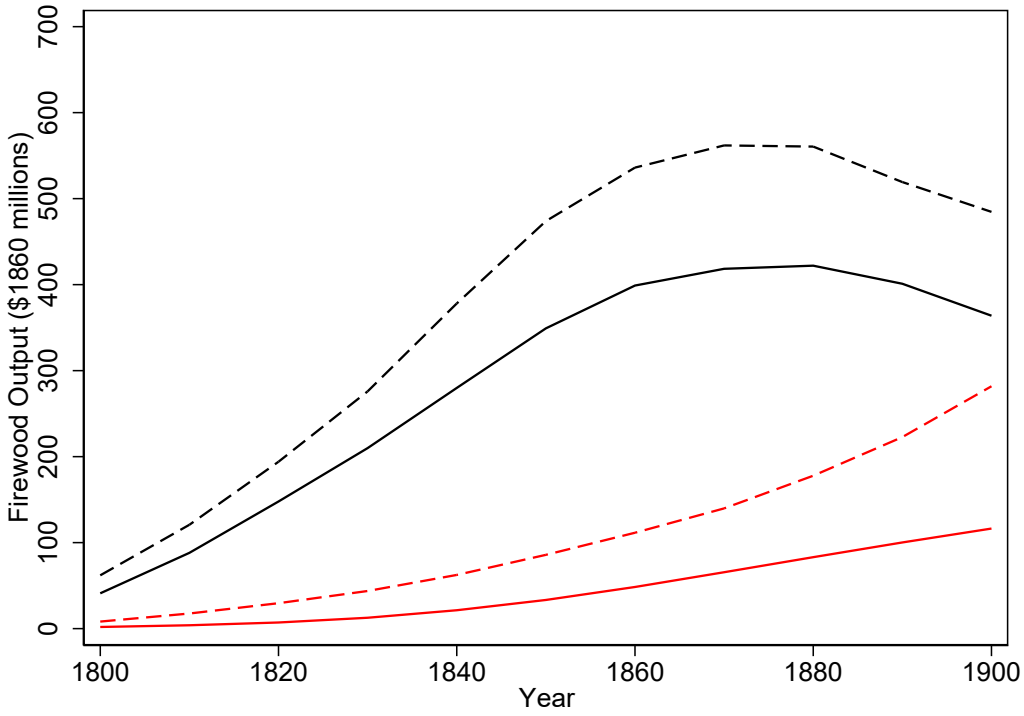
Source: Schurr et al., (1960), USDOE (2019) and author's calculations.

Figure A11: Comparison of Total Value of Firewood Output with Barger (1955).



Red line: Solid = Barger (1955) estimates of total value of firewood output. Dash = total value of firewood output using Barger price and USDA quantity of cords consumed.
Black line: Solid = estimates of total value of firewood output using eight city price index from the present analysis and USDA quantity of cords consumed. Dash = estimates of total value of firewood output using regional price index from the present analysis and USDA quantity of cords consumed.

Figure A12: Comparison of Total Value of Firewood Output with Towne and Rasmussen (1960).



Red line: Solid = Towne and Rasmussen (1960) estimates of total value of firewood output. Dash = total value of firewood output using Towne and Rasmussen price and USDA quantity of cords consumed.
Black line: Solid = estimates of total value of firewood output using the regional price index from the present analysis and USDA quantity of cords consumed. Dash = estimates of total value of firewood output using the eight city price index from the present analysis and USDA quantity of cords consumed.

Figure A13: Firewood Output/Worker from 1800 to 1860.

Figure A13 shows the fitted and transformed coefficients from a regression of the log of firewood output/agricultural worker on decadal fixed effects, where 1800 to 1810 is the excluded case. The transformation is: (exp(β)-1) x 100.

Appendix A.2: Econometric Analysis of Adjusted GDP Growth.

This appendix describes the approach used in section III.D. of the manuscript to estimate growth rates in GDP as reported by Johnston and Williamson (2023) and the adjusted measure of GDP that includes the value of firewood output estimated in the present analysis.

