The Relationship between Electricity Prices and Electricity Demand, Economic Growth, and Employment

DRAFT REPORT

Prepared for:

Kentucky Department for Energy Development and Independence
Coal Education Grant RFP Number 127 1000000441

October 19, 2011

Authors: Dr. John Garen, Dr. Christopher Jepsen, and James Saunoris

Center for Business and Economic Research
Department of Economics
University of Kentucky
335 BA Gatton College of Business & Economics
Lexington, KY 40506
Phone: (859) 257-7678
Fax: (859) 257-7671
cber@uky.edu
Dr. Kenneth R. Troske, Director

Gatton
COLLEGE OF BUSINESS AND ECONOMICS

Table of Contents

Table of Contents i
List of Tables ii
List of Figures iii
Acknowledgements iv
Executive Summary 1
Introduction 3
Literature Review 4
Computable General Equilibrium (CGE) Model 4
Capital, Labor, Energy and Materials (CLEM) Model 5
Comparison of Models 6
Overview of Current Trends 7
Data and a Simple Energy Demand Model 13
Examining the Relationship among Energy Prices and Production and Employment 21
Policy Scenarios 30
Conclusion 35
References 37
Appendix A 39
Appendix B 40
Appendix C 41

List of Tables

Table 1: National Estimates: Demand for Energy 14
Table 2: Demand for Electricity by Sector 16
Table 3: Energy Intensive States.......... 18
Table 4: Demand for Electricity Interactions.......... 19
Table 5: Growth in Gross State Product 22
Table 6: Total Gross State Product 23
Table 7: Employment Growth 24
Table 8: Total Employment 25
Table 9: Growth in Gross State Product, with Current and Lagged Prices 26
Table 10: Total Gross State Product, with Current and Lagged Prices 27
Table 11: Employment Growth, with Current and Lagged Prices.......... 28
Table 12: Total Employment, with Current and Lagged Prices 29
Table 13: Policy Scenarios and Production, 10% and 25% Price of Electricity Increase 32
Table 14: Policy Scenarios and Employment, 10% and 25% Price of Electricity Increase
.... 34

List of Figures

Figure 1: Crude Oil Prices (2010$) 7
Figure 2: Gross Domestic Product (2010$) and Total Employment 8
Figure 3: Electricity Consumption per Capita 9
Figure 4: Electricity Consumption per Real Gross State Product 10
Figure 5: Electricity Price (2010$) 11
Figure 6: U.S. Energy Prices (2010$) 12
Figure 7: Simulated Effect of One-Time Shock in Electricity Prices on GSP 30

Acknowledgements

We thank the Kentucky Department for Energy Development and Independence for funding for this project. We also thank Aron Patrick at the Department for providing much of the data used in this report as well as answering questions about the data. We thank Paul Brooks, Talina Matthews, Aron Patrick, and Alan Waddell for useful comments. However, all errors are solely the responsibility of the authors.

Executive Summary

There is growing concern over the emissions of greenhouse gases in the United States. Policymakers at both the state and national levels have discussed, and in some cases enacted, policies with the goals of reducing energy demand and encouraging the use of more efficient energy technologies. Because these policies will have an effect on the cost of energy, a quantitative examination of the energy demand is warranted.

In this project, we estimate the likely effects of increased electricity prices on the demand for electricity, production as measured by Gross State Product (GSP), and employment.

We estimate two sets of models. In the first set, we study the relationship between electricity consumption and the prices for energy sources including electricity. These models are known as demand equations. In the second set, we build on the demand equations and estimate the relationship between economic output (measured either as gross domestic product or employment) and energy prices. The goal of these models is to estimate the impact of energy prices on economic output in both the short run and the long run. We highlight this distinction to illustrate that the response to a change in energy prices may be different in the short run because some factors may be difficult to modify over a short period. For example, the process of converting existing power plants to use natural gas instead of coal is a time-consuming process that does not happen overnight.

In addition to presenting the results from our economic models, we also provide policy scenarios that illustrate the long-run effects of a permanent increase in electricity prices of either 10% or 25%. We assume that the price shock is the only change of note. Other important factors such as changes in energy efficiency or costs of production are not considered because the likely changes in such factors are difficult if not impossible to predict. Furthermore, an economic model that allows for such changes is much more difficult to estimate than our economic model. Even with these caveats, the policy scenarios simulate future economic conditions under current policies and conditions. They answer the question of what would happen to future GSP and employment if electricity prices went up and nothing else changed.

The major findings of the report are:

- In the short run, coal appears to be the most sensitive to its price changes followed by natural gas consumption. For example, a 1% increase in price results in a 0.64% drop in coal consumption and a 0.42% drop in natural gas consumption. For electricity, a 1% percent increase in its price results in a 0.20% drop in electricity consumption, which is substantially below both coal and natural gas. In addition, a 1% increase in income leads to an increase in electricity consumption and fuel oil consumption of 0.13% and 0.43%, respectively.

- As expected, consumers are more sensitive to long-run price increases rather than short-run price increases. In the long run, a 1% increase in price results in a

1.71% and 1.31% drop in consumption of natural gas and coal, respectively. For electricity, a 1% percent increase in its price results in a 0.72% drop in electricity consumption.

- When we look at the demand for electricity across different sectors of the economy, we find that the industrial sector is the most sensitive to price changes in both the short and long run. The residential sector is less sensitive to price changes, and is sensitive to price changes only in the short run. The results suggest that the industrial and commercial sectors are the quickest to alter their electricity consumption, which could negatively affect economic growth and employment.

- Energy prices have the expected negative relationship with GSP growth and GSP levels. However, crude oil prices appear to have more of an effect on production growth compared to electricity prices and natural gas prices. Similarly, energy prices have a negative relationship with employment growth and employment levels. The effect of energy prices on employment is similar for electricity, natural gas, and crude oil.

- We illustrate our findings through a set of policy scenarios of assumed 10% and 25% increases in electricity prices for energy-intensive states such as Kentucky. We consider both short-run and long-effects of these price increases. For each scenario, we assume that the price increase is permanent but is not accompanied by any other notable changes such as technological advancement or the discovery of new energy supplies. We assume that, in the absence of the price shock, economic growth consists of 3% annual growth in GSP and 1% annual growth in employment, the historical averages for each.

- A 25% electricity price increase is estimated to reduce the GSP growth rate from 3% to 2.30% in the long run. The price increase is estimated to reduce employment growth from 1% to 0.61% in the long run.

Introduction

There is growing concern over the emissions of greenhouse gases in the United States. Policymakers at both the state and national levels have discussed, and in some cases enacted, policies with the goals of reducing energy demand and encouraging the use of more efficient energy technologies. Because these policies will have an effect on the cost of energy, a quantitative examination of the energy demand is warranted.

In this project, we estimate the likely effects of increased electricity prices on the demand for electricity, production as measured by Gross State Product (GSP), and employment.

We begin by discussing the strengths and weakness of various economic models used to estimate these relationships. We focus on the two main types of models used to examine long-run relationships among energy and economic activity include computable general equilibrium models (CGE) and capital, labor, energy and materials models (CLEM).

Then, we describe trends over time in electricity and other energy prices, electricity consumption, U.S. Gross Domestic Product (GDP), and employment. The descriptive analysis of the trends in energy prices, electricity consumption, and economic conditions provide insight into the underlying relationships among these variables of interest.

In the next section we document the data and build a simple stock-flow model of energy demand. We look at overall demand for electricity, coal, natural gas, and fuel oil. For electricity demand, we look at overall demand as well as demand by sector: commercial, residential, and industrial. These models provide estimates of both the short-run and long-run relationships between energy demanded and energy price, income, and substitute price.

With these estimates in mind, we develop a model to investigate the dynamic relationship between energy prices and macroeconomic aggregates (i.e. employment and production) to ascertain the affects of changes in energy prices on these aggregates. Finally, we develop policy scenarios and corresponding estimates to produce predictions of the long-run effects of electricity price shocks on economic conditions under the strong assumption that the electricity price shock is not accompanied by other changes such as technological advances.

Literature Review

In this section we briefly review the current literature of the relationship between energy and economic activity, namely, production and employment. The short-run model is relatively straight forward because the factors of production, except labor, are assumed to be fixed. The long-run model is more involved due to general equilibrium effects. Specifically, mobility of factors of production is a concern in the long run, but it is assumed to be constant in the short run.

The two dominant models used to examine long-run relationships among energy and economic activity include computable general equilibrium models (CGE) and capital, labor, energy and materials models (CLEM). In what follows we analyze the relative strengths and weaknesses of the two models in order to pick the optimal one to use for examining the long-run relationship between energy and economic activity.

Computable General Equilibrium (CGE) Model

CGE models are a primary tool for analyzing policy changes over multiple markets. These models allow researchers to trace out the effects of a policy change (e.g. a change in tax rates, subsidies or regulations) that can be transmitted through multiple markets. This approach has been taken by many in examining such things as fiscal reform and development (see, e.g. Perry et al 2001; Gunning and Keyzer, 1995) and have become increasingly important in analyzing such things as environmental regulations (see, e.g. Weyant 1999; Bovenberg and Goulder 1996;Goulder 2002).

