The Historical "Roots" of U.S. Energy Price Shocks: Supplemental Results

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This paper provides supplementary results that support the conclusions presented in a shorter paper, “The Historical ‘Roots’ of U.S. Energy Price Shocks.” The author acknowledges the constructive comments from three anonymous referees.

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Supplemental Results

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Abstract:

Sustained energy price increases in the United States have preceded declines in economic activity as far back as 1890. This finding applies to two different historical GDP data sets. It suggests a much longer national experience with rising energy prices that began well before the period after World War Two. This problem emerged well before the US transition towards petroleum products when coal was an important energy source. This relationship varies with the state of the economy and appears less evident during some periods, as in the years following the 1929 stock market crash.

Keywords: economic history, supply shocks, energy and the economy

JEL Classifications: Q43, N51, N71, O51

1. Introduction

Oil supply shocks have dominated the political and economic landscape during the last three decades of the twentieth century. These events often caused economic recession and changed political leadership within the United States (Blinder and Watson, 2016). Today many news organizations and central banks around the globe follow oil price movements with intense interest. Although recent studies have downplayed the magnitude of oil supply shocks under current conditions, this topic continues to attract much attention because political unrest and military conflicts remain important factors in some critical petroleum supply regions (Jaffe and Elass, 2015). These areas continue to supply significant amounts of crude oil, even with the recent expansion with U.S. production.

It is appropriate that the oil supply shock literature has focused on the years after World War Two. During this period oil began replacing coal as the energy engine for the U.S. economy. It is also the era when global oil production began to shift towards the Middle East. Founded in 1963, the Organization of Petroleum Exporting Countries (OPEC) eventually became a dominant energy supplier whose decisions greatly affected global petroleum markets. However, this focus masks the prior U.S. experience with energy shocks in previous decades. Pre-war energy price shocks have been very large and approximately similar in magnitude to oil price shocks after World War Two, as will be shown below. This analysis extends coverage to the earlier U.S. experience and tries to develop meaningful conclusions from this historical record about the impact of energy price shocks on the economy.

There are several important reasons for extending this discussion to the earlier years. First, it is important to know if price shocks were important to the US economy under very different economic conditions. This topic is particularly important because the impacts of energy price shocks on the economy will depend upon the state of the economy and existing policies. Second, understanding the economy's response prior to its dependence upon petroleum may be particularly valuable for developing insights about a range of current issues. If other energy forms like coal also created similar problems, it suggests that policy analysis might want to be concerned about other energy forms like natural gas and electricity, particularly as the economy begins its transition towards electricity and away from coal and other carbon-intensive fuels. Third, it may be illuminating to study a period when the US economy produced virtually all energy that it consumed rather than import significant volumes. If previous periods indicate significant economic costs from energy shocks, the problem may have less to do with whether energy sources are imported or produced domestically. And fourth, there are advantages to studying a period when energy use represented a much larger share of the economy than it does today. Although many factors and conditions shape the economy's response to energy price shocks, the relative dependence upon energy inputs could potentially be important.

The next section discusses previous studies of energy price shocks and how they relate to the long-run historical experience considered here. Section 3 examines the 1890-1930 period and the growing importance of coal mining and the organization of coal unions. Section 4 addresses some important issues related to the source of the data and the properties of the key series. Section 5 documents the results from the years after World War Two, while section 6 evaluates the results from the years prior to the 1929 Stock Market Crash. An effort to combine the two periods is undertaken in the penultimate section, which compares the oil-economy response across the two eras. Summary remarks are outlined in the final section.

2. Past Studies

This approach builds upon two recent efforts to probe the historical "roots" of energy supply shocks and their impact on the economy. Hamilton (2012) reviews a number of very large oil price shocks and emphasizes the role played by geopolitical and military events that are largely external to oil consumers, oil suppliers from more stable regions and macroeconomic policy. These Middle Eastern oil supply disruptions have preceded economic downturns rather than resulting as an endogenous response due to economic conditions in the oil-consuming countries. Certainly, these events are not a clean experiment, as new demand-side shocks cannot be held completely constant when supply shifts in the real world. However, there is a case to be made that oil supply shocks make important contributions to price shocks in this market, even though other factors may be operating, such as currency devaluation, low and sometimes negative interest rates, and world demand growth. Moreover, if economic conditions and policy were the driving factor behind oil price movements and the incentives to produce oil, it would be expected that production from OPEC members and Non-OPEC countries would respond similarly, rising when economic conditions were favorable and declining with adverse economic trends. Similarly, within the Middle East, the largest shortfalls would appear for producers who had the most to gain from curtailing production rather than for the most militant suppliers.

A second important contribution is the analysis by van de Ven and Fouquet (2014) of the UK experience with a combination of coal and oil price shocks over several centuries. These authors employ the long and rich data available for the British economy and show that there are important similarities and differences between major time periods. This finding is an important result because it emphasizes that the relationship between energy and the economy may undergo important changes as the underlying baseline conditions shift.

A number of studies have evaluated the economic impacts of oil price shocks, a fact that is amply demonstrated by several important articles that review the literature (Brown and Yücel, 2002, Jones, Leiby and Paik, 2004, and Kilian, 2008). Rather than repeat many of the insights from these review papers, this section will briefly mention a few points that tie directly to the current effort. Hamilton (1983) concludes that most of the economic recessions after World War Two have been preceded by sudden and sharp increases in the global price of crude oil following a physical disruption in world oil supplies. He argues further those these supply disruptions were essentially external geopolitical factors unrelated to past macroeconomic policies by OECD countries that might have induced delayed supply adjustments by major oil producers (Hamilton 2003). Most importantly, they are disruptive price increases lasting more than a few quarters and sustained over a year and perhaps longer. I will use the term "sustained price shocks" in the sections below to differentiate these price movements from price oscillations in the absence of a major market correction or adjustment. Sustained price shocks need not be permanent, but they should be sufficiently disruptive that the lead directly to an underutilized capital stock.

The nature of these economic impacts have been widely discussed and debated by a number of other researchers whose results are discussed in the various surveys mentioned above. Oil price shocks caused economic recessions in other OECD countries, regardless of whether these nations imported or exported petroleum (Bruno and Sachs, 1985, Mork, Olsen and Mysen, 1994, and Jiménez-Rodríguez and Sánchez, 2005). Smaller price movements appearing in many years after the 1970s had very little if any influence on economic performance, e.g., see the exchange between Hooker (1996) and Hamilton (1996). Similarly, oil price declines had no detectable effects (Mork 1989). Recent studies (e.g., Kilian 2009) indicate the importance of separating oil supply from oil demand shocks. Finally, a series of recent studies have shown that although oil price shocks still matter for the economy, the economic impacts are less than in the past (Nordhaus, 2007, Blanchard and Galí, 2010, and Blinder and Rudd, 2013). Several researchers have argued that the nature of this oil price shock has changed quite dramatically over time. Naccache (2010) explained the weakening of the oil-macroeconomic relationship by the increasing experience with "slow" rather than sudden oil price increases. Nordhaus (2007) too emphasized that oil price movements in more recent periods occur more gradually over relatively long periods rather than as sudden surprise jolts. Finally, Gronwald (2012) provided convincing evidence of the dominant effect of the 1973-74 oil price shock in explaining poor macroeconomic performances, implying that many later price movements were not really price shocks in the same sense of earlier experiences.

For the most part, this literature has focused exclusively on oil prices in the period after World War Two. Important exceptions include an analysis of west coast gasoline rationing in the 1920s (Olmstead and Rhode, 1985) and an assessment of oil price increases on industrial production during the interwar period (Mcmillin and Parker, 1994). Both studies document that these regional price shocks during these interwar years were accompanied by sharp downward movements in regional output and employment but not necessarily in their national counterparts.

3. The Pre-World-War-Two Period

In 1890 the fossil fuel transition within the United States was beginning to evolve, with coal becoming the dominant energy source (Figure 1). Coal was used for power, first in industrial processes and later in electric power in the early 20th century. The growth in electricity replaced petroleum in lighting applications, but eventually oil became the major fuel in transportation. During World War Two, petroleum became the dominant U.S. energy source economywide, although other fossil fuels (coal and natural gas) have also remained important.

Energy was substantially more important for the economy in the 1890-1930 period than after World War Two. Per dollar of real GDP, coal use intensity peaked around World War One and dominated the trend in energy intensity[1] until after World War Two, as shown in Figure 2. Petroleum use intensity emerged as an important contributor between the major wars, but total energy intensity declined substantially with coal intensity after 1920.

