Resilience, coal and the macroeconomy

Molyneaux, Lynette and Brown, Colin and Foster, John and Wagner, Liam

University of Queensland, Griffith University

12 October 2016

RESILIENCE, COAL AND THE MACROECONOMY

Lynette Molyneaux[1a], Colin Brown[b], Liam Wagner[c], John Foster[a]
a. Energy Economics and Management Group, School of Economics, University of Queensland, Australia
b. School of Agriculture and Food Sciences, University of Queensland, Australia
c. Economics, Griffith Business School, Griffith University, Brisbane, Australia

Keywords: Energy resilience, Energy security, International competitiveness

JEL Classification: Q43

Abstract

There remains a debate about 'oil and the macroeconomy' despite James Hamilton's claims. Manufacturing in 1970s US was, however, reliant on natural gas and electricity generated from coal, not oil. Whilst coal and electricity prices also rose in the 1970s their descent to pre-1974 levels was slower than the decline in oil prices. This research considers energy resilience during the 1970s. Spare capacity, natural gas and renewable energy are key resilience characteristics that predict improved manufacturing employment. The conclusion reached is that the rise in coal prices played a role, separate to oil price, in the macro-economies of US states.

1 Introduction

The period from October 1973 to the end of 1980 was characterised by oil supply volatility which led to elevated oil prices of between 2 and 5 times the price for a barrel of West Texas Intermediate (WTI) as at September 1973. Elevated prices spread fast to Natural Gas (NG) and coal fuel systems, and also electricity systems, as consumers sought substitutes which increased demand and, consequently, price for alternative energy sources. An increase in the price of oil and NG could have been foreseen due to declining US oil and NG production, but the increase in the price of coal was as a result of perceptions that energy, in all forms, would

[1] Corresponding author. Address: Energy Economics and Management Group, University of Queensland, St Lucia, Brisbane, 4072, Australia. Tel: +61 7 334 61003
Email addresses: l.molyneaux@uq.edu.au, j.foster@uq.edu.au, l.wagner@griffith.edu.au, colin.brown@uq.edu.au

never again be cheap (Fiscor, 2012). Even the fuel systems in the coal producing states lacked the spare capacity (Westerstrom, 1973; Westerstrom, 1974) to respond to policy action taken by the federal government to enforce the use of coal as a fuel for electricity generation (US Government, 1978), resulting in a large increase in the price of coal.

There is a body of research which has sought to explain the consequences of oil price rises on the US economy but there is little evidence of research focused on the consequences of the surge in coal and NG prices during that period. The cost of coal was particularly important for electricity generation and energy-intensive manufacturing. For this reason, this paper seeks to add another perspective to the body of research into the consequences of energy price rises on the macroeconomy, by looking in detail at the effect of other energy sources on US manufacturing employment during the period of the oil price crises.

The framework of the research in the paper is guided by the concept of resilience. Whilst there is a body of research into resilience and resilience in energy, most of it is directed at the application of metrics to indices or frameworks (Gea, 2012; IEA, 2011; Roege et al., 2014; Sharifi and Yamagata, 2015; Arghandeh et al., 2016). The inclusion of metrics is based on subjective assumptions of importance rather than empirical evidence of their relevance. In this regard, the measurement of resilience is similar to the field of energy security, where metrics are selected for indices based on subjective decision criteria (Ang et al., 2015). The framework employed here is discussed in (Molyneaux et al., 2016a) and applied in (Molyneaux et al., 2016b) and provides a model for identifying the resilience metrics which show statistical significance in predicting outcomes. The research into the characteristics of resilience and electricity generation indicates the significance of spare capacity and diversity in energy in predicting lower electricity prices (Molyneaux et al., 2016b), and establishes a method for analysing the consequences of a lack of spare capacity and diversity in energy on manufacturing employment.

The empirical analysis is expanded by a case study of the US Iron and Steel industry (ISI). It finds that the ISI, operating at the confluence of shock due to decreased automobile sales and increased energy costs, was seriously damaged by a lack of resilience in energy.

The paper is organised as follows. The resilience framework and the methods used in the empirical and qualitative analysis are described in section 2 while section 3 extends the discussion to prior research into the relationship between oil and the macroeconomy and how this empirical analysis differs from that prior research. Section 4 presents the results of the empirical and qualitative analysis, with discussion on the results in section 5. Some implications and concluding remarks appear in section 6.

2 Methods

2.1 Resilience framework

The framework employed here is discussed in (Molyneaux et al., 2016a) and applied in (Molyneaux et al., 2016b) and identifies the resilience metrics which show statistical significance in predicting electricity prices during the 1973-82 oil price crises. The resilience metrics found to be significant in predicting lower electricity prices include spare capacity and source of fuel and so these metrics are examined for their ability to predict manufacturing employment outcomes in the period from 1973 to 1982.

2.2 Empirical analysis model

A multiple linear regression analysis is used to examine, for each state in the US, the relationship between proportion of each fuel consumed by industry and spare capacity in energy, as explanatory variables, and the change in manufacturing employment as the dependent variable. The primary data is drawn from: the US Energy Information Agency (EIA) State Energy Database System (SEDS); the EIA's Form759 for electricity capacity and generation data by year, state and plant; the Bureau of Economic Analysis for manufacturing employment data; and the Bureau of Census Annual Survey of Manufactures for detailed Iron and Steel industry data. Throughout the analysis, real prices are used to differentiate from movements in the general level of prices.

Calculation of the two explanatory variables is as follows:

Proportion of energy consumed by industry from each fuel type

The calculation of quantity of each fuel source consumed in each state[i] is detailed in Equation 1.

$$TECI_i = \sum_{i=1}^{n} \left(ICB_i + \left(\frac{EG_i}{TEG}\ x\ ESICB\right) + \left(\frac{EG_i}{TEG}\ x\ LOICB\right) \right) \quad \textbf{Equation 1}$$

Where:

$TECI_i$	Total energy consumed by industry for fuel type i in BBtu
i	fuel types: Coal (CL), Natural Gas (NG), Petroleum (PA), Nuclear (NU), Renewable Energy (RE)
ICB_i	Primary energy consumed by industry for fuel type i (excluding electricity) in BBtu
EG_i	Electricity generated from fuel type i in TWh
TEG	Total electricity generated in TWh
$ESICB$	Electricity consumed by industry in BBtu
$LOICB$	Industry's share of electricity system losses in BBtu

Estimating the percentage of each fuel type used in each state is constructed from Equation 1 and data available in SEDS and takes the form:

$$p_i = \frac{TECI_i}{TEICB} \quad \textbf{Equation 2}$$

Where:

p_i	Percentage of energy consumed from fuel type i
i	fuel type: CL, NG, NU, PA, RE
$TECI_i$	Total energy consumed by industry from fuel type i in BBtu
$TEICB$	Total energy consumed by industry in BBtu

The total energy consumed from each fuel type for use by industry is calculated for each year 1973-82 and then averaged across the period 1973-82.

Spare capacity in the energy system

Considering the gaps in the available data on productive capacity within each of the fuel systems[ii], a proxy for spare capacity is constructed using the difference between the value of energy produced and the value of energy consumed as a proportion of GDP, and is calculated for each state as

$$EGAP = \sum_{i=1}^{n} \frac{(TECV_i - TEPV_i)}{GDPR} \qquad \textbf{Equation 3}$$

Where

$EGAP$	Total energy gap as proportion of GDP
$TECV_i$	Value of energy consumed from fuel type i
$TEPV_i$	Value of energy produced from fuel type i [iii]
$GDPR$	Real Gross Domestic Product (in $2012 millions)
i	fuel types: CL, NG, PA

The energy gap is calculated for each year 1973-82 and then summed and divided by the total real GDP for the period 1973-82.