Foundationally, CGE models are heavily rooted in economic theory. To begin, the system must be parameterized using elasticities of substitution between each pair of production inputs (and consumption goods) that come from the economic literature. Once the parameters are specified, the model is calibrated to reproduce the data for the benchmark year. This benchmark year represents the long-run equilibrium in the absence of a policy change. The system is then perturbed by a policy change (e.g. electricity price increase due to tax change) creating a new solution known as the counterfactual. For example, if the cap-and-trade system is the policy change, then the resulting equilibrium under the cap-and-trade system would be the counterfactual. The difference between the benchmark solution (i.e. the long-run equilibrium in absence of the policy change) and the counterfactual (i.e. the long-run equilibrium with the policy change) thus represents the effects of the policy change on the variables of interest (e.g. employment and production). Therefore, the main advantage of CGE models is their ability to measure the effects of policy changes over many markets in a theoretically-consistent manner. However, the usefulness of CGE models rests less on their predictive ability and more on illuminating the adjustment mechanism of prices and quantities in multiple markets (Wing, 2004). Consequently, as noted by Francois (2001), CGE models are an empirical tool used to analyze dynamic economic interactions given policy distortions.

The main criticism of CGE models, as noted in Wing (2004), is that policy makers and researchers view these models as a “black box”, meaning that their results cannot be meaningfully traced back to their data, parameters, solution method, or structure. The sheer complexity of such models makes it extremely difficult to pinpoint the precise source of the result (Panagariya and Duttagupta, 2001). A further difficulty rests on the accuracy of elasticities used for parameterization. The sometimes wide range of values for elasticity of substation found in the literature adds increased uncertainty about the final solutions. In other words, the model's results are likely dependent on the assumptions of the model, which include the elasticities of substitution among energy sources.

Despite the criticisms of CGE models, they have been used extensively in examining energy policy. For instance, Li and Rose (1995) find the adverse effect of increased carbon taxes on Pennsylvania's economy were mitigated by substitution away from energy and towards other factors of production. Further, the adverse effects on industrial states were great for more mobile factors of production. Using data from Canada, Whalley and Trela (1986) examine interregional energy policies including a wide variety of energy taxes and subsidies on both producers and consumers, which could only be evaluated within a CGE framework.

Capital, Labor, Energy and Materials (CLEM) Model

CLEM models are models where energy prices are one of the main costs along with capital, labor, and materials (and sometimes other costs as well). Because the CLEM models are designed to evaluate effects of changes in energy prices, they are well suited for studying the effects of increased electricity prices as a result of policies aimed to capture environmental costs of carbon emissions. As opposed to CGE models, the actual structural parameters of the underlying model are not estimated, only their reduced-form counterpart. Rather than having to estimate specific theoretical relationships, this approach extracts information directly from the data or, in other words, allows the data to "speak." The main advantage of reduced-form estimation relates to its ease in implementation and limited ex ante biases. The estimates of the reduced-form model provide the long-run multipliers associated with the underlying model. These estimators can then be used to estimate the variables of interest. Intuitively, if one is only interested in examining the statistical relationship among the variables of interest and not the parameters of the theoretical model, then this model is of particular interest (see, e.g., Kennedy, 2003).

Many researchers have used CLEM type models to estimate the economic effects of oil price shocks in the 1970's (see, e.g., Hamilton, 1983; Hooker, 1996; Davis and Haltiwanger, 2001). Davis and Haltiwanger (2001) examine the effects of oil and monetary shocks in the U.S. on job creation and destruction in the manufacturing sector from 1972 to 1988. They find that oil price shocks account for approximately twice as much variability in employment growth compared to monetary shocks and employment responses to oil price increases are exacerbated by capital intensity, energy intensity and product durability.

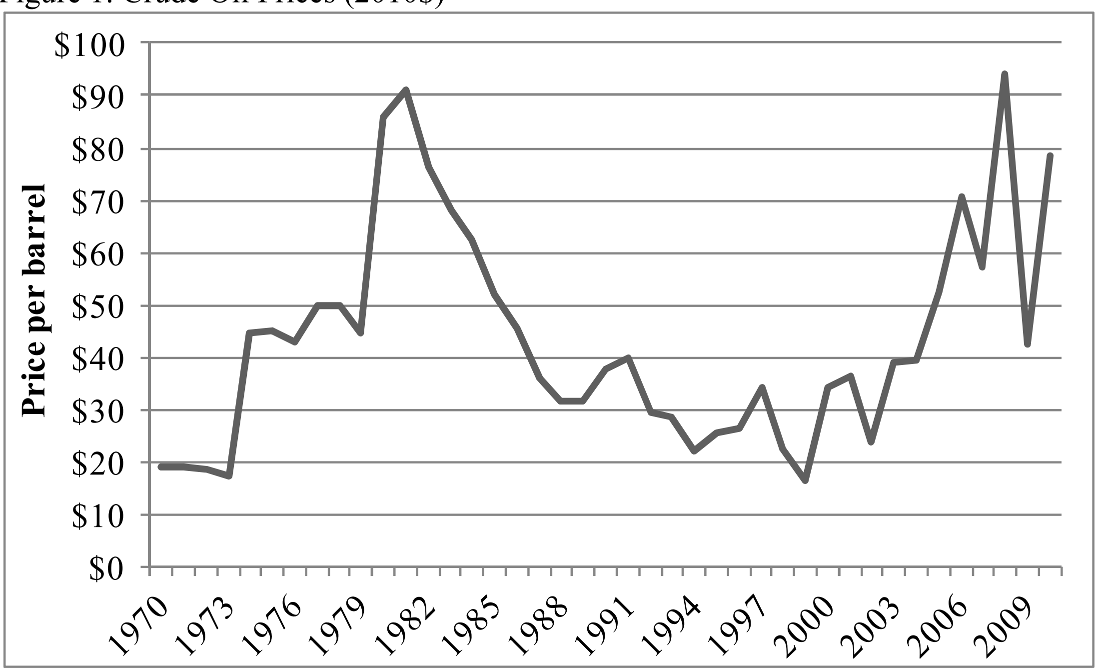
Comparison of Models

With an interest in understanding the underlying relationship between energy and economic activity, it is important to limit the amount of prior assumptions and therefore any ex ante biases while attempting to extract as much information from the data as possible. There are many assumptions that go along with developing CGE models and subsequent simulations. For example, the mathematical structure of the production function and utility functions need to be developed. These assumptions, along with many other complexities associated with CGE models, limit the usefulness in describing the underlying relationship of interest. Because the CGE models require many assumptions on the structure of the economy and are very complex, we use a model implied by the CLEM type models for the long-run analysis. In particular, we use an autoregressive distributed lag (ARDL) model to limit our assumptions concerning the variables of interest and focus on the existing relationships extracted directly from the data. Given the comprehensiveness of the data along both the time and space dimension, this model will ease the examination of the causal relationship among the variables, thus allowing us to generating policy scenarios and corresponding outcomes.

Overview of Current Trends

In this section we examine time trends of various variables of interest. We start by examining the trends in gross domestic product, employment, and crude oil prices. Figure 1 displays the trend in real crude oil prices. Expectedly, the 1970's experienced rapid increases in crude oil prices coinciding with various factors. For instance, as documented by Hamilton (1993), in 1970 there was the rupture of the trans-Arabian pipeline, Libyan production cutbacks, and coal price increases. From 1973-74 there was stagnating U.S. production and the OPEC embargo. Subsequently, from 1978-79 the Iranian revolution followed by the Iran-Iraq war and removal of U.S. price controls from 1980-81. The high oil prices encouraged production of oil from non-OPEC countries thus leading to a fall in oil prices until the Iraq's invasion of Kuwait in 1990. This invasion caused supplies to be cut back and prices to spike because Kuwait and Iraq accounted for 9% of total oil production at that time (Hamilton, 2010).

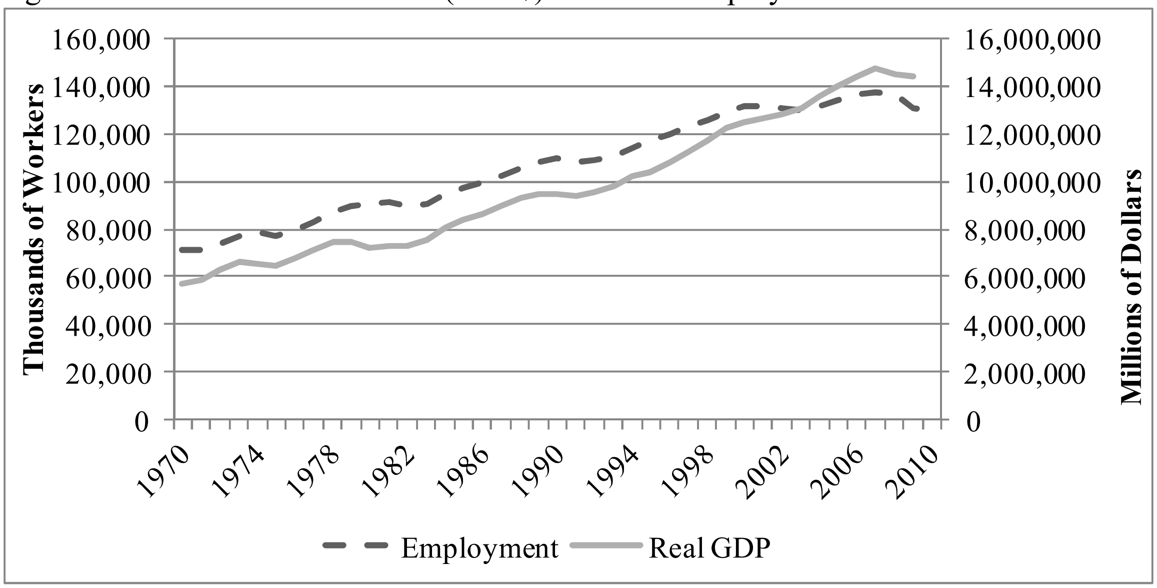
Figure 1: Crude Oil Prices (2010$)



From 1997 to 2010 the new industrial age emerged as many countries began industrializing (e.g. Brazil, China, Hong Kong, India, Singapore, South Korea, Taiwan, and Thailand). These countries accounted for 17% of world's petroleum consumption in 1998 and accounted for 69% of the increase in global oil consumption as of 1998 (Hamilton, 2010). After some minor setbacks in the oil price due to the Asian financial crisis, oil prices continued on an upward trend as oil consumption continued and supply stagnated.