The economy depended mostly upon domestic rather than imported energy supplies during this earlier period. Although coal and oil are two energy sources that can be traded

[1] Energy intensity trends are based upon GDP estimates (see Data Appendix) and primary energy consumption reported by U.S. Energy Information Administration (2011). The latter are reported for every five years only prior to 1949. For this reason, it is not possible to weight the energy price shocks by energy intensity in the regressions.

relatively easily, Figure 3 shows that US coal imports have never comprised an important share of the domestic market and that oil imports were not important until after 1970.[2]

Strikes by labor organizations and unions in the coal industry in the early twentieth century happened much more frequently than elsewhere in the economy (Fishback, 1992). More man-days were lost and a larger percentage of the coal workforce was affected than in other sectors.

During the early years of the 1890 decade, organizations representing coal workers extended their presence piecemeal, focusing upon one small strike after another (Blatz, 1991). Organization efforts usually focused on work rules and local issues at a single or several coal mines. Coal prices were relatively stable in these early years. The United Mine Workers of America (UMWA) organized a nationwide strike in bituminous industry in 1897. The union won recognition from many coal mine operators stretching from western Pennsylvania to Illinois.

UMWA organized an industrywide strike for workers in bituminous coal in 1900 resulting in a 10 percent increase in wages. Nationwide, BLS coal prices increased 9.5% faster than during the previous year. The following year, the US economy grew by 2.8% less than the previous year. These events set the stage for the much-publicized coal strike of 1902 that was eventually suspended by a commission established by President Theodore Roosevelt. UMWA won recognition for representing anthracite coal workers in eastern Pennsylvania and raised

[2] Oil import shares for 1910-2015 and coal import shares for 1970-2015 are computed from annual data derived from the US Energy Information Administration. Coal import shares prior to 1970 are computed as the percent of derived coal consumption (production + imports – exports) from US Bureau of the Census (1975) Historical Statistics of the United States, Colonial Times to 1970, Part 1. Series M 93-106. Coal imports from the two sources are from the same source and match exactly for the period that they both report, 1970-2015. Net natural gas imports first became positive but by very small amounts in 1958 (American Gas Association (1978), pp. 23).

wages. Nationwide, BLS coal prices increased 5.5% faster than during the previous year. The following year, the US economy grew by 7.4% less than the previous year.

Figure 4 shows the time profile of annual changes in the average energy price since 1890. This figure clearly documents why economists studying the energy price shock problem should be fascinated with this previous period. Energy price changes prior to 1947 displayed similar patterns to those after 1947 and in some cases represented larger annual price changes than during the later years. These earlier energy price movements happened at a time when the economy experienced a much greater dependence on energy sources per dollar of real GDP.

4. Data Sources and Properties

Economists often use quarterly data because they are advising central banks and government agencies about business cycles. For the current analysis, quarterly data are not available for the early historical period but there exists some interesting annual series that could provide some insights. Generally, using annual data shifts the focus from short-run price volatility and business cycles to sustained energy price surprises and their structural effects on capital stock utilization and economic performance. When prices oscillate within a year, some price increases in one or more quarters may be offset by price decreases in other quarters. It is expected that this tendency will exclude some of the price changes that are purely temporary rather than sustained. These more oscillating price changes are the ones that many researchers (e.g., Hamilton, 2003, and Jiménez-Rodríguez and Sánchez, 2005) try to remove by selecting only those price increases that exceed the maximum oil price over the last three years.

This analysis focuses on the relationship between economic growth and energy price changes. It builds upon the fortunate opportunity that series exist for both concepts covering the entire horizon since 1890. Each variable originates from a single data-collection organization or has been carefully collected and merged for consistency by a major study to improve historical data. One drawback of focusing upon these two concepts alone is that additional relevant variables of comparable quality are not available to construct a more rigorous framework like a structural vector autoregression (SVAR) model. Such a framework might differentiate between supply and demand shocks if appropriate instruments could be identified from the historical data. A bivariate (low dimension) model is not sufficiently robust to identify the structural shocks of interest or to clearly demonstrate causality.

Another disadvantage of using this data to establish causality conclusions exists in its frequency. Techniques for separating supply and demand shocks developed and advanced by Kilian (2009) and Kilian and Murphy (2012) were designed for generating insights about causality using monthly data, while the current study uses annual frequencies. Their approach uses additional prior information about parameters as a supplement to sign restrictions in SVARs. The power in this technique is that it may correctly identify a set of conditions with either a supply or demand shock rather than in some combination of the two events or even a third shock not accounted for in the parsimonious structural model. It is more likely that the framework will omit some important variables when annual rather than monthly frequencies are used (van de Ven and Fouquet, 2014). In these cases, there may be a greater chance that energy prices increase simultaneously with a decrease in energy production for reasons that have little to do with a supply shock. The model will incorrectly identify this coincidence as an energy supply shock.

Although the approach below cannot reveal convincingly that one variable causes the other's response, it can describe the conditional expectation of GDP growth provided that there is information about lagged values for GDP growth and oil price changes. These fairly transparent equations have been used by other researchers, including Hamilton (2003), Nordhaus (2007), Blanchard and Galí (2010) and Blinder and Rudd (2013), for evaluating oil price shocks. These forecasting results may indicate causality if additional arguments could establish that one of the variables -- oil or energy price changes-- is exogenous to the system. Unfortunately, no general conclusions apply uniformly for the 1890-2014 period. This fact seriously complicates any effort to apply one set of rules for exogeneity covering all years. Texas Railroad Commission production quotas, natural gas wellhead price regulations, and electricity price regulation on electric and natural gas utilities made energy prices more exogenous than if they had operated in a free and open market. But these factors operated between the 1930s and the 1960s for oil and possibly later for other energy forms. Prior to and after these periods, it is less likely that oil and energy prices are exogenous, even though standard tests below show that predictive causality runs from energy prices to economic growth but not from economic growth to energy prices. These results apply to both the earlier period as well as for the years after World War Two.

Historical annual data on real GDP was combined with an annual series on energy prices derived principally from the U.S. Bureau of Labor Statistics.[3] The Millennial Edition of *Historical Statistics of the United States* edited by Carter *et al* (2006) developed an extensive historical data set, prepared by Richard Sutch, on the US economy and its growth rate since 1790 with the goal of achieving consistency throughout the horizon. They label their preferred measure for inflation-adjusted economic growth as the "Millennial" series. They also provide an alternative measure which will be referenced as "Alternative GDP" below. Further details on the specifics of these two series can be found in the full description of the Millennial project.

In addition, there exists three major energy price series: the BP Statistics (2015) crude oil price, the U.S. Bureau of Labor Statistics (BLS) crude oil price series and the BLS aggregate price series that includes all energy forms, including major fossil fuel sources such as coal, oil and natural gas.

All variables are converted to logarithms. It is important to evaluate the properties of these annual series because they could differ from their quarterly counterparts. Adjusted Dickey-Fuller tests displayed in Table 1 indicate that the levels of all variables are not stationary (unit roots cannot be rejected) but their first differences are stationary. Table 2 summarizes the means and standard deviations of the change in each variable over the 1891-2014 period. Johansen tests in Table 3 indicate that the energy price and real GDP levels are not cointegrated. Therefore, no long-run equilibrium between the variables for economic growth

[3] The Data Appendix explains the construction of the real GDP and energy price series for the full 1890-2014 sample.

and energy is postulated, although prices may move with each other from one year to the next (the short-run relationship between percent changes).

Results for the Period After World War Two

This section provides a useful benchmark for understanding the earlier historical period by reviewing the results for the 1947-2014 period that followed World War Two. The results based upon annual data for this period are similar to those based upon quarterly data that have appeared in many previous studies. The largest economic impacts occur approximately one year after the energy price shock, which is comparable to the quarterly results where the largest response occurs four quarters after the shock. It is often the fourth-quarter lagged response that is significant at conventional levels in the studies evaluating quarterly data.

In the annual specification, we represent this relationship through a simple VAR with economic growth and energy price changes as dependent variables. Various information criteria tests shown in Table 4 agree that only one annual lagged value for each variable are optimal for the period after World War Two. Tests uniformly reject adding additional lagged values.

Granger causality tests are useful for understanding predictive causality when these two variables are not influenced by a third variable with different lags. Tests in Table 5 confirm that energy price changes precede real GDP changes. There is no evidence that real GDP changes precede energy price changes. The remaining results refer to the equation explaining economic growth and ignores the equation explaining energy price changes where there was no evidence of predictive causality. Although the full sample includes 125 observations, Pindyck (1999) warns about the limitations of unit root tests in small samples when the mean-reverting process is relatively slow.

Table 6 shows an annualized version of the oil-macroeconomy relationship after WW-II often estimated with quarterly data. The first three columns display coefficients when economic growth is estimated on the basis of the lagged values for the BP oil price series, the BLS oil price series and the BLS energy price series. Each equation also includes a very weak and insignificant effect of lagged economic growth on current economic growth. The specification also controls for the Great Recession's impact on the economy in 2009. Excluding the dummy variable for 2009 increases the magnitude and significance of the lagged price effects, but the basic conclusions are very similar.