The dependent variable is the change in manufacturing employment. The intention is to seek to measure the importance of spare capacity and different energy sources as predictors of manufacturing employment outcomes during an energy shock. Manufacturing employment change over the period 1973-82 is aggregated to reduce the noise of time lags over the period, providing a weighted average performance over a decade of energy price shock.

2.2.1 Regression model for manufacturing employment prediction from resilience metrics

The ordinary least squares regression model[iv] for manufacturing employment change prediction takes the form:

$$EMP\_CHG_s = \beta_0 + \beta_1 EGAP_s + \beta_2 p_{1s} + \ldots + \beta_k p_{ks} + \varepsilon_s$$

Equation 4

where

EMP_CHG_s	Change in manufacturing employment in state *s*
β_0	EMP_CHG intercept
β_k	coefficients of $EGAP_s$ and p_{ks}
$EGAP_s$	Total energy gap as a proportion of GDP in state *s*
p_{ks}	Percentage of energy consumed by fuel type k in state *s*
ε_s	random error in EMP_CHG for state *s*

2.3 Case study

Through the case study, the model seeks to understand the consequence of increased energy costs on manufacturing sector employment and particularly iron and steel industry (ISI) employment. It considers the relative size of employment in the sector to total employment and the consequences of increased energy costs on profitability, competitiveness and employment. A regional perspective is also taken.

3 Previous research into the relationship between energy and the macroeconomy

A body of research into the 1970s oil crises sought to explain the consequences of oil price rises on the US economy. James Hamilton first proposed a relationship between oil prices and US recessions after the 1970s oil crises. Analysing a 6-variable macroeconomic system, he found that none of the variables could account for the US recessions between 1949 and 1972, but that rises in the price of oil did precede all but one of the US recessions during this period (Hamilton, 1983). Since then, many researchers have produced evidence to support Hamilton's proposal. (Burbidge and Harrison, 1984) found that oil price affected both inflation and industrial production after the shocks of 1973-4 and 1979-80, although the impact of the oil price shocks differed between countries. (Gisser and Goodwin, 1986) concluded that oil prices had a significant impact on a broad range of US macro-economic indicators including Gross National Product, inflation and unemployment between 1961 and 1982. (Daniel, 1997) concluded that the oil price trend explained a significant portion of short-run variation in industrial production over the period 1960-92. (Raymond and Rich, 1997) highlighted the significant role oil prices played in the business cycle contractions during the periods 1973-75, 1980 and 1990-91, but that other factors were more important than oil prices during other expansionary and contractionary business cycles over the period 1951-95. (Mork, 1989) found evidence of a negative relationship between oil price increases and macro-economic performance over the period 1949-88, but no evidence of a related symmetrical relationship with oil price decreases and macro-economic performance.

The relationship between oil and the macro-economy remains controversial because the correlation between oil prices and the macro-economy weakened after 1985 (Hooker, 1996), which some have attributed to the declining energy intensity of the US economy (Blinder, 2009), lower real wage rigidity (Blanchard and Riggi, 2009) or a large reallocation of capital and labour to other sectors after the 1970s oil crises (Hamilton, 1988; Davis and Haltiwanger, 2001). The latter view is partially supported by (Edelstein and Kilian, 2009) who suggest that the lack of macroeconomic response to low oil prices in 1986 was heavily influenced by low business investment in equipment and structures, perhaps as a result of the removal of investment tax credits which formed part of the 1986 Tax Reform Act.

Others claim that the role of oil prices in macro-economic performance has been overstated with insufficient evidence to support the proposal (Bohi, 1991). The small fraction that the increased cost of oil represents in the larger US economy suggested to some that it was impossible that oil price increases could have induced the magnitude of the recessions in

1975, 1980 and 1982 (Tobin, 1980; Bohi, 1991). After considering the timing of oil price increases and recessions, (Barsky and Kilian, 2004) conclude that oil price shocks may contribute to recessions but that they matter less than has commonly been thought. This view has been taken up and further adapted for the lack of response of the US economy to oil price rises in the period 2003-7. Although (Hamilton, 2009) found evidence that the oil price rises had played a part in macroeconomic decline in early 2008. However, (Blinder, 2009) argued that all macroeconomic time series declined after the failure of the bank, Lehman Brothers, on September 15, 2008 and that the decline in macro-economic performance prior to September 2008 may be considered as to not have been a recession thus discounting Hamilton's findings.

There has also been discussion on the macro-economic effects of uncertainty caused by oil price volatility which resulted in pauses in consumer purchases (Bernanke, 1983). The effects of changes in consumer behaviour induced by oil price increases on regional economies dependent on manufacturing were noted in several studies (Davis and Haltiwanger, 1996; Davis et al., 1996; Davis et al., 1997; Lee and Ni, 2002). The automobile industry is identified as heavily affected by uncertainty and a decline in demand after an oil price increase (Lee and Ni, 2002; Davis et al., 1997; Hamilton, 1988; Hamilton, 2009; Edelstein and Kilian, 2009) but also structurally ill-prepared for the shifts required to respond to very large increases in oil prices (Bresnahan and Ramey, 1993). Others have found that the reduction in consumer purchases of durables like automobiles could be ascribed to increased energy expenditures, but that total factor productivity remains the major driver of the poor economic performance after oil price increases (Kim and Loungani, 1992; Dhawan and Jeske, 2008). (Edelstein and Kilian, 2009) found that without consumer spending declines, oil price increases have a small effect on macroeconomic performance. They also hypothesise that the relative size of the automobile industry with respect to the US economy has declined since the 1970s, which partly explains why the increase in oil prices since 2003 and the resulting decline of motor vehicle sales have not resulted in the macroeconomic decline experienced in the 1970s and early 1980s.

Monetary policy has been identified by some as a better predictor of US macro-economic performance than oil price rises (Bohi and Powers, 1993; Bernanke et al., 1997). Response to Bernanke et al.'s research however highlights that uncertainty remains about the extent of the real effects of monetary policy on macro-economic performance (Sims, 1997). Using the same data and model but with a longer lag length, (Hamilton and Herrera, 2004) conclude that monetary policy was not a better predictor of US macro-economic performance than oil price rises.

The debate around the significance of oil price movements for macroeconomic performance remains unresolved and is ongoing. What is notable about the debate is that the focus has been on establishing a relationship between economic performance and some version of the oil price. Only since the arrival of significant production of unconventional natural gas has some discussion emerged of the impact of non-oil prices on manufacturing. Most of this research points to modest increases in manufacturing output, investment and employment as a result of declining NG prices (Celasun et al., 2014; Sendich, 2014), but potentially significant increases for NG-intensive industries (Melick, 2014).

Oil price rises may have been a catalyst for price rises in NG, coal and electricity in 1974, but the price trajectories of those energy sources over the 1970s and 1980s was not in lock-step with oil prices. In addition, while oil was the major source of energy for the transport sector, it was not for industry. Figure 1 shows that NG was a greater contributor to industry in California (CA) and Texas (TX) than was oil. For the average across the US, NG and coal together were a larger contributor to industry than was oil.