The analysis begins by deducting the value of firewood output embedded in Johnston and Williamson's (2023) GDP series. To do so, the Gallman (1966) firewood series is reconstructed by using the firewood consumption figures from Reynolds and Pierson (1942) and the Brady (1966) price index – see Gallman (1966, p. 56). Prior to and including 1800, the firewood series in Johnston and Williamson (2023) uses estimates of per capita firewood expenditure for 1700, 1750, 1770, and 1800. These (and interpolated) values are also subtracted from GDP. Then, as stated in section III.D. of the manuscript, firewood output estimated in the present paper is added to GDP in full which embodies the assumption that all firewood was produced and consumed outside of markets. A second assumption adds two-thirds of the value of firewood output to markets, based on the urban share of population (30 percent in 1850) and the share of firewood consumed by households (90 percent in 1850).

Equation (A.1) below depicts the regression model used to estimate average differences in GDP growth rates between the series reported by Johnston and Williamson (2023) and the adjusted series described above (denoted $\widetilde{GDP_t}$ in A.1). The regression model uses 10-year growth rates due to the year-over-year volatility in the firewood price data.

$$\left(\frac{\widetilde{GDP_t}}{\widetilde{GDP_{t-10}}} - \frac{GDP_t}{GDP_{t-10}}\right) = \beta_0 + \varepsilon_t \qquad \text{(A.1)}$$

where: GDP_t = real GDP time (t).
$\varepsilon_{i,t}$ = stochastic error term
β_0 = ordinary least squares parameter estimates

The regression model in A.1 is fitted to lagging 20-year subsamples from 1794 to 1890. The coefficients (β_0) and the 95 percent confidence intervals are shown in figure A.2.1. The coefficients represent empirical differences in the 10-year growth rates for each 20-year subsample.

Figure A.2.1: GDP Growth with Alternative Estimates of Firewood Output.