The lagged oil or energy price variable is uniformly significant at the 1% level. The response to the BLS oil prices is visibly larger than the response to the BP oil price series. The two oil price series are reasonably similar to each other except for the 1970s when domestic crude oil prices represented by the BLS series did not rise as fast as the imported crude oil prices represented by the BP series. The U.S. government had an active price-control program for crude oil and refined petroleum products during most of this decade. Repeal of these price controls began in 1979 under the Carter Administration before they were eliminated in 1981 under the Reagan Administration. Some researchers (Mork, 1989) use the average refiners acquisition cost for all oil, both domestic and imported, to represent price controls during this period.

The magnitude of the response to oil prices but not its significance varies for different periods of the post-World-War-Two era. Additional equations (not reported) were estimated on this period prior to 2009 and prior to 2002. The first such equation eliminates the experience of the Great Recession and any following years. The coefficient changes to -0.044 with a higher t-statistic equal to 3.05, compared to -0.037 (t=2.85) in Table 6 with the BLS series for crude oil prices. Ending the sample in 2001 allows one to evaluate the period prior to when world demand was surging. Its negative response and t-statistic are the highest, at -0.051 (t=3.24). Additional tests could not reject the conclusion that the responses were the same after 2001 (and 2008) as their counterparts for the earlier years in this sample. These tests, however, are not strong due to the limited years covering the second time period. Finally, a structural break in 1973 did not change the results by much, although it reduced the coefficient for the 1973-2014 period to -0.030 (t=2.73).

None of these results differentiate between the impacts caused by oil price shocks due to supply shortfalls and those associated with other oil price movements. It is critical to understand that world oil production reveals little about supply shortfalls. As a fungible commodity, world oil production essentially equals world oil consumption and hence will shift whenever either supply or demand schedules move.

Beccue and Huntington (2005, Appendix E) report a series for gross oil shortfalls (before any offsets) developed by Paul Leiby based upon U.S. Energy Information Administration estimates. Factors causing these shortfalls include interregional conflicts, internal struggles, embargos and accidents. Shortfalls were assigned to each year when they were initiated. When shortfalls extended into the next year by more than one month, they were also counted again for that next year. Some of these events were relatively small, often not exceeding several hundred thousand barrels per day. To focus more directly on larger supply shocks, we set a lower threshold cutoff of 1.5 million barrels per day (MMBD). Only shortfalls that exceed this threshold were included in the shock series. The appendix includes a table with this variable. It should be noted that not all large shortfalls occurred in years when oil prices were rising due to other factors, but there is a reasonable correspondence between the two indicators.

Replacing lagged oil price changes with the lagged physical shortfall measure also produced significant coefficients in equations similar to those appearing in Table 6. This specification follows the approach suggested by Hamilton (2003) and has the benefit of focusing more directly on exogenous supply-side events due to interregional conflicts, internal struggles, embargos and accidents rather than endogenous oil-price responses caused by economic conditions. More interesting, however, is to use this variable to separate the estimates into two groups. If the gross shortfall conditions are met in any year, the price change variable is considered to be a price shock variable due to sudden supply shortages. If gross shortfalls do not reach the lower threshold of 1.5 MMBD, the price change variable is considered to be a price non-shock variable due to other factors. Although the price shock variables may not measure only the effects of supply shocks, this approach provides a transparent why of focusing upon events when supply shocks are important and differentiating them from other oil price movements when supply shocks are absent. The coefficient for the lagged oil price shock variable is - 0.062 with a t-statistic equal to 2.97, compared to -0.037 (t=2.85) in Table 6 with the BLS series for crude oil prices. The coefficient for the lagged oil price non-shock variable is -0.021 with a t-statistic equal to 1.26 that fails conventional levels for statistical significance. These results underscore the importance of focusing upon oil shocks rather than simply oil price oscillations.

The response to the aggregate energy price in the third column of Table 6 is substantially larger than the response to either oil price series in the first two columns. This larger response reflects the greater intensity for energy relative to oil in the economy and the smaller proportionate change in prices for the energy composite that includes the prices of coal, natural gas and electricity that do not change as much as oil prices.[4]

The annual estimates appear to display considerable similarities to the versions estimated by many researchers with quarterly data. Economic declines are preceded by lagged oil and energy price increases, but economic expansions do not follow lagged oil and energy price reductions. The price variable does not need to be transformed into a temporary price maximum for it to be statistically significant, although separating oil price shocks from non-shocks certainly improves the robustness of the results as shown above. Apparently, the annual frequency tends to dampen the volatility evident with quarterly oil price series. These estimates serve as the beginning stage for the current analysis.

A common finding in many studies is that oil price increases dampen economic growth but that oil price decreases have weaker and usually insignificant impacts. One cause for this asymmetric response may be downward price stickiness in wages and other prices that may influence investment through the real supply of money (Blinder and Ruud, 2013, Hickman *et al*,

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[4] This section explains results based upon nominal oil price shocks. In discussing estimates for all years, Section 6 shows that these results are robust to specifying the shocks in inflation-adjusted (real) terms as well. When based upon real energy price movements, the coefficient is -0.073 (t=3.00), or very similar to -0.069 (t=3.17) in the third column of Table 6.

1987). Oil price increases in the past have been passed through to wages and other prices constraining the real supply of money. On the other hand, oil price decreases have not directly reduced wages and other prices because workers and firms are reluctant to accept lower nominal wages and prices. Another factor may be the existence of adjustment costs and unused capacity when energy prices increase or decrease, thereby causing negative impacts even when energy prices are falling (Hamilton, 1983).

In previous empirical tests with quarterly data, oil price increases matter only if they exceed the oil price peak over the last three years. This procedure reduces the effect of oscillating prices and places more emphasis on price increases sustained over more than a single quarter. As discussed previously, the use of annual data performs a similar although perhaps less precise effect. If oil price movements in the regression analysis are separated into price increases and decreases, the response to price decreases is not significant. Price decreases are removed from the specification and the results are shown in the three right-side columns of Table 6. The magnitude of the positive oil and energy price changes are larger than their counterparts to the left for each specification. Beyond that point, the two sets of results in Table 6 are qualitatively similar.

5. Results for the Period Prior to the 1929 Stock Market Crash

The analysis next shifts to the earlier historical period for the United States covering the 1890-1929 period. The analysis initially excludes the 1930-47 period but later discusses the implications of extending the period through 1946. As discussed above, there were oil disruptions during the 1920s and the 1930-1947 years but they were often regional shocks experienced on the west coast and other areas rather than national in scope. As discussed in section 2, other researchers have documented that these regional shocks reduced regional output and employment even though their impacts were more muted at the national level. At an aggregate national level, economic conditions were influenced much more by major non-energy events, such as the 1929 stock market collapse in late October, the Great Depression and World War Two. In evaluating the period prior to 1930, it is important to control through a dummy variable for the substantial energy price increase in 1917 due to the USA joining the Allies. This control influences the economic activity response in 1918 because energy price changes have a one-year lagged effect.

Various information criteria tests were again performed for this earlier period to explore the optimal lag length for the relationship. These tests shown in Table 7 confirm that somewhat longer lagged adjustments are appropriate in many instances. When either oil or energy price changes are included, the Akaike Information Criteria and several other tests find that two lagged values should be included.

Granger causality tests can also be applied to this earlier period, although the low number of observations limit the power of these tests. They confirmed that when there was a significant relationship, economic declines followed energy price increases but not that energy price shifts followed macroeconomic performance. Only one oil price variable is evaluated in Table 8 because the BP crude oil price series uses the BLS series over these years. The results reported in the top half of the table refer to real GDP defined as the Millennial series. It is not surprising that the Granger causality tests explaining the GDP series are not statistically significant when oil prices are included in these equations, because coal and other energy sources rather than petroleum products were powering the US economy during these years.[5] The energy price variable includes these sources and the corresponding Granger causality test is statistically significant, implying that they lead real GDP.

The developers of the historical Millennial data series for economic growth recognized the problems of extending far back into the country's beginnings, using data that often required considerable merging and judgement. This volume also provides an alternative series for real GDP preceding 1929. They do not discuss the relative advantages and limitations of the two economic growth series, but they offer the Millennial series as the primary one in their document. Although this analysis will primarily use the Millennial series, some discussion of the results based upon the alternative series is valuable. Information criteria tests reported in the appendix in Table A-2 indicate that the equations should include only one lagged value for this other GDP series and the energy price variables. The lower part of Table 8 reveal that Granger causality tests are somewhat different than with the Millennial GDP series. They reject no predictive causality at traditional confidence levels (<5%) for oil prices but barely miss reaching this confidence level for aggregate energy prices. These results suggest caution when interpreting results based upon this data source for economic growth. The Millennial series implies that energy prices have predictive causality at conventional levels, while the alternative series suggests that oil prices have a significant role while energy prices just barely miss significance.