In the north east manufacturing states of Illinois (IL), Indiana (IN), Michigan (MI), New York (NY), Ohio (OH) and Pennsylvania (PA), the area now sometimes referred to as the Rust Belt, coal was by far the most important source of energy for industrial output.

There is little evidence of research focused on the consequences for industry, and particularly energy-intensive manufacturing, of the surge in coal prices prior to the large loss of manufacturing jobs between 1979 and 1982. For this reason, this analysis seeks to focus on

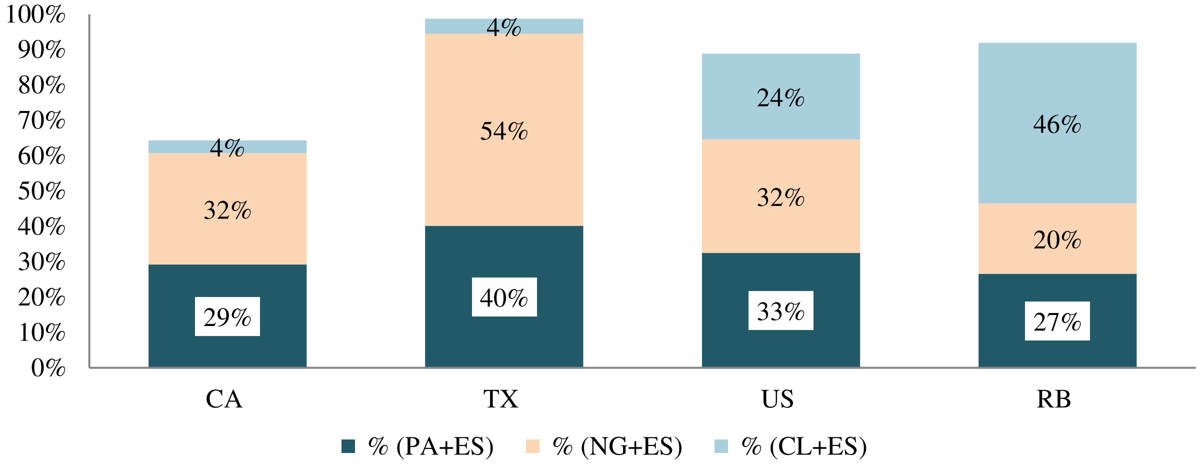

Figure 1: Fuel source for industrial production 1973-82: Various regions
Sources: (EIA, 2014a; EIA, 2014b)
Note: Electricity consumed (ES) allocated to fuel source based on electricity generated from each fuel source

the impact of all fuel sources along with spare capacity in energy, on manufacturing employment.

4 Results

4.1 Results of the empirical analysis

The explanatory variables included in the model for manufacturing employment are percentage of energy consumed by industry from: thermal coal (*pCLO*); metallurgical coal (*pCLK*); NG (*pNG*); NU (*pNU*); petroleum (pPA); renewable fuels (*pRE*); and the gap between the value of energy produced and the value of energy consumed as a proportion of GDP (*EGAP*). Including the percentage of all fuel types in the regression analysis could result in collinearity, and as this analysis seeks to establish the significance of non-oil fuel sources for industry in the US during this period, *pPA* is excluded as an explanatory variable.

Table 1: Regression analysis of resilience metrics as predictors of manufacturing employment 1973-82

	Resilience metrics	**Statistically significant resilience metrics**	**Statistically Significant resilience metrics excluding outliers**
Regression	A	B	C
Dependent variable (Weighted average change in manufacturing employment 1973-82)	EMP_CHG		
Mean of dependent variable	0.037607	0.037607	0.029962
Std Dev of dependent variable	0.092397	0.092397	0.086056
Regression	Least squares	Least squares	Least squares
Observations	50	50	48
Fit: R^2	0.397891	0.365525	0.509058
Fit: Adj R^2	0.313876	0.324147	0.475585
Fit: F-stat	4.735939	8.833643	15.20790
Intercept	-0.000769	-0.041393	-0.065703
(Prob)	(0.9848)	(0.1398)	(0.0069)
VIF	15.20	6.58	6.63
Coefficients			
EGAP	1.180120	0.191371	0.172083
(Prob)	(0.0599)	(0.0414)	(0.0268)
VIF	1.59	1.55	1.56
pCLO	-0.075709		
(Prob)	(0.3756)		
VIF	3.43		
pCLK	-0.146963		
(Prob)	(0.3502)		
VIF	1.62		
pNG	0.173056	0.215772	0.251944
(Prob)	(0.0498)	(0.0099)	(0.0004)
VIF	5.52	4.89	4.88
pNU	-0.079174		
(Prob)	(0.6771)		
VIF	1.64		
pRE	0.195676	0.255380	0.303602
(Prob)	(0.0394)	(0.0030)	(0.0000)
VIF	2.59	2.05	2.09
Jarque_Bera stat (heteroskedasticity exists if >5.99)	20.92191	14.78757	5.970001
Condition index (multicollinearity problem if >15)	18.71	10.54	10.43

After exclusion of Nevada (NV) as an outlier[v], the variables explain 31.4% of the variation in manufacturing employment as shown in Table 1, regression A. The results of the regression analysis and hypothesis tests on the coefficients for *pCLO*, *pCLK*, and *pNU* indicate a high probability that they are not statistically significant. Thus, *pCLO*, *pCLK*, and *pNU* are excluded from the model in regression B with the explanatory variables accounting for 32.4% of the variation in manufacturing employment.

However, the Jarque-Bera statistic indicates problems with heteroscedasticity. Further examination of the variables indicated that North Dakota (ND) and Utah (UT) are potential outliers in the model specification[vi]. Excluding ND and UT from the model improves the fit to explain 47.6% of the variation in employment across 48 states as shown in regression C.

Weighted average manufacturing employment across the US decreased by 1% over the period 1973-82. Regionally, the change in manufacturing employment varied from an increase of 24% in Alaska (AK) to a reduction of 12% in Maine (ME) (excluding the increase of NV of 37% as an outlier). The results from the regression analysis indicate that for every 10% of energy value surplus as a proportion of GDP, manufacturing employment increased by 1.7%. Conversely, for every 10% of energy value gap, manufacturing employment decreased by 1.7%. Consumption of NG and RE also indicated an improvement in manufacturing employment outcomes. For every 10% of NG and RE consumed by industry, manufacturing employment increased by 2.5% and 3% respectively.

4.2 Findings from the qualitative analysis

Averaging employment over the period 1973-82 masks volatility over the period from multiple shocks and recoveries. In particular, the employment decline post 1979 was the result of an extended period of elevated energy prices which eroded global competitiveness for the US manufacturing sector in general and the motor vehicle and steel industries in particular. The motor vehicle industry (MVI) and the iron and steel industry (ISI) were energy, labour and capital intensive, with high paid workforces, concentrated in the industrial states in the north east of the US. Whilst the MVI invested heavily to adapt to the oil crises, the ISI showed less adaptive capacity to the increases in coal, NG and electricity prices. The loss of competitiveness of the ISI over the 1970s marked a turning point in the ability of US energy intensive manufacturing to compete globally.

4.2.1 Relative size of energy intensive industries

The manufacturing sector was a heavy energy user and the largest employer in the US employing 21% of workers in 1973. By 1979 manufacturing employment as a percentage of the US total employment had slipped to 19% and by 1982 it was down to 17% (compared with only 7% in 2012).