Figure 2 displays the time trend in real gross domestic product and total employment. As expected both series follow a steady upward trend with production leading employment. Following the oil supply shock of 1972, production declined sharply followed by employment. The large decline in production and employment in the early and late 1970's coincide with rising energy prices and disruptions in petroleum supplies as documented previously.

Figure 2: Gross Domestic Product (2010$) and Total Employment



In order to get a sense of the relationship among the variables of interest for Kentucky, we compare Kentucky to Ohio, Tennessee and the United States as whole. These plots give us a sense of current trends over time against a backdrop of an ever-changing political, economical and demographical environment.

The following two graphs illustrate the energy intensity of each state. We use two measures of energy intensity: energy consumption per capita and energy consumption per GSP. Figure 3 shows the time series plot of total electricity consumption per capita. All series tend to follow similar upward trend over time with Kentucky surpassing Tennessee in the late 1980's. Where Tennessee, Ohio and the U.S. have leveled off throughout the 1990's, Kentucky has seen a large increase in electricity consumption per capita, likely a result of extremely low electricity prices when we document below.

Figure 3: Electricity Consumption per Capita

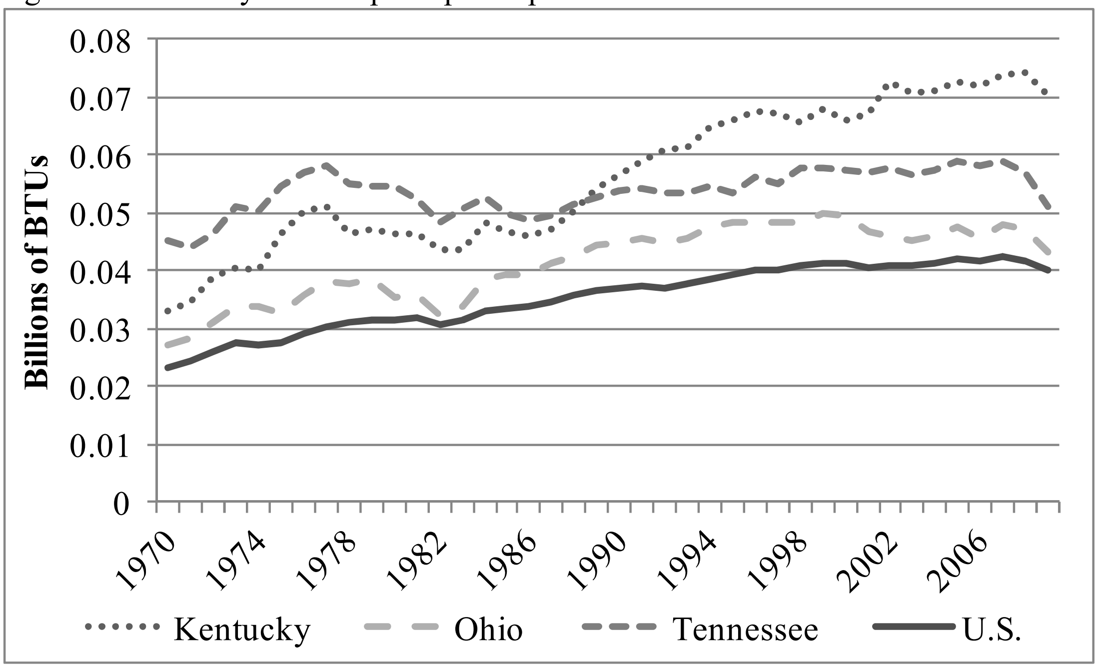
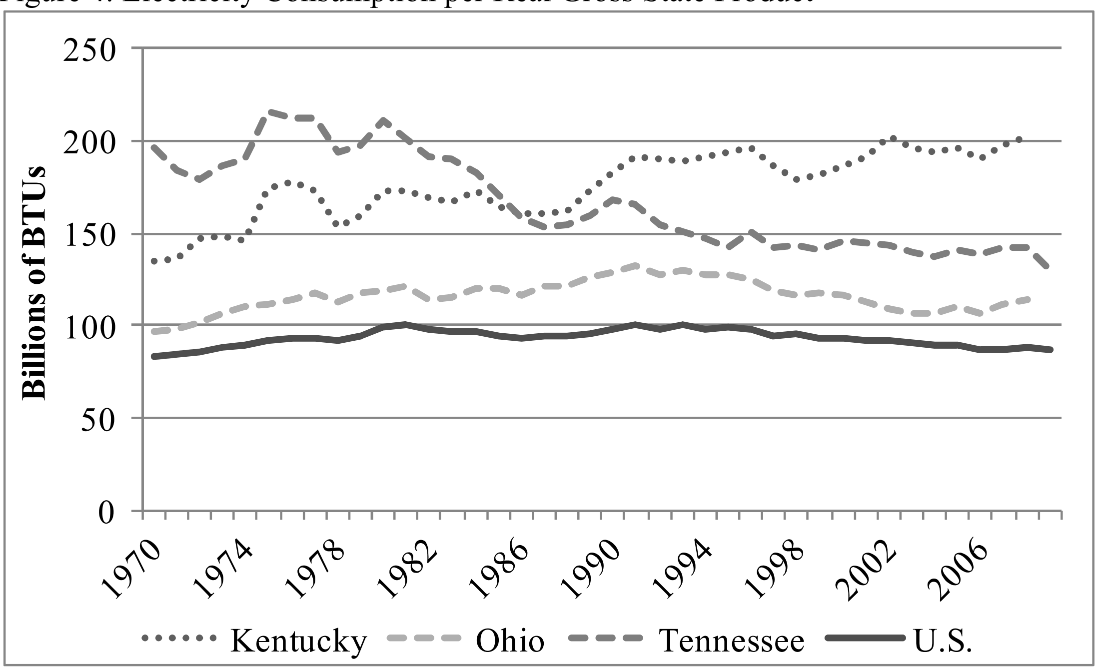


Figure 4 presents electricity consumption normalized by state GSP. The figure shows that, in the mid to late 1980's, Kentucky's electricity consumption per GSP exceeds Tennessee, in part because Tennessee's electricity consumption per GSP had been declining since the late 1970's (see Figure 4). The figure indicates that Kentucky's electricity intensity is on the rise. Consequently, any increase in regulation or energy prices will bear a much larger burden in Kentucky relative to its neighboring states. Because electricity usage is normalized by GSP, these trends could be due to increases in production in Tennessee or, alternatively, a decrease in production in Kentucky. On the other hand, the United States and Ohio have seen relatively stable electricity intensity, at least when normalized by GSP.

Figure 4: Electricity Consumption per Real Gross State Product



The time trend of average electricity price (in 2010 $), shown in Figure 5, illustrates Kentucky's superior position with the lowest average price compared to Ohio, Tennessee, and the United States for most of the time period under consideration. The general time trend follows historical patterns in regards to the energy crisis in the 1970's, remaining relatively stable throughout the 1980's and 1990's, and proceeding to increase again in the beginning part of the 21st century. Other prices, such as, fuel oil, natural gas, and coal, tend to follow national prices. Electricity price for Kentucky and Tennessee were very similar until the late 1980's where they started to diverge.

Figure 5: Electricity Price (2010$)