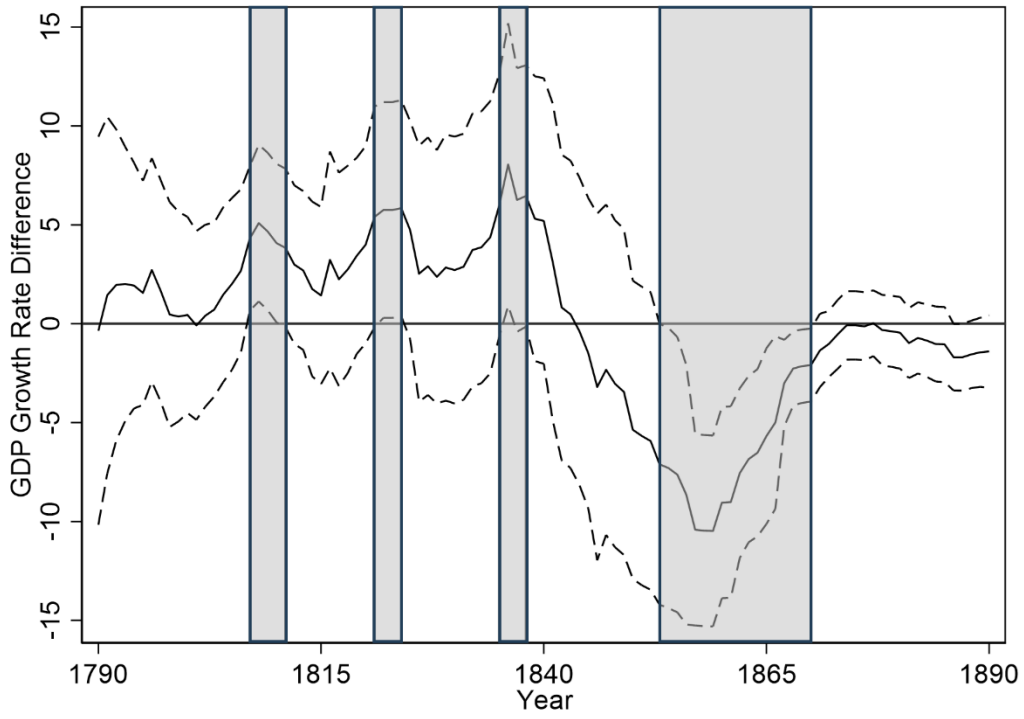


Figure A.2.1 displays the coefficients from model A.1 in percentage points. Annual growth rate differences are estimated by dividing the coefficients by 10. The shaded regions correspond to values of the coefficients that are statistically significant ($p < 0.10$). Figure A.2.1 adds 100 percent of the firewood output data back to GDP and it uses the eight-city firewood price index. The results using the regional index are very similar.

Appendix A.3: Town and Court Records from 17th Century Massachusetts.

As towns and early cities developed in the 17th century New England colonies, private lands could not support firewood demand. Resources on common land came under pressure. Concerns about local firewood scarcity are evident in records from New England towns and courts as early as the 17th century. These archives provide insight into how small colonial communities managed local public goods. Specifically, property rights to harvest firewood from town common lands were managed in (at least) three ways. First, towns explicitly granted and recognized the right to use timber situated on town commons. In the following estate record from the 1690s, rights to access resources on the town commons are explicitly granted to the spouse of the deceased who had

"…liberty to cut Wood and Timber upon ye Common Land of Town, and to feed her Cattell there."

Estate Record of Middlesex County, Massachusetts, April 30th, 1694.

Second, also in the late 17th century, constraints on extraction were established for harvests that were transported out of the town, presumably for commercial sale. The following are excerpts from Town and Court records demonstrating efforts to limit commercial use of firewood from the Town Commons. In the first excerpt, the language clearly targets harvest not for individuals' "particular use", which seems to imply personal consumption.

"The Town of Dux: did agree to impower the Town Counsell to make an order as firmly as they can against the [de]stroy of all Town wood & timber by sending it out of the Town & to impower men to see that the order so made be Ex[e]cuted and farther the Town do[] forbid any man to presume to cut Either cord wood or timber except for their own particular use upon the Town's commons from this day untill the Town Counsell have published their order upon the forfiture of all such wood or timber to cut."

Town Records from Duxbury, Massachusetts, December 13th, 1689

In the following second quote, the court targets firewood that has not been granted to an individual, and thus comprises public resources.

"It is agreed upon and determined by the town that no person or persons shall cut any wood or timber upon any of the to[w]n 's Commons th[…]at is not granted to any persons, so as to convey or transport it out of this town on the penalt[y] of the forfeiture of all such wood or timber so cut as aforesaid, and ten shillings for any timber or cord of wood of the quantit[y] of a cord of wood…"

Court Records from Eastham, Massachusetts, March 10th, 1691

Firewood is heavy and bulky. Transportation of cord wood among towns would have been laborious and costly. For individuals to expect financial gain from such an undertaking suggests significant price differentials existed among towns. The record above is a clear attempt to curtail individuals' response to market forces. One reason for doing so is to manage local scarcity.

Third, towns established regulations against improper timber and firewood harvests; the record indicates these policies were enforced. The first excerpt is from the Massachusetts Record of Valuation and it stipulates that unlawful timber harvest is subject to a fine.

"June 10, 1698 a bill providing that any one who unlawfully cut any **wood** or underwood should pay treble the value of th **wood** , recovered in court action . . Vol . 47 : 182"

Massachusetts Record of Valuation, June 10th, 1698

Next follows a quotation providing evidence of enforcement. (Names of the plaintiff and defendant have been redacted.