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[5] See Figure 3.

The results in the first two columns of Table 9 show coefficients and standard errors for the GDP equation that include two lagged values of the energy price series and real GDP as well as a dummy control variable for the 1917 war-induced energy price shock. Oil prices are included as the energy price series in the first column, while aggregate energy prices replace oil prices in the second column. Both lagged GDP variables are significant, which contrasts with the single lag used in the equation for the period after World War Two. The control for World War One is significant in the equation including aggregate energy prices.

Both lagged aggregate energy price changes have significant effects on real GDP. Meanwhile, the initial lagged value for oil prices is significant at only the 10 percent level. The magnitudes of the aggregate energy price variables are visibly greater than their oil price counterparts.

The results in the last two columns of Table 9 show coefficients and standard errors for the GDP equation that replace oil and aggregate energy price changes by price increases only. Any zero or negative price changes are excluded. The goodness of fit for these petroleum equations is similar to the previous estimates that include both price increases and decreases, but the specification based upon energy prices explains considerably less. The energy price results deserve particular attention, given the importance of fuels other than petroleum during this previous period.

Extending the sample beyond 1929 while excluding only the important Great Depression years of 1930-33 also produces significant fuel price effects. After the Great Depression, however, past economic growth rates begin to have a less pronounced effect on current growth rates in the regression results. Estimated one-year lagged responses to aggregate energy prices are significant at 5% and those for second-year lagged values are significant at 10%. However, the first lag estimate is larger (-0.172) than reported in Table 9 (-0.127), although the second-lag response is comparable (-0.138).

Table 10 provides a similar summary as Table 9 but for equations explaining the alternative GDP series. These results are not as robust as the ones in Table 9. The goodness of fit is less and the single lagged GDP variable is not significant. The lagged price effect, whether for oil or aggregate energy, however, is significant. Either energy price variable is significant when they explain the alternative GDP series. Again, the response to aggregate energy prices is larger than the response to crude oil prices. Finally, when price increases and decreases are entered separately for both oil prices and aggregate energy prices, higher prices have a significant effect on real GDP.

Results for the Combined Periods

The analysis finally shifts to the combined period of the years preceding 1930 and the years following either 1933 or 1947. It is important to exclude the Great Depression years of 1930-33 where factors other than energy prices were clearly influencing economic growth. As a robustness test, it is also interesting to exclude the years 1930-47, because many of the energy price movements in this period were regional rather than national shocks.

Granger causality tests in Table 11 continue to show that energy price shocks precede aggregate economic downturns over this combined sample regardless of which years are excluded or whether oil prices are deflated or not. For example, they reject the hypothesis that past nominal energy prices can be excluded as a predictor of economic growth for the period prior to 1933 and after 1947 with chi-square=14.80 (significant at 0.1% level). Tests applied to the equation explaining energy prices do not reject excluding past economic growth as a predictor in any case.

Estimated coefficients for explaining real GDP since 1892 when it is measured by the Millennial series are reported in Table 12. Coefficients and standard errors are shown for the constant, two lagged values of the energy price series and real GDP, and dummy control variables for 1918 and 2009. Specifications with both nominal (columns 1 and 3) and real (columns 2 and 4) energy prices are shown for robustness. Nominal oil price movements would be the key driver in a neo-Keynesian system with downward wage and price stickiness in the short run. Nominal prices are also likely to be more exogenous than real oil prices because the shock would exclude the endogenous response of inflationary policies. However, additional estimates based upon real oil prices have also been evaluated as a robustness test. This specification would represent the oil price movement as a technology shock in a real-business-cycle framework that also included economic dislocations between sectors and an underutilized capital stock.[6]

The explanatory power of the equations that exclude 1930-47 in the last two columns lies between 14.6% and 18.9%, and these estimates are noticeably higher than those that exclude only 1930-33. The poor performance of the sample that excludes only 1930-33 is due to the insignificant effects for the first and second year lagged effects for real GDP. The lagged

[6] Mankiw (1989) provides a straightforward discussion of these two approaches for explaining aggregate output fluctuations, although his arguments favor the neo-Keynesian framework.

energy price coefficients, however, are significant in either sample and with either nominal or real prices. When lagged two years, the nominal energy price coefficient is significant when 1930-47 is excluded and just barely misses significance (at 5.5%) when only 1930-33 is excluded.[7] In addition, the stimulating effect of World War One on real U.S. GDP is also significant.

Given the relatively low explanatory power of these equations, it might be useful to evaluate whether the responses shifted after the Great Depression. The break between the two periods is already given by the 1929 Stock Market Crash in October and does not need an Andrews test or some similar procedure to determine when the break occurs. Using interaction terms, we can construct series for the constant, energy price change and economic growth for the later period after 1933 (or 1947). The estimates in Table 13 exclude the post-depression interaction terms for the second-year lagged GDP and the first-year lagged energy price, which were never significant and almost always had t-statistics less than unity.

The explanatory power of these equations is substantially greater than their counterparts without the interaction terms. The first and second-year lagged effects for real GDP are significantly negative in all specifications. Moreover, the first and second-year lagged effects of energy prices are significantly negative for seven of the eight coefficients and barely misses significance (at 6%) for the eighth one. For years after the Great Depression, one must combine the estimates for the interaction terms with those estimated over the full sample. For

[7] Appendix B provides charts showing the impulse responses of the nominal energy price shock equal to the unexpected one standard deviation of the error term. These response functions are based upon the estimates shown in the third column of Table 13.

example, the effect of energy prices lagged two years is often almost zero for the post-1933 years because the positive interaction term essentially cancels the negative coefficient for the second-year energy price lag covering all years. This effect tends to make the dampening of economic growth due to energy prices greater prior to the Great Depression than after it. Simple extrapolations from the coefficients in Table 13 suggest that equilibrium declines in economic growth due to an energy price increase may be about 60 percent more in the earlier period when the energy intensity was greater.[8] One needs to interpret these results cautiously, however, because the historical data underlying this earlier experience may exaggerate the economic output volatility (Sutch, 2006).

These results are robust when the Alternative real GDP estimates replace the Millennial series. Granger causality tests reported in Table 14 continue to reject the hypothesis that lagged energy prices (real or nominal) are unimportant in explaining economic growth for either time period. Meanwhile, there is little evidence that lagged economic growth precedes energy prices. Regression results based upon the Alternative real GDP estimates are shown in Table 15 and are similar to those based upon the Millennial series that were displayed in Table 13. Most importantly, the significance of the lagged energy price effects remains the same. Fewer lagged GDP effects are statistically significant and that may be the reason why the

[8] Assume that energy prices increase by one percent in each of the past two years. The equilibrium economic growth rate associated with these energy price changes will equal the sum of the two lagged energy price effects divided by one minus the sum of the two lagged GDP effects. Based upon the results in column 3 in Table 13, these computations result in -0.146% for the earlier period and -0.091% for the later period. These magnitudes are purely illustrative and do not represent the impact of an energy price shock on the economy after incorporating all of the other effects that operate in the actual economy.

equations' explanatory power may be somewhat lower for the period when only the 1930-33 years are excluded.[9]

Conclusion

The results demonstrate that: (a) there is a negative association between changes in energy prices and changes in U.S. GDP in the time before the Great Depression, (b) the earlier economy was more dependent on energy inputs and producing most of its energy without relying upon fuel imports, and (c) the associated economic impacts of energy price increases were roughly two times higher during the period before the Great Depression than during the Post-World War Two period. It is important not to overemphasize this effect. There were clearly other key economic policies and conditions that were shaping the macroeconomic trends during these times. These empirical estimates, however, do show that energy price shocks have deep historical "roots" in the performance of the US economy. At the same, they suggest that there are periods, e.g., during the 1930s or perhaps after the 2009 Great Recession, when this relationship may be less pronounced depending upon the state of the economy.

Oscillating energy prices may be a problem, but individuals and firms can adopt strategies that circumvent these cyclical price movements. Sustained energy price shocks caused by sudden and disruptive supply shortfalls, on the other hand, can lead towards serious economic dislocations and unused productive capacity. Sustained energy price increases in the United States have preceded many declines in economic activity as far back as 1890. This

[9] However, the explanatory power is higher than in Table 13 when the 1930-47 years are excluded.

finding suggests a much longer national experience with rising energy prices that began well before the period after World War Two. This problem emerged well before the US transition towards petroleum products when coal was an important energy source and when most energy was produced domestically rather than imported.

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Data Appendix

The analysis uses the two Millennial Project series for the period prior to 1929, after converting their 1996-dollar estimates to 2009 counterparts using the GDP deflator provided by the U.S. Bureau of Economic Analysis. It merges this data with the most recently available estimates for real GDP that the U.S. Bureau of Economic Analysis provides for the 1929-2014 period.