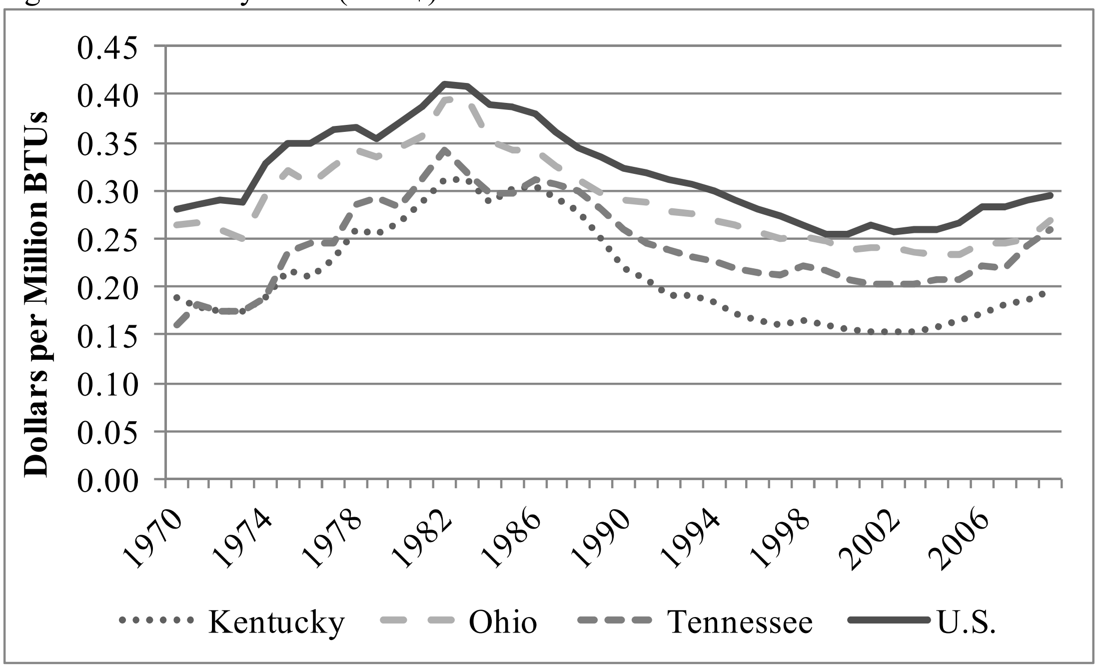
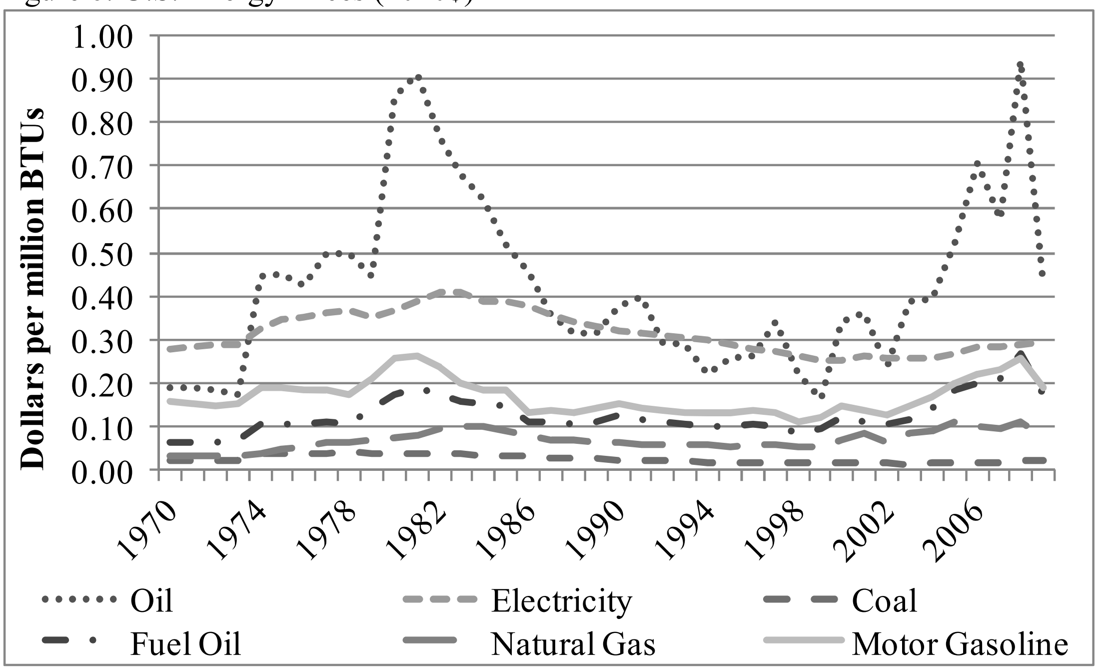


Figure 6 displays time series plots of the five energy price variables along with the price of crude oil (prices are in 2010 dollars). From the graph, the price of coal has remained surprisingly stable over the time period. Likewise, the price of natural gas appears relatively stable; however, since the early 1970's the price of natural gas has increased. This increase is perhaps due to the aforementioned oil price shocks of the early 1970's. Furthermore, the price of fuel oil and motor gasoline appear to follow very similar time paths, thus appearing to be highly correlated. Overall, each price seems to be influenced, not surprisingly, by the price of oil.

Figure 6: U.S. Energy Prices (2010$)



These cursory relationships provide insight into the underlying relationships among the variables of interest. We use these insights to develop more sophisticated econometric models in order to further understand the role of energy in the economy. Our goal is that these models allow us to take a closer look at the statistical relationships among the variables in both the short and long run. Specifically, the causal relationships among energy use, energy prices, employment and production are of particular interest.

Data and a Simple Energy Demand Model

In this section we document the data and build a simple stock-flow model of energy demand with the intention of estimating the relationship between energy demanded and energy price, income, and substitute price.

The data used in this study include observations from each of the 48 continental U.S. states over the period 1970 through 2010.[1] Data on total energy consumption (measured in billions of BTU's) for coal, electricity, natural gas, and fuel oil along with their corresponding average energy price level (measured in MMBTU's) and crude oil prices (measured in dollars per barrel) were collected by the Department of Energy and Independence from the *U.S. Energy Information Administration*. Furthermore, energy consumption and price were collected for each sector in the economy including residential, commercial, and industrial. Additional data on personal income, nominal gross domestic product, gross state product, consumer price index, and population were collected from the Bureau of Economic Analysis.[2] Finally, data used to calculate the climate index were collected from the National Oceanic and Atmospheric Administration, *National Climate Data Center*.[3] All variables are measured in natural logs so that the results can be interpreted in terms of elasticities.

There is growing concern over the emissions of greenhouse gases in the United States that has provoked federal policies complementary to reducing energy demand and encouraging the use of more efficient energy technologies. These policies will have an effect on the cost of energy and thus a quantitative examination of the energy demand is warranted. The purpose of this section is to estimate the demand for energy in order to examine the sensitivity of energy consumption to changes in price and income. The model used to estimate the demand curve is a stock-flow model developed by Houthakker et al. (1974) and used by Berstein and Griffin (2005).[4] This model is conducive to short-run dynamics in the demand relationship and allows for computation of both short-run and long-run relationships. Specifically, this setup gives consumers the ability to modify their energy consumption in the short run by adjusting their use of energy-intensive appliances (the flow). In the long-run, consumers have access to more energy-efficient technologies and can adjust the type of appliances (the stock) they use much more easily.

In estimating the demand curve and corresponding elasticities, energy price and quantity are determined by interaction of supply and demand. Therefore, in order to isolate the effects on the demand curve, the following assumptions need to hold: (1) the model includes all the determinants of the demand for energy; (2) energy price is exogenous; and (3) there is no serial correlation in the residuals. These assumptions allow identification of the model parameters through shifts in the supply curve that, subsequently, trace out the demand curve. In reference to assumption (1), and consistent

---

[1] We exclude Hawaii and Alaska given their unique climate and energy use.
[2] The Consumer Price Index (CPI) was used to convert prices to 2010 dollars.
[3] Climate index was calculated as the sum of the number of heating degree days and cooling degree days.
[4] See the Appendix for more technical details of estimation.

with microeconomic theory, the model captures the basic attributes of the demand curve such as income and substitute price.[5] Furthermore, we control for changes in energy demand relating to climate and population.[6] With respect to the second assumption, as argued by Bernstein and Griffin (2005), a component of utility bills are derived from fuel costs which are determined on a world market and therefore not affected by changes in demand from the U.S.

Table 1: National Estimates: Demand for Energy

Variables	(1) Coal	(2) Electricity	(3) Natural Gas	(4) Fuel Oil
	Short-Run Elasticity Estimates			
Price	-0.638***	-0.198***	-0.419***	-0.0603
	(0.179)	(0.0360)	(0.115)	(0.127)
Substitute Price	0.137	-0.0147	0.0474	0.0307
	(0.125)	(0.0139)	(0.0404)	(0.0274)
Income	0.0137	0.129***	0.0779	0.432*
	(0.292)	(0.0438)	(0.0734)	(0.240)
	Long-Run Elasticity Estimates			
Price	-1.311***	-0.719***	-1.708***	0.0933
	(0.387)	(0.0819)	(0.507)	(0.314)
Substitute Price	0.324	0.0824*	0.266	0.332***
	(0.686)	(0.0474)	(0.281	(0.0998)
Income	0.786	0.705***	1.111***	0.651***
	(0.585)	(0.0617)	(0.281)	(0.175)
Observations	1,860	1,872	1,872	1,872
R-squared	0.835	0.992	0.940	0.880
Number of States	48	48	48	48
Adj. R-Squared	0.830	0.992	0.938	0.877
Log Likelihood	-456.2	4094	1940	1909

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

The law of demand dictates that the price elasticity of demand should be negative, suggesting that quantity demanded for energy decreases with increases in the price, all else equal. Furthermore, provided that energy is a normal good, income elasticity of

[5] For our model, natural gas serves as a substitute for electricity, fuel oil, and coal. Electricity serves as a substitute for natural gas.

[6] In addition to the control variables, we control for state-specific fixed effects such as geography and other state-specific policies that may influence energy demand. Also, time fixed effects are included to control for time-varying factors that affect all states over time (e.g. Federal policies affecting all states or business cycle fluctuations).

demand is expected to be positive; accordingly, increases in income result in increases in energy consumption, all else equal. Finally, cross-price elasticity is expected to be positive if electricity and natural gas are substitutes and negative if they are complements. Long-run price elasticities are expected to be higher (in absolute values) as consumers have greater flexibility in adopting more energy-efficient technologies and avoiding price increases. Likewise, income elasticity is expected to be greater in the long run than in the short run. Using a panel of U.S. states, allowing for both state-specific fixed effects and time effects, estimates for energy demand are given in Table 1.

Notice that all price elasticity estimates are negative as expected. In the short run, coal appears to be the most sensitive to price changes followed by natural gas consumption. For example, a 1% increase in price results in a 0.64% drop in coal consumption and a 0.42% drop in natural gas consumption. Electricity, on the other hand, has a price elasticity of only 0.20%, which is substantially below both coal and natural gas. This estimate is in line with the -0.14 price elasticity found by Dahl and Roman (2004). This is an indication that there are no readily-available substitutes in the short run for electricity as compared to coal and natural gas. The price elasticity of fuel oil is insignificantly different from zero; therefore price does not affect the consumption of fuel oil.[7] With respect to income elasticity, only electricity and fuel oil display statistically significant income effects. For instance, a 1% increase in income leads to an increase in electricity consumption and fuel oil consumption of 0.13% and 0.43%, respectively. This result is as expected since both electricity and fuel oil are perceived as normal goods, thus increases in income are associated with more use of electricity-intensive appliances (e.g. consumers are more likely to leave lights and other appliances on when away from the home). Surprisingly, the estimate for the cross-price elasticity is not significant in any equation. This result implies that either natural gas is a bad proxy for energy substitutes or that substitution from natural gas to other energy sources might not be feasible in the short run.