"[A] resident in Boston prosecuted by [a resident] of Milton and convicted of stealing from him a cord of wood valued at six Shillings eight pence The Court sentenced him to pay twenty Shillings in money unto sd [resident] being treble damages according to law and fees of Court…"

Town Records of Boston, Massachusetts, May 6th, 1696

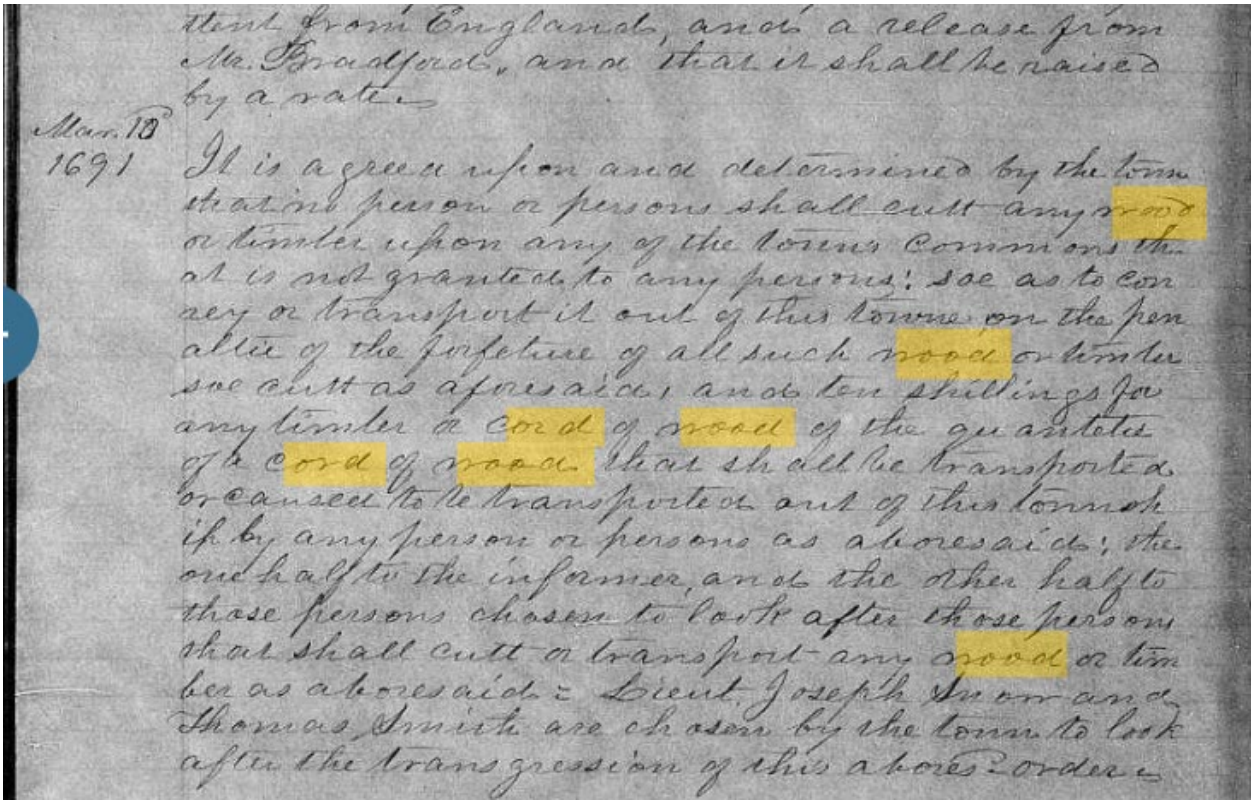
Original Sources and Transcriptions.

These original documents were extracted from the familysearch.org website using keywords "cord" and "wood" restricted to the Massachusetts colony during the period 1650 to 1700.