Table 2: US employment by sector 1973-82, in millions

	1973		1979		1982		1979-1982	
	million	**% total**	**million**	**% total**	**million**	**% total**	**million**	**% change 1979/82**
All employment	98.4		113.1		114.2		1.0	0.9%
Agriculture	4.5	5	4.7	4	4.6	4	(0.07)	-1.4%
Construction	5.1	5	5.9	5	5.3	5	(0.54)	**-9.1%**
Financial services	7.1	7	8.6	8	8.9	8	0.32	3.7%
Government	16.7	17	18.4	16	18.6	16	0.15	0.8%
Manufacturing	20.4	21	21.5	19	19.2	17	(2.23)	**-10.4%**
- ISI	0.828	1	0.789	1	0.523	0	(0.266)	**-33.7%**
- MVI	0.969	1	1.001	1	0.707	1	(0.294)	**-29.4%**
Mining	0.8	1	1.2	1	1.5	1	0.35	**30.2%**
Retail Trade	15.0	15	17.6	16	18.0	16	0.36	2.0%
Services	19.2	19	24.0	21	26.6	23	2.6	**10.9%**
Transport & Utilities	5.1	5	5.6	5	5.7	5	0.02	0.3%
Wholesale trade	4.5	5	5.6	5	5.7	5	0.04	0.8%

Source: (US Bureau of Economic Analysis, 2015a)

Between 1979 and 1982, half a million MVI and ISI workers lost employment in the US, 70% of which were employed in the north east industrial states of the area now sometimes referred to as the Rust Belt.

Table 3: US average compensation and income from employment by sector: 1979 and 1982

	1979		1982		
	Average compensation ($2012/person)	**Income from employment** ($2012 billions)	**Average compensation** ($2012/person)	**Income from employment** ($2012 billions)	**Income loss 1979/82** ($2012 billions)
All employment	41,639	4,711	39,739	4,537	(175)
Agriculture	9,182	43	8,444	39	(4)
Construction	47,055	277	42,000	224	(52)
Financial services	30,515	263	31,194	279	16
Government	49,613	914	49,025	910	(4)
Manufacturing	60,053	1,290	58,970	1,135	(155)
- ISI	86,592	68	83,263	44	(25)
- MVI	88,719	89	87,836	62	(27)
Mining	65,620	76	60,268	91	15
Retail Trade	25,750	454	23,233	418	(36)
Services	29,563	710	29,109	775	65
Transport & Utilities	65,691	370	63,370	358	(12)
Wholesale trade	55,835	315	54,034	307	(8)

Source: (US Bureau of Economic Analysis, 2015a; US Bureau of Economic Analysis, 2015b)

The impact on consumer purchases of manufactured goods from the loss of 384,000 jobs in the Rust Belt was severe leading to a decline in manufacturing employment of 1.5 million for all manufacturing in the Rust Belt and 2.2 million across the US.

New jobs were created in mining and services, but the mining jobs were created in states already enjoying the benefits of increased income from energy market activity while the services jobs were associated with a 50% reduction in compensation packages. A structural shift of this nature is not of itself a problem, but the sudden erosion of income was.

4.2.2 Energy intensive industries reliant on coal

Industry in the large manufacturing states of MI, IN, OH and PA were dependent on NG and electricity generated from coal, not oil, for production. Due to a lack of spare capacity in the coal and the coal transport systems, coal prices for industrial users increased 84% 1974 over 1973, only returning to pre-1972 levels in 1991 well after the price of oil had bottomed out in 1986.

Figure 2 shows the price of electricity to industry in the Rust Belt states, where IN, MI, OH and PA were dependent on coal for electricity generation. IL and NY were reliant on oil for electricity generation, and for comparison, Texas (TX) and Washington (WA) were dependent on electricity generated from NG and hydro. So electricity costs for the manufacturing states escalated sharply with oil prices but were much slower to decline in price than was oil after 1982.

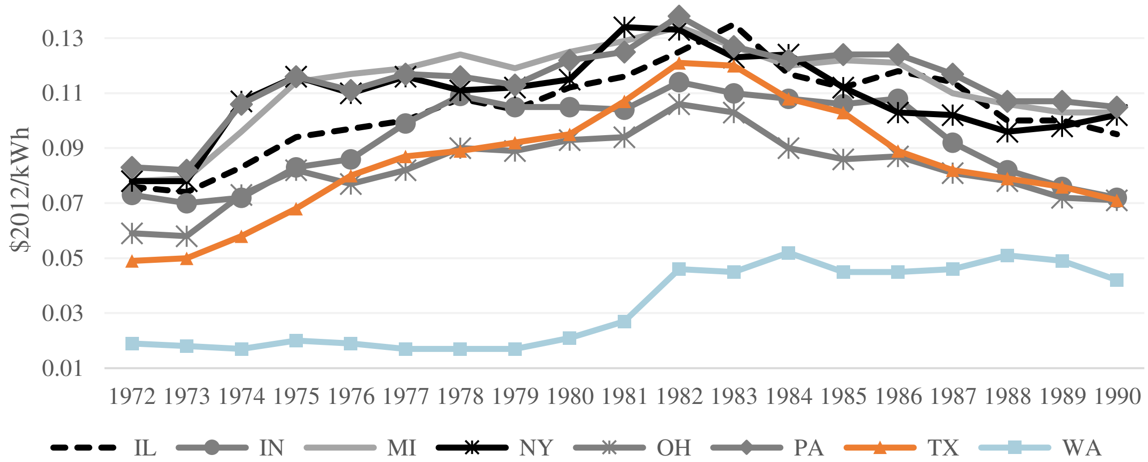

Figure 2: Price of electricity to industry in various states: 1972-90
Source: (EIA, 2014b)

Figure 3 shows the proportion of fuels consumed by industry[vii] in the Rust Belt over the period 1973-82. As is shown in Figure 3, MI, the automobile manufacturing state, relied on coal for 45% of its industrial production energy needs, whilst the iron and steel producing

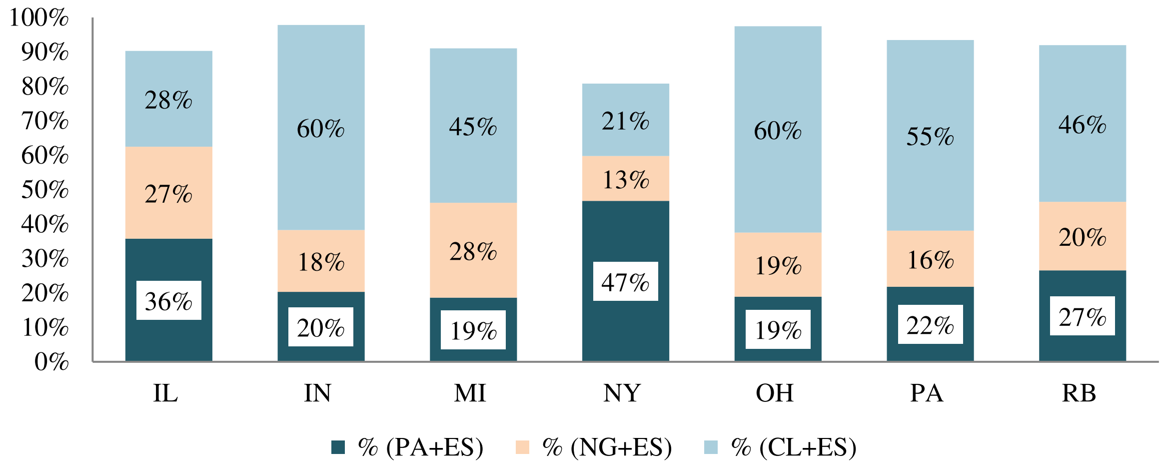

Figure 3: Fuel source for industrial production 1973-82: Rust Belt states
Sources: (EIA, 2014b; EIA, 2014a)
Note: Electricity consumed (ES) allocated to fuel source based on electricity generated from each fuel source

states of IN, OH and PA relied on coal for 60%, 60% and 55% of their industrial energy needs. Across the Rust Belt, coal underpinned 46% of energy consumed by industry.