The long-run estimates in Table 1 show interesting results. For instance, natural gas is more sensitive to price changes (-1.71) compared to coal (-1.31). However, both goods are highly elastic in the long run since a 1% increase in price results in a 1.71% and 1.31% drop in consumption of natural gas and coal, respectively. Electricity maintains its position as being relatively inelastic compared to natural gas and coal but has higher price elasticity in the long run as expected. However, this estimate is significantly higher than the -0.32 long-run price elasticity found by Dahl and Roman (2004). These results are consistent with the fact that consumers of energy have greater flexibility in avoiding price changes in the long run by adopting less energy-intensive appliances. Income effects appear to be more significant in the long run. Electricity, natural gas and fuel oil all have positive income effects. This finding makes sense that, all else equal, increases in income allow consumers to afford more energy-intensive appliances, thus increasing their energy consumption. Surprisingly, natural gas consumption has a high income elasticity. For example a 1% increase income in the long run results in an increase in natural gas consumption of 1.11%.

[7] The possible reason for no price effects in the short run could be due to the storable characteristic of fuel oil in which consumers can avoid paying higher prices for a period of time (Kilian, 2008).

Overall, these results show that, in the short run, consumers have some flexibility in avoiding price changes by simply limiting their energy use, but will bear some burden of price changes; however, in the long run consumers have much greater flexibility in avoiding price changes by adopting less energy-intensive appliances. This result indicates that consumers would bear a much larger burden in the short run given a change in regulation or tax policy, but in the long run these effects are mitigated as consumers have greater flexibility in adjusting to the adverse events.

The possibility that elasticities can vary substantially across sectors warrants a sectoral analysis of electricity demand. To this end, the electricity demand equation is estimated for the commercial, residential, and industrial sector. The results are in Table 2.

Table 2: Demand for Electricity by Sector

Variables	(1) Total	(2) Commercial	(3) Residential	(4) Industrial
	Short-Run Elasticity Estimates			
Price	-0.198***	-0.205***	-0.137***	-0.220***
	(0.036)	(0.053)	(0.021)	(0.063)
Substitute Price	-0.015	0.010	-0.008	-0.010
	(0.014)	(0.016)	(0.010)	(0.033)
Income	0.129***	0.045	0.095***	0.219**
	(0.044)	(0.075)	(0.033)	(0.101)
	Long-Run Elasticity Estimates			
Price	-0.719***	-0.559***	-0.607***	-0.832***
	(0.082)	(0.116)	(0.0504)	(0.130)
Substitute Price	0.0824*	0.106	0.186***	0.187*
	(0.047)	(0.084)	(0.047)	(0.107)
Income	0.705***	0.684***	0.857***	0.343*
	(0.062)	(0.173)	(0.049)	(0.181)
Observations	1,872	1,872	1,872	1,872
Number of States	48	48	48	48
Adj. R-Squared	0.992	0.978	0.991	0.921
Log Likelihood	4094	2541	3916	2099

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

The own-price elasticity in all sectors displays the expected negative sign consistent the law of demand. The most sensitive sector to electricity price changes is the industrial sector and the least sensitive is the residential sector. For the industrial sector, a 1% increase in electricity price leads to a decline in electricity consumption by 0.22% and only 0.14% decline in the residential sector. Although the price elasticity of -0.22 is exactly in line with Taylor's (1977) estimate, the residential price elasticity is relatively small (in absolute value) compared to previous findings (approximately -0.20, see Bohi and Zimmerman, 1984). In the long run, the price elasticities are more elastic than the short run, again confirming the idea that consumers have greater flexibility to avoid higher electricity prices. In the long run, the industrial sector remains the most sensitive with a price elasticity of -0.83; however, the commercial sector is now the least sensitive to price changes at only -0.56. Both these estimates fall within the bounds set in the current literature.

The industrial sector displays the highest sensitivity to income changes in the short run with an income elasticity of 0.22, but, in the long run, the industrial sector becomes the least sensitive to income changes with an income elasticity of only 0.34. The income elasticity of the commercial sector is statistically insignificant, implying that changes in income have no effect on commercial sector electricity consumption. And, the residential sector has an income elasticity of only 0.10.

In the long run, the effect of electricity consumption due to income changes is most profound in the residential sector. A 1% increase in income increases residential electricity consumption by as much as 0.87% in the long run. The same increase in income would lead to an increase in electricity consumption in the industrial and commercial sectors by 0.34% and 0.68%, respectively.

Results for the short-run cross-price elasticities have the same statistically insignificant effect on electricity consumption. Again this result could be an indication that natural gas is not a good substitute for electricity. Indeed, there might not be a good substitute for electricity in the short run. The cross-price elasticity is positive, statistically significant and is approximately the same magnitude (0.18) for the residential and industrial sectors in only the short run. This result suggests that natural gas serves as a substitute to electricity in the long-run. In other words, a 1% increase in natural gas price increases electricity consumption by approximately 0.18% in the two above-mentioned sectors. This finding indicates that substituting from electricity to natural gas is feasible only in the long run.

Next, we take a closer look at the demand for electricity related to Kentucky and other closely related states. To do this, we interact Kentucky's intercept with electricity price, natural gas price, and income, or order to differentiate the elasticity of Kentucky from the rest of the U.S. We also create a variable (labeled "Group") to include states similar to Kentucky in their reliance on energy. Group is constructed based on coal generated as a percent of total electricity and total electricity consumption as a share of real gross state product. We chose states above the 37.5th percentile in order to capture states with similar reliance on energy as Kentucky. These states with their corresponding values of electricity generated from coal as a percent of total electricity generation and electricity consumption as a share of real gross state product are listed in Table 3.

Table 3: Energy Intensive States

States	(1) % of Electricity generate from Coal	(2) Electricity Consumption (bil BTU) per Dollar of Real Gross State product
Alabama	62.31%	1.94
Arkansas	55.08%	1.65
Arizona	46.09%	1.02
Georgia	64.65%	1.09
Iowa	84.41%	1.13
Indiana	95.07%	1.33
Kansas	72.53%	1.13
Kentucky	**96.84%**	**1.87**
Missouri	82.13%	1.08
Montana	61.25%	1.82
North Carolina	62.10%	1.15
North Dakota	92.84%	1.39
Nebraska	63.41%	1.15
New Mexico	85.43%	1.01
Nevada	53.35%	0.99
Ohio	86.92%	1.17
Oklahoma	64.17%	1.46
Tennessee	64.92%	1.45
Virginia	51.51%	1.00
Wisconsin	70.93%	0.99
West Virginia	98.21%	1.80
Wyoming	95.78%	1.95

The first column of Table 4 presents results from separate effects for Kentucky, and the second column contains results from the high-electricity group. The Table shows clearly that Kentucky and similar states are more price elastic. For example, a 1% increase in electricity price would cause a 0.27% decrease in electricity consumption, which is less than the national estimate of only a 0.20% drop in electricity consumption. Substitute price is negative indicating that natural gas and electricity are complements in the short run, and this relationship is stronger for Kentucky. The income elasticity is also slightly higher at 0.168 for Kentucky compared to only 0.127 for the U.S. Finally, comparing the long-run estimates to the estimates in column 1 of Table 4 reveal a more elastic demand curve for Kentucky compared to other states.

Table 4: Demand for Electricity Interactions		
	(1)	(2)
Variables	Kentucky	Group
Price	-0.196***	-0.178***
	(0.037)	(0.026)
Price (Interaction)	-0.077*	-0.045
	(0.041)	(0.072)
Substitute Price	-0.014	-0.022*
	(0.014)	(0.0127)
Substitute Price (Interaction)	-0.041***	0.009
	(0.007)	(0.012)
Income	0.127***	0.122*
	(0.044)	(0.068)
Income (Interaction)	0.041	0.003
	(0.044)	(0.064)
Short-Run Elasticity		
Price	-0.273***	-0.224***
	(0.022)	(0.076)
Substitute Price	-0.055***	-0.0130
	(0.011)	(0.014)
Income	0.168***	0.135***
	(0.049)	(0.038)
Long-Run Elasticity		
Price	-0.821***	-0.666***
	(0.130)	(0.103)
Substitute Price	0.037	0.032
	(0.050)	(0.061)
Income	0.679***	0.740
	(0.089)	(0.071)
Observations	1,872	1,872
Number of States	48	48
Adj. R-Squared	0.992	0.992
Log Likelihood	4096	4101

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Overall, the results reveal a very disparate pattern of the sensitivity of electricity consumption to price and income changes across sectors. The industrial sector is the most sensitive to price changes in both the short and long run. In the short run the commercial sector is also sensitive to price changes. The results suggest that the industrial and commercial sectors are the quickest to alter their electricity consumption, which could negatively affect economic growth and employment. For instance, industrial and commercial sectors can limit their consumption by decreasing hours of operation, producing less, closing down industries and firms, to name a few. All of these solutions are ways in which electricity consumption can be decreased given a price increase, but they will also result in lower employment and economic growth.

Given the close relationship between energy prices and both production and employment found in graphs above along with the estimates for energy demand, in the next section we develop a model of production and employment to examine the relationship between these variables and the corresponding energy prices. Specifically, we are interested in the effect of energy prices (i.e. crude oil, natural gas, and electricity) on production and employment.