Court Records from Eastham, Massachusetts, March 10th, 1691

Transcription:

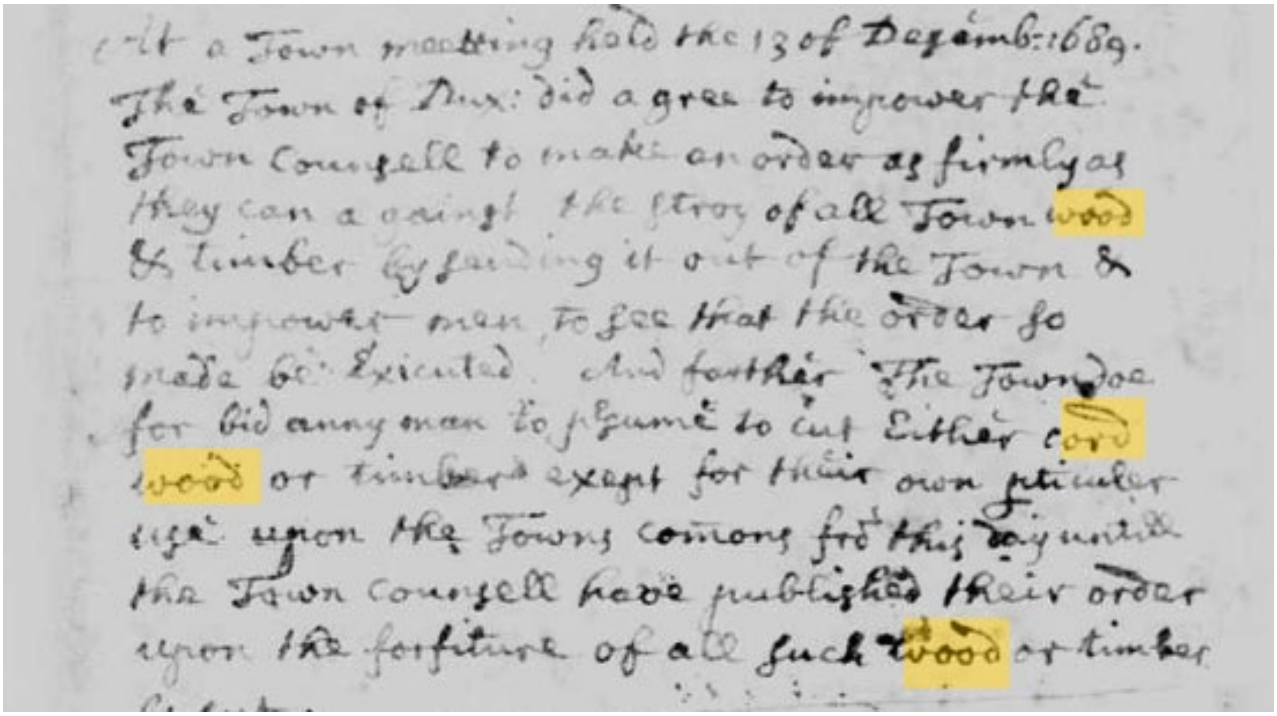
It is agreed upon and determined by the town that no person or persons shall cut any wood or tim ber upon any of the to[w]n 's Commons th[…]at is not granted to any persons , so as to convey or transport it out of this town on the penaltie of the forfeiture of all such wood or timber so cut as aforesaid , and ten shillings for any timber or cord of wood of the quantitie of a cord of wood t hat shall be transported or caused to be transported out of this townsh if by any person or persons as aforesaid ; the one half to the informer , and the other half to those persons chosen to look a fter those persons that shall cult or transport any wood or timeber as abovesaid - Lieut . Joseph Snow and Thomas Smith are chosen by the town to look after the transgression of this above o rder.


Mar. 10
1691
It is agreed upon and determined by the town that no person or persons shall cutt any wood or timber upon any of the towns Commons that is not granted to any persons; soe as to convey or transport it out of this towne on the penaltie of the forfeiture of all such wood or timber so cutt as aforesaid; and ten shillings for any timber a cord of wood of the quantetie of a cord of wood that shall be transported or caused to be transported out of this towneh if by any person or persons as aboresaid; the one half to the informer, and the other half to those persons chosen to look after those persons that shall cutt or transport any wood or timber as aboresaid: Lieut Joseph Snow and Thomas Smith are chosen by the towne to look after the transgression of this aboresaid order.