The BP crude oil price series is reported from 1861 in dollars per barrel. Prices through 1944 are the US average domestic price as reported below for the BLS oil price series. Thereafter, they represent international rather than domestic crude oil prices. Prices between 1945 and 1983 are for Arabian Light crude oil posted at their Ras Tanura oil facility. Prices after 1983 refer to the Brent crude oil price.

The BLS oil price series are based upon the BLS price index for domestic crude oil. Prior to 1947, they are the average wellhead price as reported in the US Bureau of the Census (1975) Historical Statistics of the United States, Colonial Times to 1970, Part 1. Series M 138-142. The BLS producer price index for domestic crude oil is used to develop price estimates after 1946.

The BLS energy price series before 1926 are the wholesale price index for fuel and lighting reported in the US Bureau of the Census (1975) Historical Statistics of the United States, Colonial Times to 1970, Part 1. Series E 40-51. The BLS producer price index for fuel and power is used to develop price estimates after 1926.

Table 1. Adjusted Dickey-Fuller test for unit root, 1890-2014 (125 observations)

	Level	Change
Real GDP (Millennial)	-0.569	-7.417*
Real GDP (Alternative)	-0.723	-6.464*
Crude Oil Price (BP)	0.205	-10.652*
Crude Oil Price (BLS)	0.066	-10.882*
Energy Price (BLS)	0.436	-10.148*

All variables are logarithms initially.
* Significant at 1% level

Table 2. Data Summary, 1891-2014

Variable (Change)	Mean	Standard Deviation	Minimum	Maximum
Real GDP (Millennial)	0.032	0.054	-0.141	0.173
Real GDP (Alternative)	0.033	0.050	-0.138	0.173
Crude Oil Price (BP)	0.038	0.251	-0.647	1.258
Crude Oil Price (BLS)	0.035	0.218	-0.605	0.542
Energy Price (BLS)	0.032	0.126	-0.517	0.443

All price and GDP variables are first differences in logarithms.

Table 3. Johansen tests for cointegration, 1891-2014

	Trace Statistic	Max Statistic
Real GDP - Crude oil price (BLS)	6.73	5.85
Real GDP - Crude oil price (BP)	8.11	7.38
Real GDP - Energy price	6.26	5.22

All trace statistics fail to exceed critical 5% value for rank = 0 and thus this test cannot reject the null of 0 cointegrating vectors.
All max statistics fail to exceed critical 5% value for rank =0 and thus this test cannot reject rank = 0 in favor of rank =1.
Tests include constant and one lag.

Table 4. Criteria for Selecting Optimal Lag Length with Real GDP, 1947-2014

Price	**Lags**	**FPE**	**AIC**	**HQIC**	**SBIC**
Oil (BP)	1	0.000032*	-4.685*	-4.581*	-4.422*
	2	0.000035	-4.59	-4.433	-4.195
	3	0.000038	-4.512	-4.304	-3.985
	4	0.000039	-4.474	-4.213	-3.816
Positive Oil (BP)	1	.000021*	-5.097*	-4.993*	-4.834*
	2	0.000023	-4.998	-4.842	-4.604
	3	0.000025	-4.929	-4.721	-4.403
	4	0.000026	-4.905	-4.645	-4.247
Oil (BLS)	1	.000018*	-5.242*	-5.138*	-4.979*
	2	0.000019	-5.193	-5.037	-4.798
	3	0.000021	-5.085	-4.877	-4.559
	4	0.000022	-5.033	-4.773	-4.375
Positive Oil (BLS)	1	7.8e-06*	-6.09*	-5.986*	-5.827*
	2	8.10E-06	-6.047	-5.89	-5.652
	3	8.80E-06	-5.966	-5.758	-5.44
	4	9.40E-06	-5.902	-5.642	-5.244
Energy	1	5.3e-06*	-6.471*	-6.366*	-6.207*
	2	5.90E-06	-6.369	-6.213	-5.974
	3	6.30E-06	-6.306	-6.098	-5.78
	4	6.40E-06	-6.291	-6.03	-5.633
Positive Energy	1	3.2e-06*	-6.963*	-6.859*	-6.7*
	2	3.60E-06	-6.854	-6.698	-6.46
	3	3.80E-06	-6.796	-6.588	-6.27
	4	3.90E-06	-6.779	-6.519	-6.121

* indicates optimal lag for each test.
Columns indicate tests for: final prediction error (FPE), Akaike's information criterion (AIC), Hannan and Quinn information criterion (HQIC) and the Schwarz's Bayesian information criterion (SBIC).

Table 5. Granger Causality Tests, 1948-2014

	GDP Equation		**Energy Price Equation**	
	Chi-square	Probability	Chi-square	Probability
GDP-oil (BP)	7.058*	0.008	0.446	0.504
Positive oil (BP)	8.001*	0.005	1.310	0.252
GDP-oil (BLS)	8.531*	0.003	0.575	0.448
Positive oil (BLS)	16.558*	0.000	0.059	0.809
GDP-energy	10.03*	0.002	0.105	0.746
Positive energy	13.293*	0.000	0.110	0.741

* Significantly rejects hypothesis that past energy prices do not explain current GDP at 1% level.

Table 6. Estimated Coefficients for Real GDP Equation, 1948-2014

	Price Change			Positive Price Change		
	Oil(BP)	Oil(BLS)	Energy	Oil(BP)	Oil(BLS)	Energy
Lagged GDP	0.051	0.063	0.049	0.014	-0.014	-0.015
	(0.109)	(0.108)	(0.107)	(0.11)	(0.105)	(0.107)
Lagged Price	-0.026**	-0.037**	-0.069**	-0.035**	-0.073**	-0.102**
	(0.01)	(0.013)	(0.022)	(0.012)	(0.018)	(0.028)
Great Recession	-0.053*	-0.047*	-0.049*	-0.054**	-0.042*	-0.048*
	(0.021)	(0.021)	(0.021)	(0.021)	(0.02)	(0.021)
Constant	0.032**	0.032**	0.034**	0.036**	0.04**	0.039**
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
R-squared	0.192	0.208	0.223	0.202	0.284	0.255

All price and GDP variables are first differences in logarithms.
Standard errors are shown in
parentheses.
* indicates 5% significance
** indicates 1% significance

Table 7. Criteria for Selecting Optimal Lag Length with Millennial Real GDP, 1891-1929

Price	Lags	FPE	AIC	HQIC	SBIC
Oil (BLS)	1	0.000282	-2.498	-2.376	-2.157*
	2	0.000265*	-2.564*	-2.381*	-2.052
	3	0.000286	-2.496	-2.251	-1.813
	4	0.000284	-2.513	-2.207	-1.66
Positive Oil (BLS)	1	0.000094	-3.603	-3.481*	-3.262*
	2	.000092*	-3.626*	-3.442	-3.114
	3	0.0001	-3.549	-3.304	-2.867
	4	0.000097	-3.588	-3.282	-2.735
Energy	1	0.000126	-3.302	-3.179	-2.947*
	2	.000112*	-3.428*	-3.244*	-2.895
	3	0.000134	-3.256	-3.010	-2.545
	4	0.000151	-3.156	-2.849	-2.267
Positive Energy	1	.000062*	-4.019*	-3.896*	-3.663*
	2	0.000063	-4.001	-3.817	-3.468
	3	0.000065	-3.976	-3.731	-3.265
	4	0.000071	-3.908	-3.601	-3.019

* indicates optimal lag for each test.
Columns indicate tests for: final prediction error (FPE), Akaike's information criterion (AIC), Hannan and Quinn information criterion (HQIC) and the Schwarz's Bayesian information criterion (SBIC).

Table 8. Granger Causality Tests, 1890-1929

	GDP Equation		**Energy Price Equation**	
	Chi-square	Probability	Chi-square	Probability
GDP (Millennial)				
GDP-oil (BLS)	4.065	0.131	0.391	0.822
Positive oil (BLS)	3.750	0.153	1.617	0.446
GDP-energy	6.586	0.037*	1.808	0.405
Positive energy	2.592	0.107	0.158	0.691
GDP Alternative				
GDP-oil (BLS)	4.014	0.045*	0.396	0.529
Positive oil (BLS)	5.042	0.025*	0.039	0.844
GDP-energy	3.111	0.078	1.900	0.168
Positive energy	3.681	0.055	0.114	0.736

* Significantly rejects hypothesis that past energy prices do not explain current GDP at 5% level.