Examining the Relationship among Energy Prices and Production and Employment

In this section we examine the relationship among energy prices (i.e. crude oil, electricity and natural gas), production (measured by gross state product), and total employment. In order to investigate these relationships we take a more agnostic approach using an autoregressive distributed lag (ARDL) approach to estimate a simple model implied by the CLEM model with energy prices as the main production costs. The main benefits of this model are its ease in implementation and limited *ex ante* biases. For instance, ARDL models require very limited assumptions for identification. As a result, there is no need to declare a functional form for the production function as in CGE models, which in turn limits the amount of bias introduced into the model. Moreover, this model permits information to be extracted directly from the data, thereby allowing the data to describe the relationships.

Using data from 1970 to 2010 allows us to capture large variations in energy prices and enhances identification of the underlying causal relationships. Our approach differs from the traditional vector autoregression (VAR) analysis in that we assume contemporaneous effects of changes in energy prices on state macroeconomic aggregates. In particular, we view the price of electricity, natural gas, and crude oil as affecting production and employment. Also, we investigate both level effects and growth effects given changes in energy prices. To control for other factors that affect production at a point in time or that are unique to each state (such as regulatory issues), we add in state fixed effects and time effects.

Similar to the model used to estimate the energy demand equations, the partial adjustment model is employed here.[8] The partial adjustment model assumes there is some adjustment process in production and employment moving each to their respective equilibriums. Using these estimates, we then conduct a series of policy scenarios in which we perturb energy prices and document the changes in production and employment (in growth and levels) over time. In other words, the effects of energy price shocks brought about by enactment of energy policies can be examined. Notably, the model used to estimate these effects does not distinguish between supply and demand shocks. Consequently, we focus only on the overall effect of energy prices on production and employment.

Our baseline model includes estimates containing the 48 continental U.S. states and then we re-estimate the model focusing on Kentucky and our select group of states (labeled Group) similar to Kentucky in energy reliance. The outcomes of interest are the level of production, the level of total employment, the growth in production, and the growth in employment. To further examine the adjustment process we re-estimate each specification including contemporaneous energy prices and lagged energy prices. The lagged energy prices illustrate the adjustment process with respect production and employment. The coefficients in each specification represent percentage change effects.

[8] See Appendix C for a more technical description of the model and estimation.

Table 5 provides the results for three separate specifications with percentage production growth as the dependent variable, i.e., the percent growth in state GSP. The prices of electricity and natural gas are entered as the logarithm of their prices per BTU and the price of oil is the logarithm of the price per barrel of crude oil.

Column 1 shows that each energy price negatively affects production growth. For example, a 10% increase in electricity prices is estimated to decrease production growth by 0.13%, holding everything else constant. However, crude oil prices appear to have more of an effect on production growth compared to the other two energy prices. Column 2 and 3 allow for different effects of the prices on Kentucky and for the group of similar states. The pattern of finding is similar, though there is some difference in magnitudes. These differences will be discussed more thoroughly below.

Table 6 reports the estimated coefficients of energy prices on the level of production, with the latter entered in logarithms. As with the growth regressions, energy prices enter in negatively. Also as in Table 5, the effects for Kentucky and similar state are broadly consistent with some differences in magnitudes.

Table 5: Growth in Gross State Product

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
GSP Growth (t-1)	0.285***	0.285***	0.280***
	(0.0549)	(0.0549)	(0.0540)
Oil price	-0.0192***	-0.0192***	-0.0196***
	(0.00361)	(0.00365)	(0.00349)
Oil Price (Interaction)		-0.000305	0.000667
		(0.00387)	(0.00727)
Natural Gas Price	-0.0132***	-0.0131***	-0.00996**
	(0.00483)	(0.00485)	(0.00456)
Natural Gas price (Interaction)		-0.00276	-0.00800
		(0.00431)	(0.00730)
Electricity Price	-0.0130**	-0.0129**	-0.00652
	(0.00565)	(0.00573)	(0.00635)
Electricity Price (Interaction)		-0.000426	-0.0134
		(0.00612)	(0.0114)
Constant	0.144***	0.144***	0.143***
	(0.0203)	(0.0204)	(0.0216)
Observations	1,872	1,872	1,872
R-squared	0.507	0.507	0.509
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 6: Total Gross State Product

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
GSP Level (t-1)	0.965***	0.965***	0.965***
	(0.00644)	(0.00649)	(0.00705)
Oil price	-0.0141***	-0.0140***	-0.0172***
	(0.00507)	(0.00514)	(0.00431)
Oil Price (Interaction)		-0.00204	0.00599
		(0.00596)	(0.0104)
Natural Gas Price	-0.0200***	-0.0197***	-0.0112*
	(0.00689)	(0.00691)	(0.00606)
Natural Gas price (Interaction)		-0.0128**	-0.0174*
		(0.00577)	(0.0103)
Electricity Price	-0.0166*	-0.0164*	-0.0102
	(0.00948)	(0.00962)	(0.00980)
Electricity Price (Interaction)		0.00815	-0.0128
		(0.00852)	(0.0149)
Constant	0.579***	0.583***	0.580***
	(0.0789)	(0.0795)	(0.0847)
Observations	1,872	1,872	1,872
R-squared	0.992	0.992	0.992
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Tables 7 and 8 contain the effect of energy prices on employment growth and (the logarithm of) total employment, respectively. Again, the prices enter negatively into each specification as shown in column 1, i.e., higher energy prices reduce states' employment and employment growth. The Kentucky-specific estimates and the similar states estimates again display a similar pattern, though magnitudes of effects vary somewhat.

Table 7: Employment Growth

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
Employment Growth (t-1)	0.609***	0.608***	0.607***
	(0.0178)	(0.0179)	(0.0178)
Oil price	-0.00668***	-0.00655***	-0.00579***
	(0.00145)	(0.00147)	(0.00156)
Oil Price (Interaction)		-0.00832***	-0.00180
		(0.00165)	(0.00300)
Natural Gas Price	-0.00621***	-0.00625***	-0.00665***
	(0.00201)	(0.00204)	(0.00233)
Natural Gas price (Interaction)		0.00506***	0.000154
		(0.00184)	(0.00378)
Electricity Price	-0.00678***	-0.00698***	-0.00527**
	(0.00232)	(0.00237)	(0.00243)
Electricity Price (Interaction)		0.0102***	-0.00319
		(0.00234)	(0.00454)
Constant	0.0579***	0.0580***	0.0582***
	(0.00819)	(0.00829)	(0.00805)
Observations	1,872	1,872	1,872
R-squared	0.791	0.791	0.791
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Total Employment

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
Employment Growth (t-1)	0.968***	0.968***	0.968***
	(0.00498)	(0.00497)	(0.00522)
Oil price	-0.00715***	-0.00688***	-0.00696***
	(0.00233)	(0.00237)	(0.00252)
Oil Price (Interaction)		-0.0157***	-0.000503
		(0.00309)	(0.00546)
Natural Gas Price	-0.0109***	-0.0109***	-0.00873*
	(0.00382)	(0.00385)	(0.00441)
Natural Gas price (Interaction)		0.00433	-0.00500
		(0.00370)	(0.00672)
Electricity Price	-0.0141***	-0.0141**	-0.0103*
	(0.00523)	(0.00533)	(0.00559)
Electricity Price (Interaction)		0.0139***	-0.00772
		(0.00441)	(0.00802)
Constant	0.345***	0.344***	0.346***
	(0.0406)	(0.0405)	(0.0417)
Observations	1,872	1,872	1,872
R-squared	0.997	0.997	0.997
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Next, we consider a generalization of the above approach. We enter both the contemporaneous and lagged values of the energy prices and examine their effects on the four state-level variables of interest. This allows for energy prices to affect these outcome variables both currently and from one period in the past.

Tables 9 and 10 show the findings for the production growth and production level equations. The interpretation of the coefficients is less transparent since the total effect is the sum of the effects of the current and lagged values. Nevertheless, Tables 9 and 10 tell a similar story to that above. With respect to crude oil, a price increase in period t-1 induces a positive impact on contemporaneous growth and level of production followed by a negative impact in period t, with the sum of the effects being negative. Also, increases in natural gas prices do not exhibit any contemporaneous effect on growth and level of production, but in period t-1 an increase in natural gas prices decrease growth and level of production. Finally, electricity prices reveal similar patterns of adjustment to changes in crude oil prices.