4.2.3 Energy cost increases and international competitiveness

With its reliance on electricity from cheap thermal coal and metallurgical coal for coke, the ISI was particularly vulnerable to the large price increases for thermal and metallurgical coal that were meted out after 1973.

Whilst metallurgical coal is a feedstock for the creation of coke, its price is determined by market forces in the thermal coal system. As shown in Figure 4, the price of metallurgical coal escalates exponentially when thermal coal prices rise.

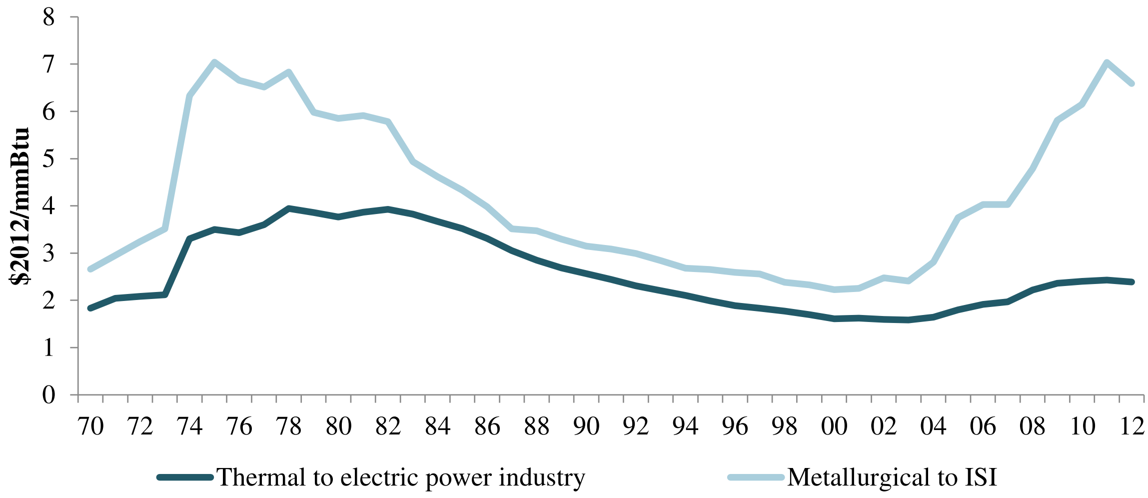

Figure 4: Thermal coal versus metallurgical coal prices 1970-2012
Source: (EIA, 2014b)

Traditionally, it has been assumed that resilience requires a diversity of options be available to enable adaptation. However, the benefits of diversity are reduced if there is a lack of spare capacity and potential for substitution. The lack of spare capacity in all fossil fuel systems caused all prices to rise and the integrated, capital-intensive nature of the ISI in the 1970s precluded the industry from contemplating diversification to alternate fuel sources. This meant that the industry was forced to absorb or pass on the costs inflicted on it by a lack of resilience in its core energy source.

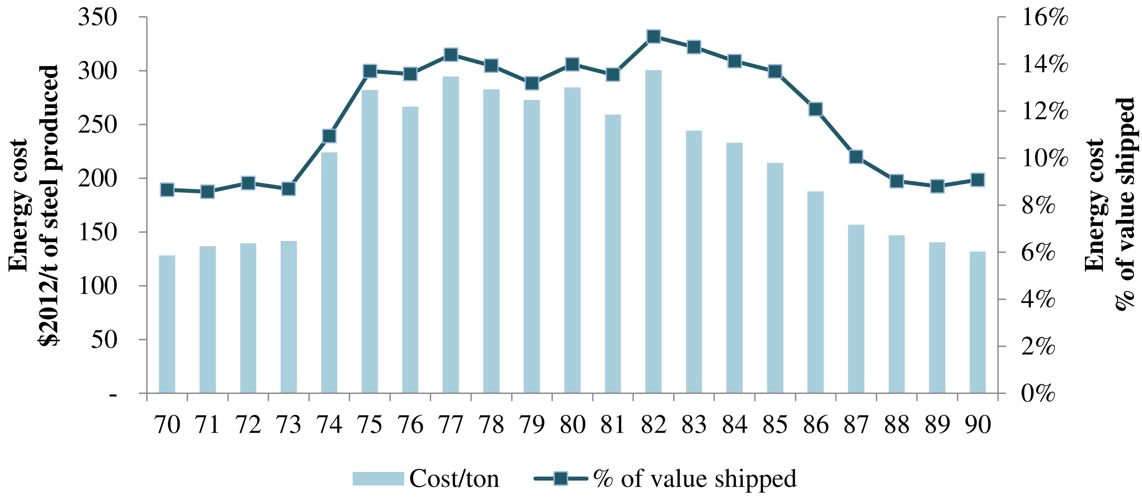

Figure 5: Energy cost for the Iron and Steel industry 1970-1990
Source: (Becker et al., 2009; EIA, 2014b; US Geological Survey, 2014)

Initially, price controls in the US, implemented to contain inflation, held back energy price increases, but in April 1974 price controls were lifted. Because of the large increase in coal and iron ore prices (freight rates as a result of oil price increases were cited as underpinning iron ore price rises (Klinger, 1973; Klinger, 1974)), the industry increased prices by 30% over the remainder of the year (Reno, 1974). This improved profitability but made the US market attractive to international competitors.

As evidenced in Figure 5, energy costs rose from 8.7% of revenue in 1973 to 14% of revenue in 1980, causing the US ISI to stumble, with its contribution to GDP falling $22 billion alongside a $44 billion decline in contribution to GDP for the MVI. By 1981 the MVI managed to stem the decline through massive investment which facilitated adaptation to high energy costs with the production of more fuel efficient vehicles. By comparison, the ISI had few adaptation options available to respond to its rising energy costs. Between 1979 and 1982, the value of product shipments declined 48% and employment fell by 34%. However 1982 was not the end of the employment woes for the workers in the industry, as 19% more jobs were shed by 1986.

5 Discussion

Some of the key findings to emerge from the analysis in Section 4 are discussed below.

5.1 States with energy deficits and reliance on oil and coal experience higher manufacturing employment decline

The empirical analysis provides evidence of the impact of energy deficits on manufacturing employment. It also shows that consuming either NG or RE (mainly hydro) instead of oil or coal provided a buffer against the consequences of the oil price shock. As spare capacity and diversity are core characteristics of resilience, the evidence from the quantitative analysis shows that energy resilience plays an important role in manufacturing employment. The transmission of the oil price shock to the coal system meant that industry in states that were reliant on coal for energy suffered worse employment outcomes than states with high levels of NG or RE.

5.2 Competition from Japan

Japan's economy was propelled by exports and imported energy. Domestic energy was in short-supply, so Japanese cars were engineered to be fuel efficient. Consequently, in an oil constrained world, international demand for Japanese motor vehicles increased by 26% in 1973-75 and by 23% 1979-82, although there was an annual decline of 7% in 1982. Exports to the US increased 10% in 1979, 16% in 1980 as less fuel-efficient domestic vehicle sales declined. Exports to the USA declined only after 1986 (JAMA, 2015) when the oil price had fallen reducing the attractiveness of fuel efficiency, epitomised by the rise of the Sports Utility Vehicle (Davis and Truett, 2000).