Town Record from Duxbury, Massachusetts, December 13th, 1689

Transcription:

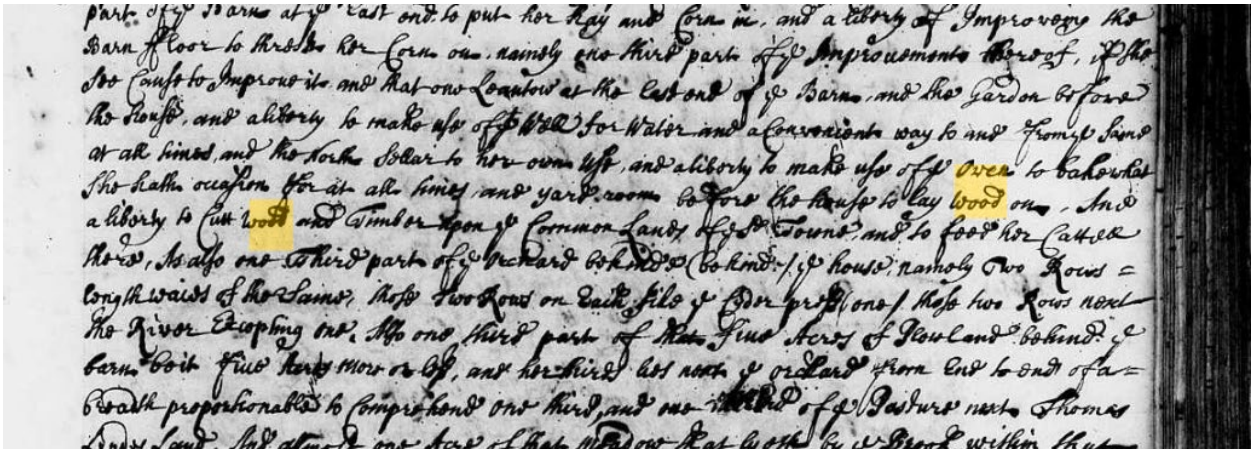
a Town meeting held the 13 of [December,1689]. The Town of Dux : did agree to impower the Town Counsell to make an order as firmly as they can against the [de]stroy of all Town wood & timber by sending it out of the Town & to impower men to see that the order so made be Ex[e]cuted and farther the Town do[] forbid any man to presume to cut Either cord wood or timber except for their own particular use upon the Town's commons from this day untill the Town Counsell have published their order upon the forfiture of all such wood or timber to cut.



Estate Record from Middlesex County, Massachusetts: April 30th 1694

Transcription:

"…liberty to cut Wood and Timber upon ye Common Land of Town, and to feed her Cattell there."



Regulation from Massachusetts Record of Valuation, June 10th, 1698.

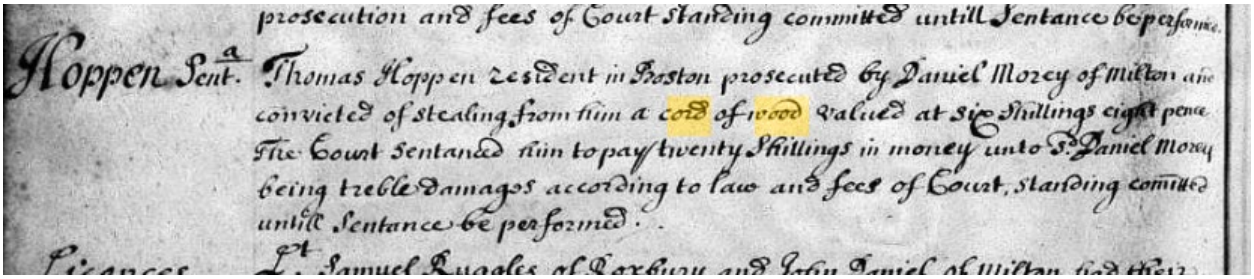
Transcription:

June 10 , 1698 a bill providing that any one who unlawfully cut any **wood** or underwood should pay treble the value of th **wood** , recovered in court action . . Vol . 47 : 182

Sentence from Milton, Massachusetts: May 6th, 1696.