Table 9: Growth in Gross State Product, with Current and Lagged Prices

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
GSP Growth (t-1)	0.281***	0.281***	0.276***
	(0.0547)	(0.0547)	(0.0542)
Oil Price	-0.0625***	-0.0627***	-0.0619***
	(0.00465)	(0.00469)	(0.00659)
Oil Price (t-1)	0.0295***	0.0295***	0.0283***
	(0.00336)	(0.00341)	(0.00420)
Oil Price (interaction)		0.0101**	-0.00226
		(0.00443)	(0.00965)
Oil Price (interaction) (t-1)		0.0171***	0.00323
		(0.00385)	(0.00618)
Natural Gas Price	0.00822	0.00891	0.0145
	(0.0111)	(0.0111)	(0.0129)
Natural Gas Price (t-1)	-0.0241**	-0.0249**	-0.0274**
	(0.00970)	(0.00970)	(0.0129)
Natural Gas Price (interaction)		-0.0518***	-0.0120
		(0.00611)	(0.0107)
Natural Gas Price (interaction) (t-1)		0.0307***	0.00394
		(0.00485)	(0.0102)
Electricity Price	-0.0285	-0.0276	-0.0301
	(0.0202)	(0.0203)	(0.0183)
Electricity Price (t-1)	0.0163	0.0155	0.0265
	(0.0182)	(0.0184)	(0.0190)
Electricity Price (interaction)		-0.118***	0.00542
		(0.0223)	(0.0404)
Electricity Price (interaction) (t-1)		0.0920***	-0.0222
		(0.0191)	(0.0362)
Constant	0.176***	0.177***	0.174***
	(0.0160)	(0.0162)	(0.0184)
Observations	1,872	1,872	1,872
R-squared	0.509	0.510	0.512
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 10: Total Gross State Product, with Current and Lagged Prices

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
GSP Level (t-1)	0.965***	0.965***	0.965***
	(0.00636)	(0.00640)	(0.00698)
Oil Price	-0.0709***	-0.0712***	-0.0726***
	(0.00510)	(0.00520)	(0.00677)
Oil Price (t-1)	0.0342***	0.0342***	0.0321***
	(0.00518)	(0.00522)	(0.00502)
Oil Price (interaction)		0.00414	0.00168
		(0.00578)	(0.0109)
Oil Price (interaction) (t-1)		0.0174***	0.00460
		(0.00336)	(0.00477)
Natural Gas Price	0.00523	0.00626	0.0155
	(0.0114)	(0.0114)	(0.0130)
Natural Gas Price (t-1)	-0.0281***	-0.0290***	-0.0295**
	(0.00922)	(0.00923)	(0.0132)
Natural Gas Price (interaction)		-0.0559***	-0.0193*
		(0.00665)	(0.0115)
Natural Gas Price (interaction) (t-1)		0.0271***	0.00183
		(0.00540)	(0.0116)
Electricity Price	-0.0382*	-0.0377*	-0.0424**
	(0.0206)	(0.0208)	(0.0187)
Electricity Price (t-1)	0.0231	0.0227	0.0360*
	(0.0175)	(0.0177)	(0.0197)
Electricity Price (interaction)		-0.0753***	0.0122
		(0.0214)	(0.0398)
Electricity Price (interaction) (t-1)		0.0603***	-0.0291
		(0.0174)	(0.0349)
Constant	0.631***	0.634***	0.626***
	(0.0769)	(0.0773)	(0.0838)
Observations	1,872	1,872	1,872
R-squared	0.992	0.992	0.992
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

When focusing on Kentucky-specific estimates, column 2 shows that the effect of oil price increases are dampened for Kentucky compared to other states. Alternatively, Kentucky is affected more by increases in natural gas and electricity prices compared to overall. The results for the similar states estimated in column 3 are comparable.

Tables 11 and 12 provide the results from estimating each this specification for employment growth and employment levels. In column 1 of Table 11, crude oil and natural gas prices exhibit a statistically significant and negative effect on employment growth both in period t-1 and period t. Electricity prices reveal a negative effect in period t, but this effect is damped by a positive effect in period t-1, though overall effects are negative.

Table 11: Employment Growth, with Current and Lagged Prices

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
Employment Growth (t-1)	0.607***	0.606***	0.604***
	(0.0179)	(0.0180)	(0.0180)
Oil Price	-0.0143***	-0.0142***	-0.0142***
	(0.00274)	(0.00279)	(0.00280)
Oil Price (t-1)	-0.0211***	-0.0212***	-0.0204***
	(0.00185)	(0.00187)	(0.00201)
Oil Price (interaction)		-0.00332	-0.000577
		(0.00222)	(0.00367)
Oil Price (interaction) (t-1)		0.00275*	-0.000846
		(0.00156)	(0.00236)
Natural Gas Price	-0.00146	-0.00114	0.00104
	(0.00374)	(0.00370)	(0.00402)
Natural Gas Price (t-1)	-0.00401	-0.00441	-0.00750*
	(0.00396)	(0.00391)	(0.00426)
Natural Gas Price (interaction)		-0.0202***	-0.00711
		(0.00357)	(0.00592)
Natural Gas Price (interaction) (t-1)		0.0206***	0.00732
		(0.00290)	(0.00504)
Electricity Price	-0.0369***	-0.0370***	-0.0342***
	(0.00861)	(0.00872)	(0.00793)
Electricity Price (t-1)	0.0326***	0.0324***	0.0316***
	(0.00837)	(0.00847)	(0.00810)
Electricity Price (interaction)		-0.00593	-0.00653
		(0.0108)	(0.0175)
Electricity Price (interaction) (t-1)		0.00868	0.00289
		(0.00934)	(0.0155)
Constant	0.135***	0.136***	0.136***
	(0.00983)	(0.00994)	(0.0100)
Observations	1,872	1,872	1,872
R-squared	0.794	0.795	0.795
Number of States	48	48	48

Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 12 shows the findings for the level of employment in the states. They are generally are consistent with the above results.

Table 12: Total Employment, with Current and Lagged Prices

Variables	(1) Baseline	(2) KY Interaction	(3) Group Interaction
Employment Level (t-1)	0.968***	0.968***	0.968***
	(0.00466)	(0.00466)	(0.00490)
Oil Price	0.0465***	0.0467***	0.0463***
	(0.00600)	(0.00605)	(0.00558)
Oil Price (t-1)	-0.0365***	-0.0365***	-0.0363***
	(0.00294)	(0.00295)	(0.00279)
Oil Price (interaction)		-0.00800***	6.76e-06
		(0.00266)	(0.00426)
Oil Price (interaction) (t-1)		-0.00248	-0.000534
		(0.00210)	(0.00371)
Natural Gas Price	-0.00355	-0.00325	0.00158
	(0.00446)	(0.00444)	(0.00500)
Natural Gas Price (t-1)	-0.00693	-0.00732	-0.0105*
	(0.00463)	(0.00460)	(0.00572)
Natural Gas Price (interaction)		-0.0179***	-0.0117**
		(0.00398)	(0.00582)
Natural Gas Price (interaction) (t-1)		0.0195***	0.00711
		(0.00314)	(0.00670)
Electricity Price	-0.0458***	-0.0451***	-0.0434***
	(0.00983)	(0.00993)	(0.00967)
Electricity Price (t-1)	0.0342***	0.0334***	0.0360***
	(0.00817)	(0.00824)	(0.00950)
Electricity Price (interaction)		-0.00782	-0.00380
		(0.0141)	(0.0210)
Electricity Price (interaction) (t-1)		0.0177*	-0.00456
		(0.0105)	(0.0169)
Constant	0.249***	0.249***	0.250***
	(0.0462)	(0.0462)	(0.0479)
Observations	1,872	1,872	1,872
R-squared	0.997	0.997	0.997
Number of States	48	48	48

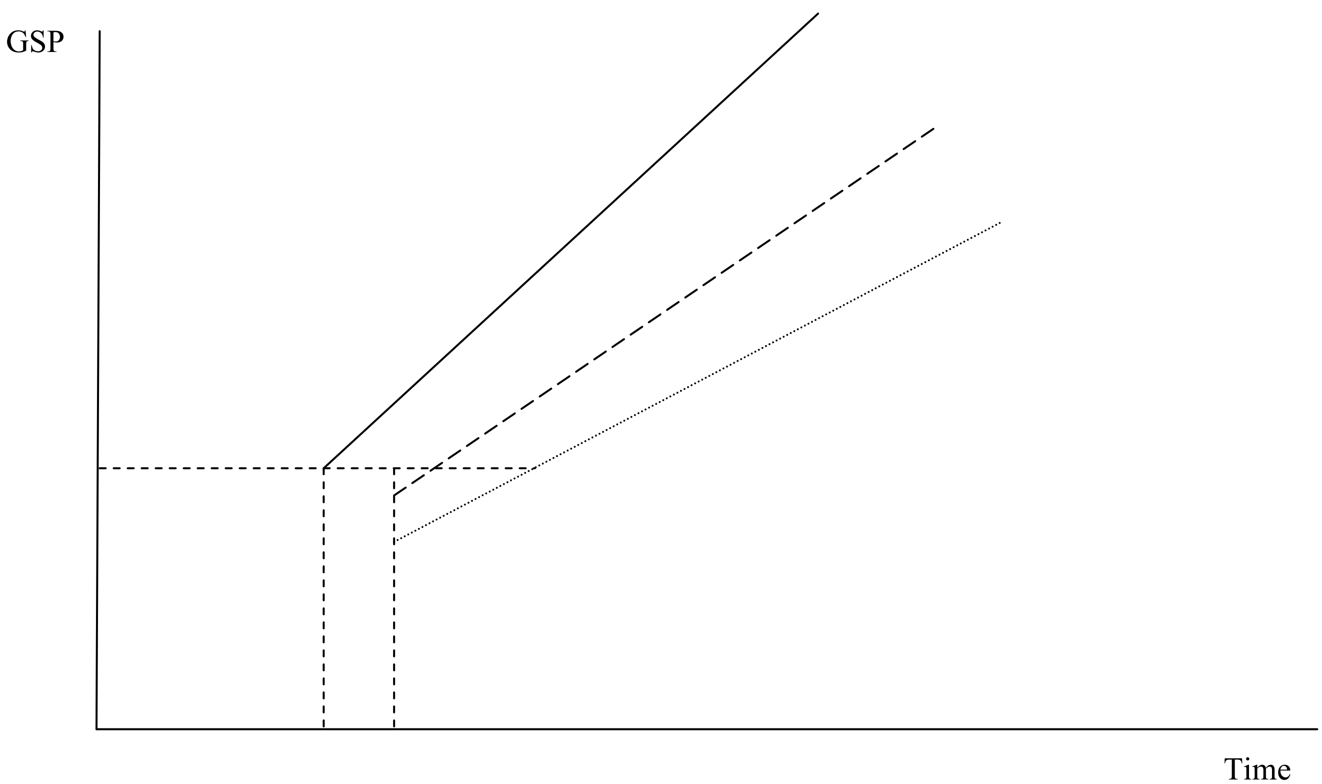
Notes: Robust standard errors in parentheses. Asterisks denote significance at the following levels: *** p<0.01, ** p<0.05, * p<0.1.