Due to its lack of raw materials, Japan protected its interests with 12-15 year terms on contracts for raw materials. With a focus on diversity of supply, investment in raw material extraction and transportation, and efficiency in the use of raw materials in production

(Bunker and Ciccantell, 2007; Queensland Coal Board, 1973-1983), Japan secured lower energy costs than the US.

Figure 6 shows the energy cost for steel production in the US and Japan. From reports it appears that most US investment was directed to meet the automobile industry's projections of significant growth (Duke et al., 1977) rather than address cost factors to improve international competitiveness.

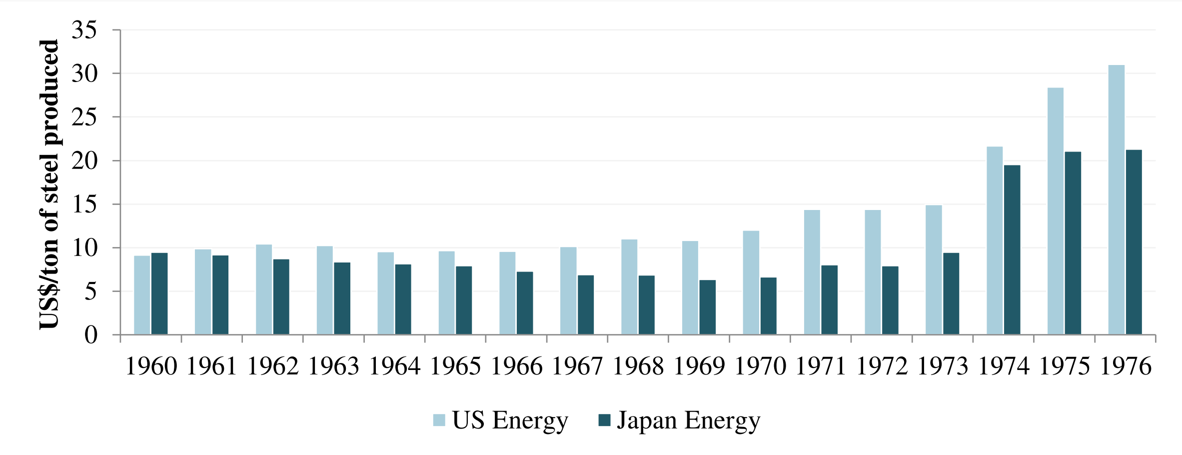

Figure 6: Energy cost for steel production, US versus Japan 1960-76
Source: (Duke et al., 1977)

Discussion on the progress of technology after 1975 in the Department of Mines' Iron and Steel Yearbooks emphasized weight reduction required by the automotive industry (Desy, 1977; Desy, 1978-79). It would seem that the ISI was unprepared for the consequences of the oil price rise in terms of thermal and metallurgical coal price increases. Little research had been conducted on reducing energy and metallurgical coal requirements because of the ready availability of US coal. Direct Reduction, the process of by-passing the coke oven/blast furnace smelting in the production of iron, needed very large quantities of cheap fuel (generally NG), of which there was little available in the north-east industrial regions of the US at the time. There appeared to be no viable alternatives for steel producers to consider.

The conclusion that is drawn from the comparison of the US MVI and ISI with their Japanese counterparts is that Japan, despite its lack of natural resources, showed evidence of higher levels of energy resilience. A lack of domestic production of oil had led to the production of motor vehicles better adapted to an oil-constrained world than US motor vehicles. Whilst Japanese producers still used metallurgical coal for the production of iron, Japan's strategy to source metallurgical coal from multiple countries, by directly investing in mines, and developing technology to tolerate varying qualities of metallurgical coal, provided iron producers with the spare capacity and diversity to adapt to rapidly increasing coal prices. As a result of this resilience in energy, their manufacturing industries were better able to adapt and compete internationally as energy prices escalated, as evidenced by the increase in exports of motor vehicles and steel during and after the oil crises of the 1970s.

5.3 Decline in US manufacturing states hegemony

With high costs of energy, US labour efficiencies became the prime focus to accomplish cost reductions to compete with international competitors. The decline in manufacturing in the Rust Belt led to a structural change to economic enterprise which was more focussed on the provision of services at home than dominance in global manufacturing. This reduced US energy-intensity, cushioning the economy from future energy shocks, but the long term consequences for the Rust Belt was population stagnation and sclerotic economic performance decades into the future, as seen in Figure 7. The size of the Rust Belt economy only returned to its 1978 size in 1985, and in every decade since 1985, the Rust Belt has had significantly lower average annual growth than the rest of the country. The shift to a serviceled economy produced small benefits for the economies of the states in the Rust Belt.

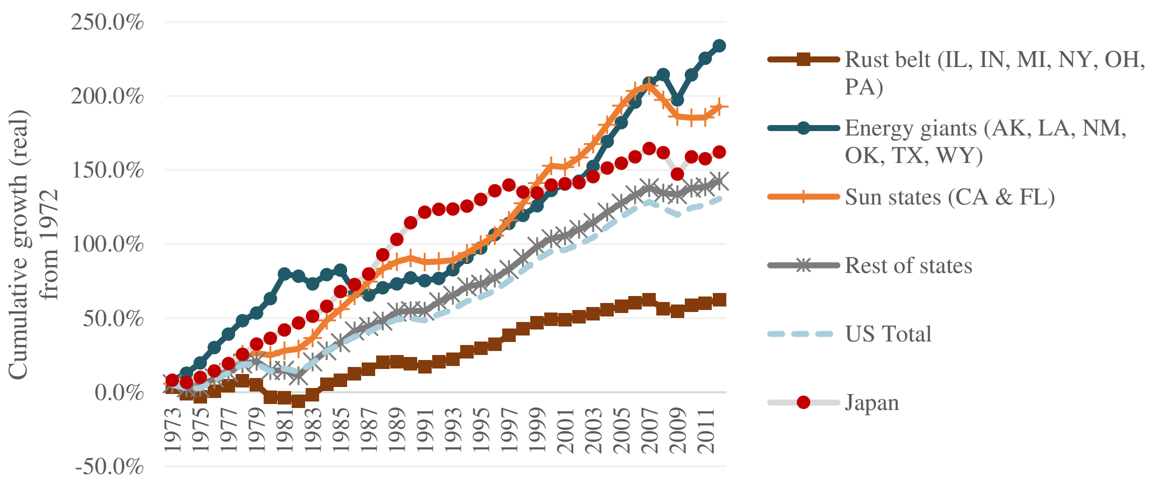

Figure 7: Cumulative GDP growth from 1972: Various US regions and Japan
Sources: (EIA, 2014b; World Bank, 2016)

6 Conclusions

The very high oil prices in evidence between 1974 and 1982 were coupled with significant declines in the economic fortunes of some countries and industries. The empirical analysis and case study reported in this paper seek not to support or discount any of the existing body of research that has sought to identify causes of the economic woes of the 1970s and 1980s, but rather to present another view of the causes and consequences of related energy price rises.