Transcription of Sentence:

Thomas Hopper resident in Boston prosecuted by Daniel Morey of Milton and convicted of steali ng from him a **cord** of **wood** valued at six Shillings eight pence The Court sentenced him to pay twenty Shillings in money unto sd Daniel Morey being treble damages according to law and fees of Court ,


prosecution and fees of Court standing committed untill Sentance be performe.

Hoppen Sent.

Thomas Hoppen resident in Boston prosecuted by Daniel Morey of Milton and convicted of stealing from him a cord of wood valued at six Shillings eight pence. The Court sentanced him to pay twenty Shillings in money unto S.d Daniel Morey being treble damages according to law and fees of Court, standing committed untill Sentance be perfozmed.

Lt Samuel Ruggles of Roxbury and John Daniel of Milton had their

Appendix A.4: Firewood in the 17th Century Colonial American Economy.

This appendix assembles firewood valuation data for Massachusetts from 1645 to 1701 gathered from town, estate, and probate court records. These data are assembled and reported in Muller (2019t). For the most part, the valuation estimates are not prices as observed in market transactions but rather values as reported in asset inventories. The nominal firewood values are strongly positively correlated (0.65, $p < 0.01$) with McCusker's index relating the Massachusetts pound to the U.K. pound sterling (McCusker, 1992a). McCusker's index is based on colonial prices for staples such as molasses, flour, rum, and salt. The positive correlation between nominal firewood values and this index therefore suggests that firewood values reflect prices for other colonial commodities.

Valuation of firewood is denominated in nominal colonial currency (pounds, shillings, and pence) and converted into inflation-adjusted U.K. pounds sterling using McCusker's indices (1992a). The valuation data are then used together with per capita consumption estimates (Reynolds and Pierson, 1942) to calculate per capita expenditure on firewood, or firewood output. For the purposes of comparing total firewood consumption to estimates of colonial GDP, firewood valuations are converted in U.S. dollars from nominal colonial currency and then U.K. pounds sterling using McCusker's (1992a) conversions from the early decades of the 18th century. It should be recognized that this conversion is tenuous and only intended to facilitate a rough comparison of firewood consumption to total economic output in colonial America. Growth rates are estimated using equation (A.2), which uses firewood values (V_t) to demonstrate the specification.

$$ln(V_t) = \beta_0 + \beta_1 Y_t + \varepsilon_t \quad \text{(A.2)}$$

where: β_0, β_1 = statistically estimated parameters.
$\varepsilon_{i,t}$ = stochastic error term
Y_t = year.

Table 1 below reports the estimated growth rates of per-capita firewood consumption in physical units, per-cord values, and per-capita firewood output (the product of values and consumption). During the 17th century, per capita firewood consumption increased at a rate of 0.8 percent annually. McCusker (2000) estimates that real per capita GDP increased at 0.6 percent annually from 1650 to 1720. So, consumption growth appears to have been roughly in line with estimates of economic growth for this period. In contrast, real per-cord firewood values increased far more rapidly; the annual growth rate of 1.7 percent is nearly three times that of real GDP. This rate is robust to whether values are reported in U.S. currency or U.K. pounds sterling. The product of these two series, which reflects per capita energy expenditure, increased at 2.5 percent or four times the rate of GDP growth. Figure A.4.1 below indicates that, cumulatively, the per-cord value of firewood doubled between 1645 and 1700 and that per capita firewood output exhibits a four-fold increase in over the same period. These results suggest that energy expenditure comprised an increasing share of GDP in the 17th century.