Table 9. Estimated Coefficients for Millennial Real GDP Equation, 1891-1929

	Price Change		Positive Price Change	
	Oil	Energy	Oil	Energy
Lagged GDP	-0.347*	-0.34*	-0.286	-0.227
	(0.15)	(0.147)	(0.154)	(0.154)
Lagged GDP-2	-0.329*	-0.300*	-0.363*	--
	(0.146)	(0.146)	(0.148)	
Lagged Price	-0.065	-0.127*	-0.128*	-0.159
	(0.038)	(0.063)	(0.066)	(0.099)
Lagged Price-2	-0.039	-0.137*	-0.004	--
	(0.039)	(0.063)	(0.072)	
WW-One	0.114	0.157*	0.111	0.089
	(0.061)	(0.065)	(0.066)	(0.067)
Constant	0.052**	0.053**	0.064**	0.047**
	(0.012)	(0.011)	(0.014)	(0.012)
R-squared	0.276	0.326	0.271	0.155

Dependent variable is Millennial Real GDP.
All price and GDP variables are first differences in logarithms.
Standard errors are shown in parentheses.
* indicates 5% significance
** indicates 1% significance

Table 10. Estimated Coefficients for Alternative Real GDP Equation, 1891-1929

	Price Change		Positive Price Change	
	Oil	Energy	Oil	Energy
Lagged GDP	-0.129	-0.129	-0.08	-0.134
	(0.153)	(0.157)	(0.156)	(0.155)
Lagged GDP-2	--	--	--	--
Lagged Price	-0.067**	-0.096*	-0.13*	-0.157*
	(0.033)	(0.054)	(0.058)	(0.082)
Lagged Price-2	--	--	--	--
WW-One	0.059	0.067	0.071	0.079
	(0.05)	(0.053)	(0.051)	(0.055)
Constant	0.037**	0.039**	0.048**	0.047**
	(0.009)	(0.01)	(0.01)	(0.01)
R-squared	0.142	0.125	0.162	0.137

Dependent variable is Alternative Real GDP.
All variables except WW-One are first differences in logarithms.
Standard errors are shown in parentheses.
* indicates 5% significance
** indicates 1% significance

Table 11. Granger Causality Tests for GDP and Energy Prices, Combined Samples

	GDP Equation		Energy Price Equation	
	Chi-square	Probability	Chi-square	Probability
1892-1929; 1933-2014				
GDP-Energy Prices	10.249**	0.006	0.428	0.807
GDP-Real Energy Prices	6.908*	0.032	0.575	0.682
1892-1929; 1948-2014				
GDP-Energy Prices	14.797**	0.001	0.766	0.750
GDP-Real Energy Prices	8.762*	0.013	0.101	0.951

* Significantly rejects hypothesis that past energy prices do not explain current GDP at 5% level.
** Significantly rejects hypothesis that past energy prices do not explain current GDP at 1% level.

Table 12. Estimated Coefficients for Real GDP Equation Since 1892

	(1)	(2)	(3)	(4)
Energy Price Variable	Nominal	Real	Nominal	Real
Excluded Years	1930-33	1930-33	1930-47	1930-47
GDP(t-1)	0.097	0.096	-0.262**	-0.252**
	(0.093)	(0.093)	(0.094)	(0.095)
GDP(t-2)	-0.065	-0.072	-0.214*	-0.213*
	(0.091)	(0.092)	(0.086)	(0.089)
Energy Price(t-1)	-0.101**	-0.098*	-0.085**	-0.08*
	(0.037)	(0.043)	(0.029)	(0.035)
Energy Price(t-2)	-0.055	-0.061	-0.072*	-0.07
	(0.037)	(0.044)	(0.03)	(0.036)
World War One	0.115*	0.098**	0.112**	0.094*
	(0.053)	(0.052)	(0.042)	(0.043)
Great Recession	-0.043	-0.043	-0.056	-0.056
	(0.049)	(0.05)	(0.039)	(0.041)
Constant	0.039**	0.035**	0.051**	0.047**
	(0.007)	(0.006)	(0.006)	(0.006)
Adjusted R-square	0.066	0.041	0.189	0.146

Dependent variable is Millennial Real GDP.
All price and GDP variables are first differences in logarithms.
Standard errors are shown in parentheses.
* indicates 5% significance
** indicates 1% significance

Table 13. Estimated Coefficients for Real GDP Equation Since 1892 Allowing for Post 1933 Breaks

	(1)	(2)	(3)	(4)
Fuel Price	Nominal	Real	Nominal	Real
Excluded Years	1930-33	1930-33	1930-47	1930-47
GDP(t-1)	-0.334**	-0.327**	-0.335**	-0.327**
	(0.116)	(0.117)	(0.103)	(0.105)
GDP(t-2)	-0.233**	-0.243**	-0.231**	-0.240**
	(0.087)	(0.089)	(0.087)	(0.09)
GDP(t-1)>1933	0.935**	0.932**	0.434	0.440
	(0.177)	(0.181)	(0.245)	(0.251)
Energy Price (t-1)	-0.102**	-0.092*	-0.099**	-0.088*
	(0.034)	(0.040)	(0.031)	(0.036)
Energy Price (t-2)	-0.130**	-0.117	-0.129**	-0.115*
	(0.049)	(0.062)	(0.043)	(0.055)
Energy Price (t-2)>1933	0.153*	0.129	0.125*	0.104
	(0.069)	(0.082)	(0.063)	(0.075)
World War One	0.140**	0.110*	0.138**	0.109*
	(0.050)	(0.050)	(0.044)	(0.045)
Great Recession	-0.031	-0.031	-0.045	-0.045
	(0.044)	(0.045)	(0.039)	(0.041)
year>1933	-0.024*	-0.023*	-0.010	-0.010
	(0.011)	(0.011)	(0.012)	(0.012)
Constant	0.051**	0.047**	0.051**	0.047**
	(0.009)	(0.009)	(0.008)	(0.008)
Adjusted R-square	0.260	0.222	0.217	0.158

Dependent variable is Millennial Real GDP.
All price and GDP variables are first differences in logarithms.
Standard errors are shown in parentheses.
* indicates 5% significance
** indicates 1% significance

Table 14. Granger Causality Tests for “Alternative GDP” and Energy Prices, Combined Samples

	GDP Equation		Energy Price Equation	
	Chi-square	Probability	Chi-square	Probability
1892-1929; 1933-2014				
GDP-Energy Prices	10.854**	0.004	0.046	0.977
GDP-Real Energy Prices	6.34*	0.042	0.443	0.801
1892-1929; 1948-2014				
GDP-Energy Prices	16.613**	0.000	0.529	0.768
GDP-Real Energy Prices	7.652*	0.022	0.012	0.994

* Significantly rejects hypothesis that past energy prices do not explain current GDP at 5% level.
** Significantly rejects hypothesis that past energy prices do not explain current GDP at 1% level.

Table 15. Estimated Coefficients for Alternative Real GDP Equation Since 1892

	(1)	(2)	(3)	(4)
Energy Price Variable	Nominal	Real	Nominal	Real
Excluded Years	1930-33	1930-33	1930-47	1930-47
GDP(t-1)	0.202*	0.209*	-0.154	-0.130
	(0.093)	(0.094)	(0.096)	(0.098)
GDP(t-2)	-0.018	-0.022	-0.100	-0.092
	(0.092)	(0.094)	(0.088)	(0.092)
Energy Price(t-1)	-0.098**	-0.091*	-0.085**	-0.075*
	(0.033)	(0.039)	(0.026)	(0.031)
Energy Price(t-2)	-0.039	-0.036	-0.059*	-0.046
	(0.033)	(0.039)	(0.027)	(0.032)
World War One	0.090	0.071	0.093*	0.071
	(0.047)	(0.047)	(0.038)	(0.039)
Great Recession	-0.040	-0.040	-0.052	-0.053
	(0.044)	(0.045)	(0.035)	(0.036)
Constant	0.033**	0.030**	0.045**	0.040**
	(0.006)	(0.006)	(0.006)	(0.006)
Adjusted R-square	0.096	0.063	0.142	0.073

Dependent variable is Alternative Real GDP.
All price and GDP variables are first differences in logarithms.
Standard errors are shown in parentheses.
* indicates 5% significance
** indicates 1% significance

Table A- 1. Gross World Oil Shortfalls

Year	Reported	Adjusted	Year	Reported	Adjusted
1951	0.7	0.0	1978	3.7	3.7
1952	0.0	0.0	1979	3.7	3.7
1953	0.0	0.0	1980	3.0	3.0
1954	0.0	0.0	1981	0.0	0.0
1955	0.0	0.0	1982	0.0	0.0
1956	2.0	2.0	1983	0.0	0.0
1957	2.0	2.0	1984	0.0	0.0
1958	0.0	0.0	1985	0.0	0.0
1959	0.0	0.0	1986	0.0	0.0
1960	0.0	0.0	1987	0.0	0.0
1961	0.0	0.0	1988	0.5	0.0
1962	0.0	0.0	1989	1.5	1.5
1963	0.0	0.0	1990	4.6	4.6
1964	0.0	0.0	1991	0.0	0.0
1965	0.0	0.0	1992	0.0	0.0
1966	0.7	0.0	1993	0.0	0.0
1967	2.5	2.5	1994	0.0	0.0
1968	0.0	0.0	1995	0.2	0.0
1969	0.0	0.0	1996	1.0	0.0
1970	1.3	0.0	1997	0.2	0.0
1971	0.6	0.0	1998	0.3	0.0
1972	0.0	0.0	1999	3.3	3.3
1973	2.1	2.1	2000	3.3	3.3
1974	1.6	1.6	2001	0.0	0.0
1975	0.0	0.0	2002	2.0	2.0
1976	0.7	0.0	2003	3.9	3.9
1977	0.7	0.0			