US manufacturing, in particular manufacturing in the heavily industrialised states of the north-east, was reliant on metallurgical coal for steel production and electricity generated from coal. A lack of spare capacity in the coal system and the coal transport systems, led to sharp increases in the cost of coal, a commodity which was always expected to be cheap because of its abundance. The increase in coal prices led to escalating electricity prices for industry and soaring metallurgical coal prices for the production of iron. ISI energy cost increases were passed on to customers, making the US steel market attractive to international producers experiencing decline in domestic demand in the wake of high oil prices. It is illuminating that Japan, a country with few domestic natural resources, had lower energy, metallurgical coal and iron ore costs during the 1970s and 1980s, than the US with its substantial deposits of all of these resources.

This study finds that the reason for high energy costs in the US was a lack of spare capacity in energy. The lack of spare capacity in oil meant that embargoes and political instability led inexorably to increased prices. These increased prices spread to the NG and coal fuel systems due to a lack of spare capacity within these fuel systems to respond to demand for substitutes to oil. The ensuing increase in coal price had severe consequences for iron and steel manufacturing which was reliant on cheap fuel, electricity and raw materials to compete with international steel producers. The ISI was buffeted by the winds of both income and input cost shocks as the oil price decreased demand for motor vehicles and construction, and the coal price increased costs of production. As resilience is characterized by adequate levels of spare capacity and a diversity of options, the ISI suffered the consequences of being at the confluence of both direct and indirect effects of a lack of resilience in energy.

References

ANG, B. W., CHOONG, W. L. & NG, T. S. 2015. Energy security: Definitions, dimensions and indexes. *Renewable and Sustainable Energy Reviews,* 42**,** 1077-1093.

ARGHANDEH, R., VON MEIER, A., MEHRMANESH, L. & MILI, L. 2016. On the definition of cyber-physical resilience in power systems. *Renewable and Sustainable Energy Reviews,* 58**,** 1060-1069.

BARSKY, R. B. & KILIAN, L. 2004. Oil and the Macroeconomy since the 1970s. *The Journal of Economic Perspectives,* 18**,** 115-134.

BECKER, R., GRAY, W. & MARVAKOV, J. 2009. *NBER-CES Manufacturing Industry Database* [Online]. Cambridge, MA: National Bureau of Economic Research. Available: http://www.nber.org/data/nberces.html 2015].

BERNANKE, B. S. 1983. Irreversibility, Uncertainty, and Cyclical Investment. *The Quarterly Journal of Economics,* 98**,** 85-106.

BERNANKE, B. S., GERTLER, M. & WATSON, M. W. 1997. Systematic Monetary Policy and the Effects of Oil Price Shocks. *Brookings Papers on Economic Activities,* 1**,** 91-148.

BLANCHARD, O. J. & RIGGI, M. 2009. Why are the 2000s so different from the 1970s? A structural interpretation of changes in the macroeconomic effects of oil prices. *National Bureau of Economic Research Working Paper Series*.

BLINDER, A. S. 2009. Comments on: Causes and Consequences of the Oil Shock of 2007-08. *Brookings Papers on Economic Activity,* Spring 2009.

BOHI, D. R. 1991. On the macroeconomic effects of energy price shocks. *Resources and Energy,* 13**,** 145-162.

BOHI, D. R. & POWERS, J. R. 1993. Energy Price Shocks And Regional Output And Employment. *The Review of Regional Studies,* 23**,** 129-142.

BRESNAHAN, T. F. & RAMEY, V. A. 1993. Segment Shifts and Capacity Utilization in the U.S. Automobile Industry. *The American Economic Review,* 83**,** 213-218.

BUNKER, S. G. & CICCANTELL, P. S. 2007. *East Asia and the global economy: Japan's ascent, with implications for China's future,* Baltimore, MD, Johns Hopkins University Press.

BURBIDGE, J. & HARRISON, A. 1984. Testing for the Effects of Oil-Price Rises using Vector Autoregressions. *International Economic Review,* 25**,** 459-484.

CELASUN, O., DI BELLA, G., MAHEDY, T. & PAPAGEORGIOU, C. 2014. The U.S. Manufacturing Recovery: Uptick or Renaissance? *IMF Working Paper*.

DANIEL, B. C. 1997. International interdependence of national growth rates: A structural trends analysis. *Journal of Monetary Economics,* 40**,** 73-96.

DAVIS, S. C. & TRUETT, L. F. 2000. *An analysis of the impact of Sport Utility Vehicles in the United States* [Online]. Knoxville, TN: Oak Ridge National Laboratory. Available: http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2000_147.pdf 2015].

DAVIS, S. J. & HALTIWANGER, J. 1996. Driving forces and employment fluctuations. *NBER Working Paper Series*.

DAVIS, S. J. & HALTIWANGER, J. 2001. Sectoral job creation and destruction responses to oil price changes. *Journal of Monetary Economics,* 48**,** 465-512.

DAVIS, S. J., HALTIWANGER, J. C. & SCHUH, S. 1996. *Job Creation and Destruction,* Cambridge, Mass., MIT Press.

DAVIS, S. J., LOUNGANI, P. & MAHIDHARA, R. 1997. Regional labor fluctuations: oil shocks, military spending, and other driving forces. *Governors of the Federal Reserve System, International Finance Discussion Papers*.

DESY, D. H. 1977. Minerals Yearbook: Iron and Steel. *Minerals Yearbook.* USGS Bureau of Mines.

DESY, D. H. 1978-79. Minerals Yearbook: Iron and Steel. *Minerals Yearbook.* USGS Bureau of Mines.

DHAWAN, R. & JESKE, K. 2008. Energy Price Shocks and the Macroeconomy: The Role of Consumer Durables. *Journal of Money, Credit and Banking,* 40**,** 1357-1377.

DUKE, R. M., JOHNSON, R. L., MUELLER, H., OUALLS, P. D., ROUSH, C. T. & TARR, D. G. 1977. The United States Steel Industry and its International Rivals: Trend and Factors Determining International Competitiveness. Washington, DC: Federal Trade Commission.

EDELSTEIN, P. & KILIAN, L. 2009. How sensitive are consumer expenditures to retail energy prices? *Journal of Monetary Economics,* 56**,** 766-779.

EIA. 2014a. *Net Generation by State by Type of Producer by Energy Source (EIA-906, EIA-920, and EIA-923)* [Online]. Washington: EIA. Available: http://www.eia.gov/electricity/data/state/ 2014].

EIA. 2014b. *State Energy Data System (SEDS): 1960-2012 (Complete)* [Online]. Washington: EIA. Available: http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US 2014].

FISCOR, S. 2012. Celebrating 100 years with Coal Age. *Coal Age.* Denver, CO: Mining Media.

GEA 2012. *Global Energy Assessment - Toward a Sustainable Future,* Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.

GISSER, M. & GOODWIN, T. H. 1986. Crude Oil and the Macroeconomy: Tests of Some Popular Notions: Note. *Journal of Money, Credit and Banking,* 18**,** 95-103.

HAMILTON, J. D. 1983. Oil and the Macroeconomy since World War II. *Journal of Political Economy,* 91**,** 228-248.

HAMILTON, J. D. 1988. A Neoclassical Model of Unemployment and the Business Cycle. *Journal of Political Economy,* 96**,** 593-617.

HAMILTON, J. D. 2009. Causes and Consequences of the Oil Shock of 2007-08. *Brookings Papers on Economic Activity,* Spring 2009.

HAMILTON, J. D. & HERRERA, A. M. 2004. Comment: Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy. *Journal of Money, Credit and Banking,* 36**,** 265-286.