Figure A.4.2 below characterizes firewood output as a share of GDP. Between 1645 and 1700, firewood output increased from under 5 percent of GDP to between 15 and 20 percent of GDP. While the GDP estimates used as the basis for characterizing the size of the colonial economy

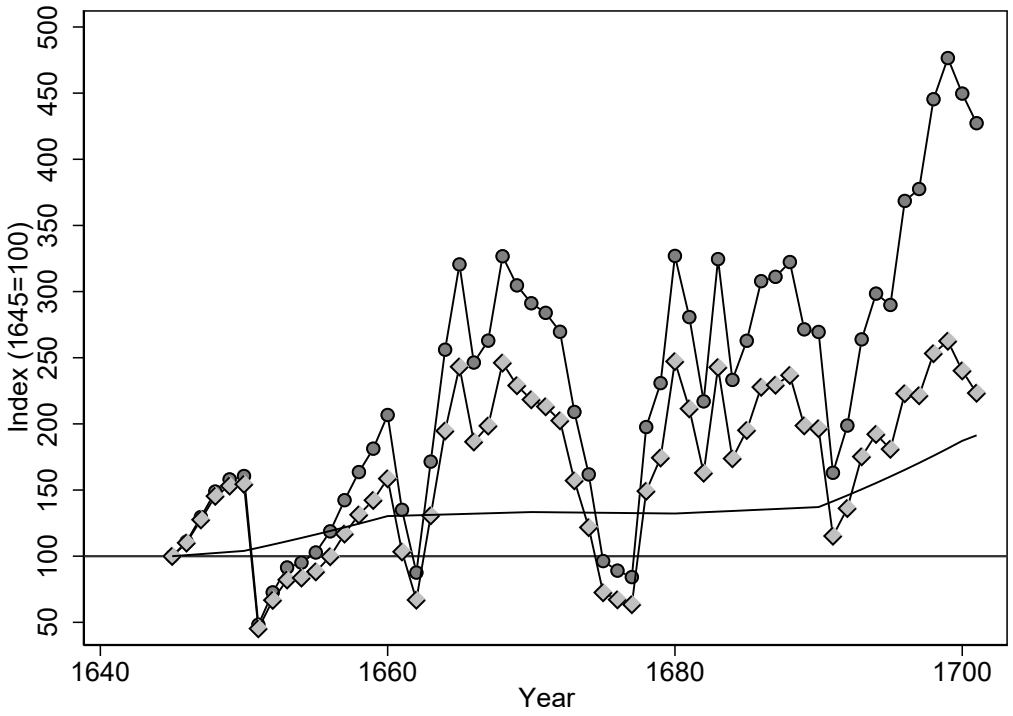
are very rough estimates reported in McCusker (2000), these estimates help to gauge the magnitude of firewood output and the expenditure in the colonial economy on its primary energy fuel.

Table A.4.1: Growth in Consumption/Capita and Firewood Prices.

	U.S. Dollar			U.K. Pound	
	Wood Cons.[A]	Per-Cord Firewood Value[B]	Firewood Output[C]	Per-Cord Firewood Value[B]	Firewood Output
Year	0.008***	0.017***	0.025***	0.017***	0.025***
	(0.001)	(0.002)	(0.003)	(0.00240)	(0.00246)
constant	-12.40***	-30.16***	-42.56***	-30.55***	-42.95***
	(0.980)	(4.024)	(4.134)	(4.024)	(4.134)
adj. R^2	0.814	0.362	0.539	0.362	0.539
N	57	57	57	57	57

Robust standard errors in parentheses.
* p < 0.010; ** p < 0.05; *** p < 0.01.
A = per capita consumption (cords/person/year)
B = Real firewood per cord value (monetary unit/cord)
C = Real firewood output (monetary unit/person/year)

Figure A.4.1: Firewood Consumption, Output, and Price Indices.



Circles: real per capita firewood output. Diamonds: real firewood price. Line: per capita firewood consumption.

Figure A.4.2: Firewood Output and Gross Domestic Product.