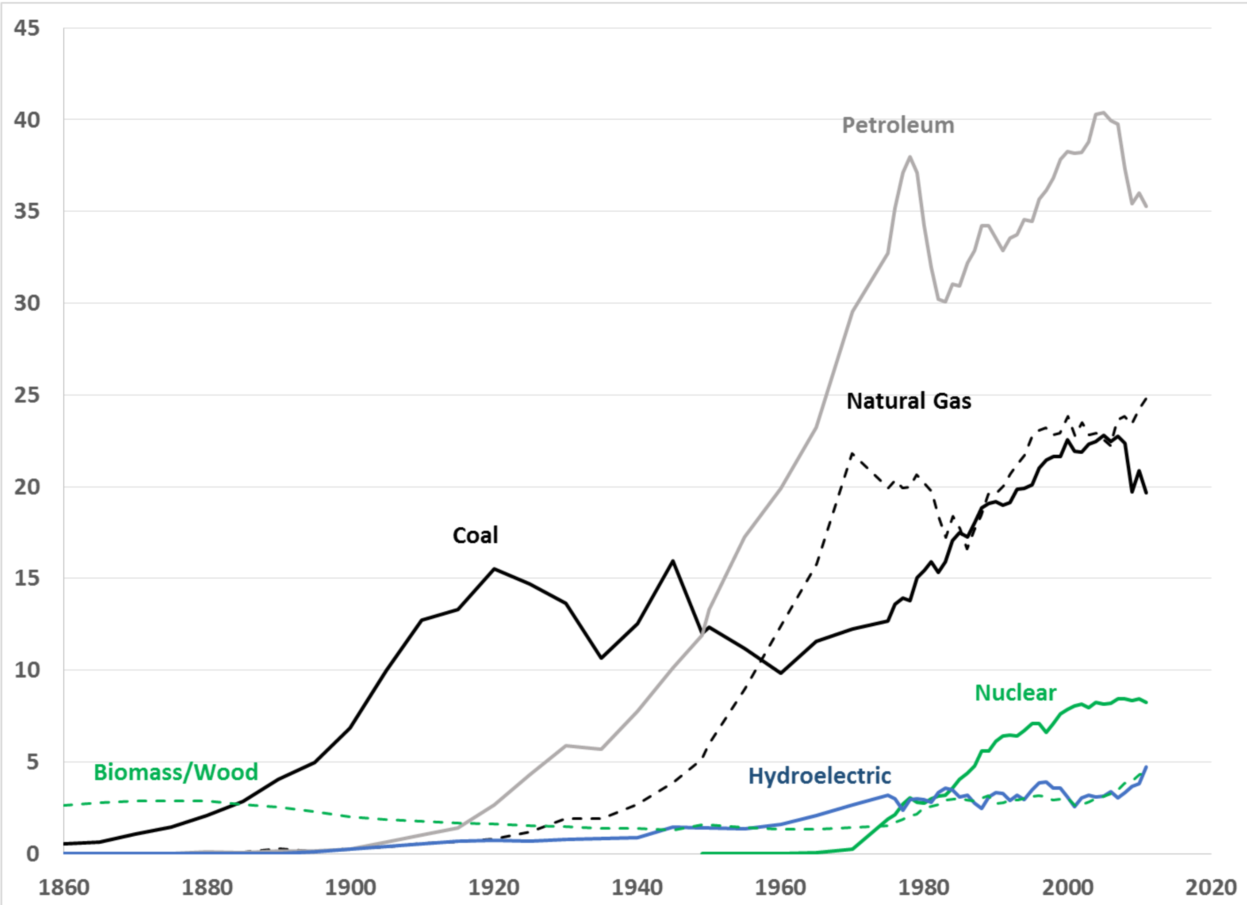
Source: Energy Information Administration, tabulated by Paul Leiby and reported by Beccue and Huntington (2005, Appendix E).

Table A- 2. Criteria for Selecting Optimal Lag Length with Alternative Real GDP, 1891-1929

Price	Lags	FPE	AIC	HQIC	SBIC
Oil (BLS)	1	0.000188*	-2.905*	-2.782*	-2.563*
	2	0.000191	-2.89	-2.707	-2.379
	3	0.000221	-2.754	-2.509	-2.072
	4	0.000221	-2.763	-2.457	-1.91
Positive Oil (BLS)	1	.00006*	-4.047*	-3.925*	-3.706*
	2	0.000065	-3.974	-3.791	-3.463
	3	0.000073	-3.858	-3.613	-3.176
	4	0.000071	-3.904	-3.598	-3.051
Energy	1	0.000092*	-3.621*	-3.498*	-3.265*
	2	0.000093	-3.618	-3.434	-3.085
	3	0.00011	-3.452	-3.206	-2.741
	4	0.000116	-3.421	-3.114	-2.532
Positive Energy	1	0.000045*	-4.339*	-4.216*	-3.983*
	2	0.000053	-4.185	-4.001	-3.652
	3	0.000055	-4.155	-3.910	-3.444
	4	0.000055	-4.165	-3.858	-3.276

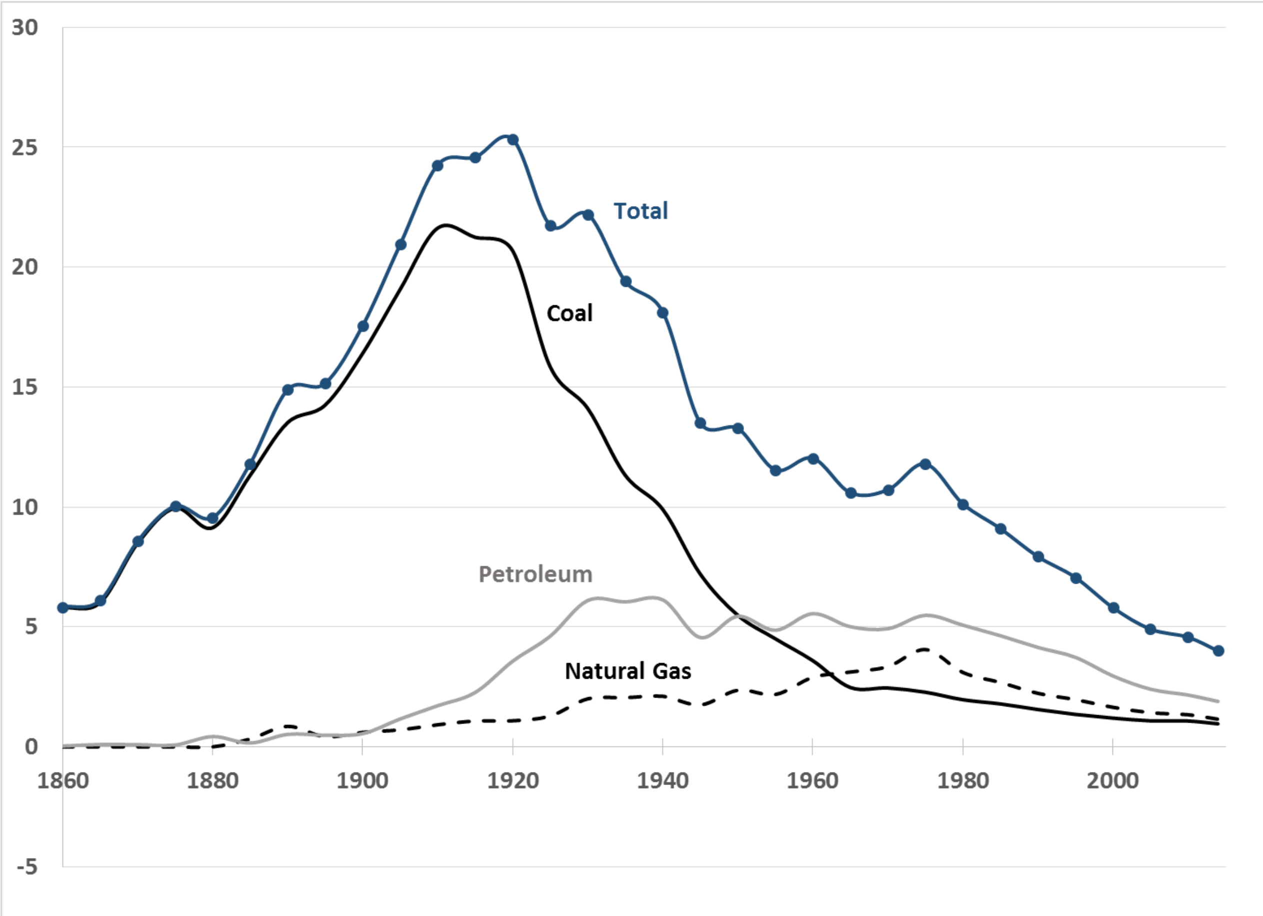
* indicates optimal lag for each test.
Columns indicate tests for: final prediction error (FPE), Akaike's information criterion (AIC), Hannan and Quinn information criterion (HQIC) and the Schwarz's Bayesian information criterion (SBIC).