HOOKER, M. A. 1996. What happened to the oil price-macroeconomy relationship? *Journal of Monetary Economics,* 38**,** 195-213.

IEA 2011. The IEA Model of Short-Term Energy Security: Primary Energy Sources and Secondary Fuels. Paris: International Energy Agency.

JAMA. 2015. *Active Matrix Database System: Exports* [Online]. Tokyo, Japan: Japan Automobile Manufacturers Association. Available: http://jamaserv.jama.or.jp/newdb/eng/index.html 2015].

KIM, I.-M. & LOUNGANI, P. 1992. The role of energy in real business cycle models. *Journal of Monetary Economics,* 29**,** 173-189.

KLINGER, F. L. 1973. Minerals Yearbook: Iron Ore. *In:* BUREAU OF MINES (ed.). US Bureau of Mines.

KLINGER, F. L. 1974. Minerals Yearbook: Iron Ore. *In:* BUREAU OF MINES (ed.). US Bureau of Mines.

LEE, K. & NI, S. 2002. On the dynamic effects of oil price shocks: a study using industry level data. *Journal of Monetary Economics,* 49**,** 823-852.

MELICK, W. R. 2014. The energy boom and manufacturing in the United States. *Federal Reserve System: International Finance Discussion Papers*.

MOLYNEAUX, L., BROWN, C., WAGNER, L. & FOSTER, J. 2016a. Measuring resilience in energy systems: Insights from a range of disciplines. *Renewable and Sustainable Energy Reviews,* 59**,** 1068-1079.

MOLYNEAUX, L., BROWN, C., WAGNER, L. & FOSTER, J. 2016b. Resilience in electricity generation: An empirical analysis. University of Queensland: Energy Economics and Management Group.

MORK, K. A. 1989. Oil and the Macroeconomy When Prices Go Up and Down: An Extension of Hamilton's Results. *Journal of Political Economy,* 97**,** 740-744.

QUEENSLAND COAL BOARD 1973-1983. Report of the Queensland Coal Board. Brisbane, Australia: Queensland Coal Board.

RAYMOND, J. E. & RICH, R. W. 1997. Oil and the Macroeconomy: A Markov State-Switching Approach. *Journal of Money, Credit and Banking,* 29**,** 193-213.

RENO, H. T. 1974. Minerals Yearbook: Iron and Steel. USGS Bureau of Mines.

ROEGE, P. E., COLLIER, Z. A., MANCILLAS, J., MCDONAGH, J. A. & LINKOV, I. 2014. Metrics for energy resilience. *Energy Policy,* 72**,** 249-256.

SENDICH, E. 2014. The importance of Natural Gas in the Industrial Sector with a focus on energy-intensive industries. *EIA Working Paper Series*.

SHARIFI, A. & YAMAGATA, Y. 2015. A Conceptual Framework for Assessment of Urban Energy Resilience. *Energy Procedia,* 75**,** 2904-2909.

SIMS, C. A. 1997. Comments and discussion on: Systematic Monetary Policy and the Effects of Oil Price Shocks. *Brookings Papers on Economic Activities,* 1**,** 91-148.

TOBIN, J. 1980. Stabilization Policy Ten Years After. *Brookings Papers on Economic Activities,* 1980.

US BUREAU OF ECONOMIC ANALYSIS. 2015a. *CA25: Total Full-time and Part-time employment by SIC industry* [Online]. Washington, D.C: US Department of Commerce. Available: http://www.bea.gov/regional/downloadzip.cfm 2015].

US BUREAU OF ECONOMIC ANALYSIS. 2015b. *Regional Economic Accounts: Annual Gross Domestic Product (GDP) by State* [Online]. Washington, D.C.: US Department of Commerce. Available: http://www.bea.gov/regional/downloadzip.cfm 2015].

US GEOLOGICAL SURVEY. 2014. *Iron and Steel Statistics* [Online]. US Geological Survey Data Series 140. Available: http://minerals.usgs.gov/minerals/pubs/historical-statistics/#ironore 2015].

US GOVERNMENT. 1978. *Powerplant and industrial fuel use* [Online]. Ithaca, New York: Cornell University Law School,. Available: https://www.law.cornell.edu/uscode/text/42/8301 [Accessed 18 May 2015.

WESTERSTROM, L. 1973. Minerals Yearbook: Coal. US Bureau of Mines.

WESTERSTROM, L. 1974. Minerals Yearbook: Coal. US Bureau of Mines.

WORLD BANK 2016. World Development Indicators 2016. Washington, D.C.: World Bank.

[i] SEDS provides estimations of primary energy consumed by industry by fuel type, but does not include the fuel consumed in the generation of electricity. The fuel source for industry consumption of electricity is estimated here by establishing the proportion of each fuel type in total electricity generation and applying that proportion to electricity consumed by industry and industry's share of energy losses within the electricity system.

[ii] Identifying spare capacity in the energy system is challenging. There are no reports available on oil productive capacity. As oil was imported for much of the US over both periods, it would be reasonable to assume that in both periods there was a lack of spare capacity in the oil fuel system across the US. There are estimations available from the EIA on productive capacity of NG, but only from 1980-2003, and for 2012. There is no data available from the EIA on the productive capacity of coal mines prior to 1979.

[iii] SEDS provides an estimate of the value of energy consumed and an estimate of energy production but no estimate of the value of energy produced. To estimate the value of energy produced requires a value for energy at the 'mine-mouth' which again is not reliably available. In this exercise, the price of oil is assumed to be the price for West Texas Intermediate (WTI) as provided by EIA. This does not take into account the complicated price control structure for different oil producers in place for much of the period 1973-82. In theory the actual value of production could be calculated based on the EIA's Crude Oil First Purchase Price but this series is not available by state for most of 1973-82. Using WTI as a value metric at least projects the increasing value of production in line with the increasing value for consumption. For NG and coal, the price is assumed to be the price of energy supplied to the electric power industry. It is recognised that these estimations may produce value metrics which overstate the value of production and thus undervalue the spare capacity.

In effect, differences will most likely reflect profit and transportation costs, most of which are likely to be within state and therefore less relevant for a metric which seeks to understand the consequences of value of funds leaving the state.

[iv] Alternative functional forms were considered for regression analysis. In particular, log-linear models were considered and found to provide no improved relationship information.

[v] Over the period 1973-82, Nevada experienced very high manufacturing employment growth, more than 3 standard deviations higher than the mean average growth over the period of 4.4%. However, over this period, Nevada's manufacturing sector was very small, contributing only 4.1% to total employment, whereas tourism including legalised gambling, was the dominant sector employing more than 40% of all workers. As manufacturing employment was such a small part of the Nevada economy and its manufacturing employment growth was so much higher than the rest of the states, it is excluded as an outlier from this analysis.

[vi] North Dakota and Utah, like Nevada, experienced good employment growth in manufacturing employment over the period 1973-82. This level of growth is not representative of states with a very small energy value surplus (like ND) or a small gap (like UT). As an example, Kentucky had a small energy value surplus, similar to North Dakota's but experienced a contraction in manufacturing employment of 2.8% over the period. Kansas had a small energy value gap similar to Utah's but experienced a 10% increase in manufacturing employment, less than half of Utah's manufacturing employment growth. So, there are good reasons for excluding ND and UT from the model.

[vii] For the purposes of accurately reflecting fuel consumption, industrial electricity consumption is included based on the proportion of electricity generated from each fuel source for the state.