Figure 1. History of US Energy Consumption, 1775-2015 (Quadrillion BTU)



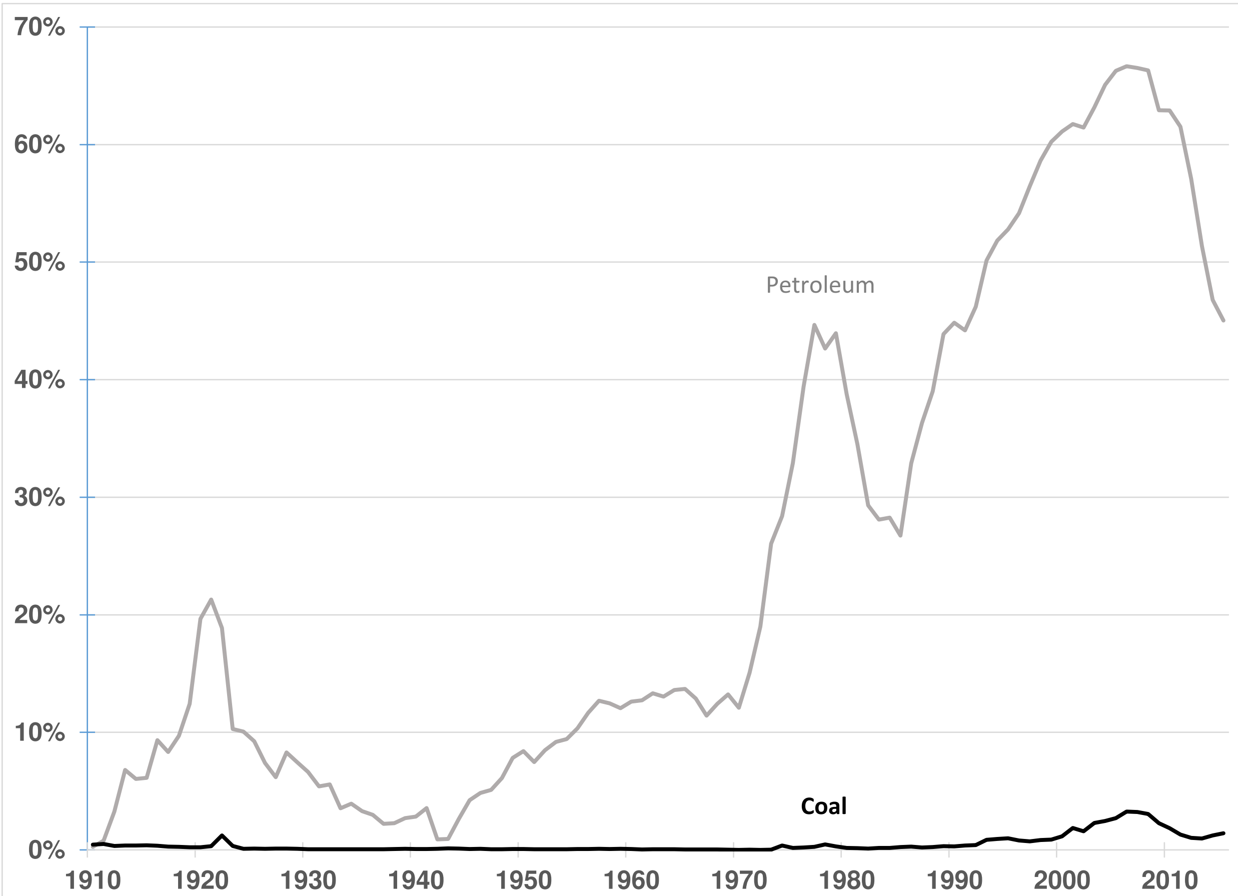
Source: US Energy Information Administration; see Data Appendix.

Figure 2. Energy Intensity (Thousand BTU/2009 US Dollars) for Different Sources, 1860-2010



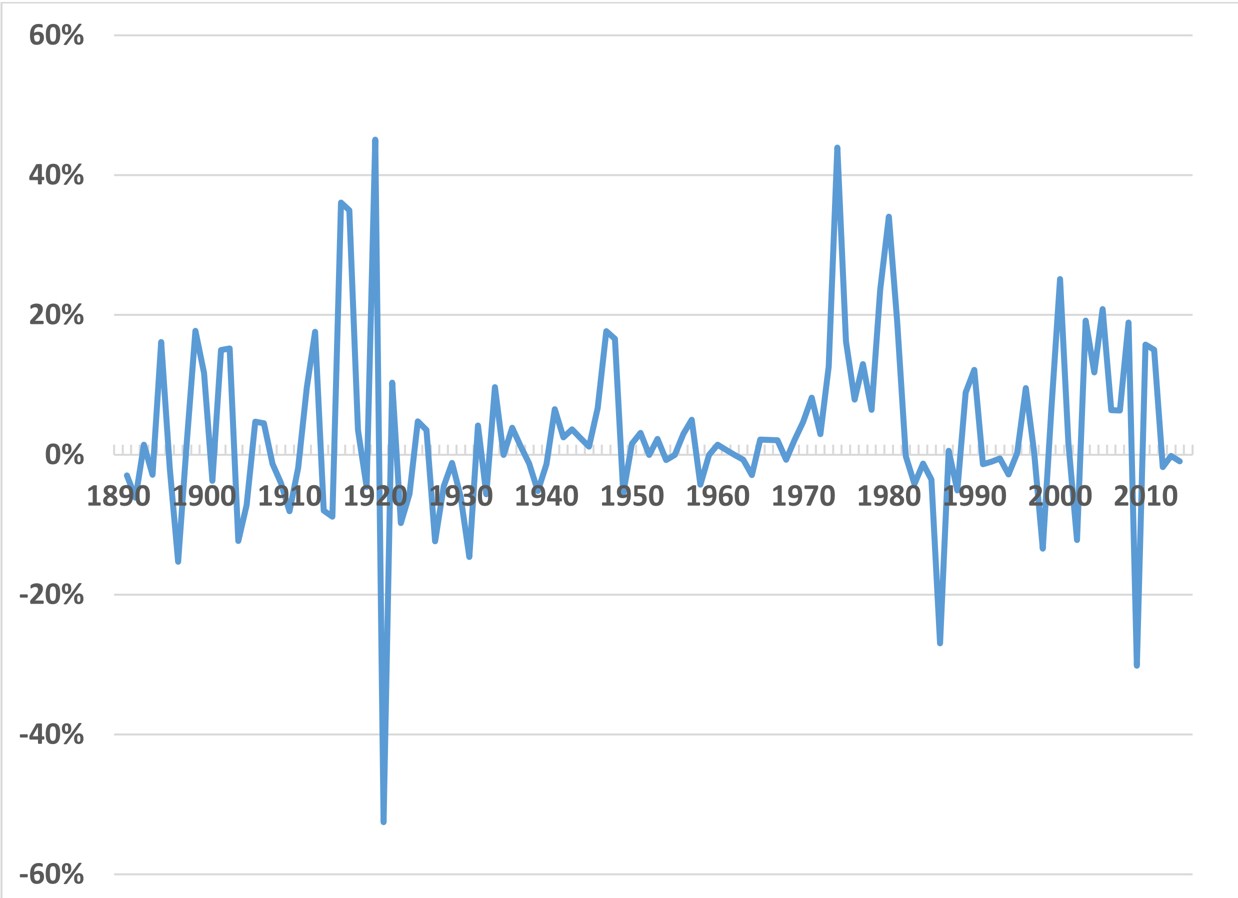
Source: US Energy Information Administration, Carter et al (2006); see Data Appendix.

Figure 3. U.S. Energy Import Shares (%), 1910-2015



Source: US Energy Information Administration.

Figure 4. Percent Change in Average Energy Price, 1890-2014



Source: U.S. Bureau of Labor Statistics, Producer Price Indexes.

Appendix B: Impulse Response Functions for the Combined Sample