Policy Scenarios

In this section we explore a number of hypothetical policy scenarios and their effects on production and employment. We continue with examining both level and growth of each respective variable. The policy scenario analysis is important because policy changes can affect both the level and the growth rate of each variable. For illustrative purposes, Figure 7 shows a graph of gross domestic product over time. The first line (far left) shows the baseline projection assuming a level of production in the amount of $163.3 billion and an annual growth rate of 3.0%. The following two lines show the effect of a 10% and 25% increase in electricity prices, respectively. A policy that reduces the level of production would move the position of the line downward. A policy that reduces the growth of production flattens the slope of the line as shown in Figure 7.

Thus, a 10% increases in the price of electricity shifts the path of GSP from the solid line to the dashed one, i.e., to a lower level and smaller rate of increase. A 25% increase the price of electricity shifts it further to the dotted line.

Figure 7: Simulated Effect of One-Time Shock in Electricity Prices on GSP



Also, it is important to keep in mind the difference between a one-time shock and a permanent shock in energy prices. In this analysis, we consider only permanent shocks in energy prices because implementation of energy policies usually persists for many years at a time. However, even if the policy was repealed shortly after being introduced, business and individual expectations still serve a role in determining long-run production and employment decisions.

Another important caveat in these scenarios is the strong assumption that the electricity price shock is not accompanied by other changes such as technological advances. Such technological advances could lessen the impact of the shocks. Therefore, our scenarios should be treated as simulations of future conditions under the status quo (except for the shock) rather than forecasts or estimates of future growth.

The policy scenarios are carried out for using estimates for all U.S. states (U.S. estimates), the Kentucky-specific estimates (KY), and the estimates for the group of states similar in energy reliance to Kentucky (Group). Regarding the estimates that apply to Kentucky, we have more confidence in the Group simulations. These estimates are based on many states similar in energy reliance to Kentucky, but the estimates rely on a much wider variation in prices than in just Kentucky itself.

The model scenarios assume a baseline growth rate for production as 3.0% and annual gross domestic product $163.3 billion. The former is the long run historical growth rate of GDP for the U.S. economy and $163.3 billion was Kentucky's GSP in 2010. Table 13 contains the simulated effects of the 10% and 25% increases in the price of electricity on economic growth and GSP level. Panel A of Table 13 gives the short-run (SR) and long-run (LR) growth rate of production following a 10% and 25% permanent shock to electricity prices.

For the overall (U.S.) estimates, a 10% permanent increase in electricity prices would decrease the production growth rate to 2.88% in the short run and to 2.83% in the long run, all else equal. Using the Kentucky-specific estimates (KY), these simulated growth rates are lower; 2.62% and 2.47%. However, we feel that the similar states estimates (Group) are more reliable. These estimates that the short run growth rate would be reduced to 2.80% and in the long run to 2.72%. Given the linearity of the forecasts, the estimates for the 25% shock to electricity prices are increased accordingly.

To put these estimates into perspective, the rule of 70 is used to describe the amount of time it takes the economy to double at a given growth rate. For instance, at an annual growth rate of 3% it would take the economy 23 years to double in size (70/3.0=23). With a 10% increase in electricity prices that reduces the growth rate to 2.83%, it would take 24.7 years to double the size of the economy. If it pushes the growth rate down to 2.47%, it takes 28.3 years to double the economy and it takes 25.7 years with a 2.72% growth rate. If instead we consider a 25% price increase, then we consider three possible reductions in the growth rate to 2.58%, 1.68%, or 2.30%. The time it takes to double the size of the economy would take 27.1, 41.6 years, and 30.4 year, respectively.

Table 13: Policy Scenarios and Production, 10% and 25% Price of Electricity Increase

Panel A: GSP Growth.

Relative to 3.0% Growth

	U.S.	KY	Group
10% Price Incr., SR	2.88	2.62	2.80
10% Price Incr., LR	2.83	2.47	2.72
25% Price Incr., SR	2.70	2.05	2.49
25% Price Incr., LR	2.58	1.68	2.30

Panel B: GSP Level

Relative to $163.3 billion

	U.S.	KY	Group
10% Price Incr., SR	163.1	162.8	162.9
10% Price Incr., LR	156.3	149.3	152.4
25% Price Incr., SR	162.7	162.1	162.3
25% Price Incr., LR	145.7	128.3	136.1

Panel C: GSP Over Time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
10% price increase	3% gth.	2.83%	Less level	2.47%	less level	2.72%	less level
5 years	189.31	187.75	179.65	184.49	168.67	186.75	174.32
10 years	219.46	215.87	206.55	208.43	190.56	213.57	199.35
20 years	294.94	285.35	273.03	266.02	243.22	279.31	260.72
25% price increase		2.58%	Less level	1.68%	less level	2.30%	less level
5 years	189.31	185.48	165.48	177.49	139.46	182.96	152.51
10 years	219.46	210.68	187.96	192.90	151.57	204.99	170.87
20 years	294.94	271.79	242.48	227.88	179.05	257.34	214.50

Notes: The estimates used to develop policy scenarios were extracted from Tables 9 and 10. SR=short run, LR=long run

Panel B provides the effect of an electricity price shock on the level of GSP. Beginning with a level of production of $163.3 billion, a 10% permanent increase in electricity prices would induce a decrease in production by $0.2 billion in the short run accumulating to a long-run loss of $7 billion. This amounts to a 4.5% drop in production. For a 25% price shock the drop in production drops to 162.7 in the short run and 145.7 in the long run, a drop of over 12%. The simulation for the Kentucky-specific estimates and the similar states estimates are bleaker. For example, the same 10% (25%) price increase induces an additional drop in Kentucky production to $162.8 ($162.1) billion in the short run to $162.1 ($128.3) billion in the long run.

To complement Panels A and B, Panel C provides simulations of production over 5, 10, and 20 years. Column 1 gives the baseline results assuming a constant 3% annual growth rate in production over 5, 10, and 20 years. For instance, at a 3% growth rate, production would increase from $163.3 billion in year 1 to $189.31 billion in year 5; $219.46 billion in year 10; and $294.94 billion in year 20. Column 2 uses the annual growth rate generated from the long-run 10% increase in electricity price (found in Panel A). Column 3 uses the production estimate (found in Panel B) of $156.3 billion in year 1 and projects forward using 2.83% as the new growth rate. After 20 years the difference between columns 1 and 3 shows a 8% lower production following a 10% increase in electricity prices. For a 25% increase in electricity prices, the difference is a 21.6% lower production. These results illustrate the substantial impact of electricity price shocks on the economy.

Columns 4 and 5 give the same scenario with the Kentucky-specific estimates. With a 10% increase in electricity prices the effect is a decline in production from $294.94 billion to $266.02 billion after 20 years. When accounting for the decline in the level of production, the fall in production becomes $243.22 billion. The simulated effect using the similar states estimates, in columns 6 and 7, shows smaller effect than the Kentucky-specific estimates but larger than for the overall estimates. For example, after 20 years the difference between the baseline model and the similar-states model that contains a level and growth effect (difference in columns 1 and 7) a lower GSP from $294.94 billion to $260.72 billion.

Table 14 contains the policy simulations for employment. It is assumed that a steady state growth rate of employment is 1% which is the approximate annual growth rate of employment for Kentucky. Replicating the above analysis using employment growth and employment as the macro variables of interest, Panel A displays the short and long run effect of a 10% and 25% increase in electricity prices on employment growth. Interestingly, the Kentucky-specific estimate show smaller effects, though as noted above, we think that the similar states estimates are a more reliable guide to the effect on Kentucky. The latter show a slightly larger effect than do the estimates for the whole U.S. These show a long run employment growth rate of 0.84% for a 10% electricity price increase, compare to a 0.89% growth rate based on total U.S. estimates.

Panel B simulates the effect of an electricity price shock on the level of employment. Beginning with an employment level 1,900 thousand (the approximate employment in Kentucky for the past few years), a 10% permanent increase in electricity prices would induce a decrease in employment by 2.2 thousand in the short run and by 68.9 thousand the long run, according to the U.S. based estimates. For the similar states estimates, these reductions are 3.0 thousand in the short run and 93.6 thousand in the long run. The effects for a 25% increase in the price of electricity are proportionately larger

Panel C of Table 14 is similar to that of Table 13, providing simulations of employment over 5, 10, and 20 years. Column 1 gives the baseline results assuming a constant 1% annual growth rate in employment over 5, 10, and 20 years. For instance, at a 1% growth rate, employment would increase from 1,900 thousand in year 1 to 1,996.92 thousand in year 5; 2,098.78 thousand in year 10; and 2,436.62 thousand in year 20. Column 2 uses the annual growth rate in employment generated from the long-run 10% increase in electricity price (found in Panel A). Column 3 uses the employment estimate (found in Panel B) of 1,831.1 thousand in year 1 and projects forward using 0.89% as the new growth rate. After 20 years, comparing columns 1and 3 shows 250,000 less employment following a 10% increase in electricity prices. For a 25% increase in electricity prices, the difference is 438,000 in employment .

Columns 4 and 5 give the same scenario with the Kentucky-specific estimates. With a 10% increase in electricity prices, this simulation shows a decline in employment from 2,436.62 thousand to 2,392.95 after 20 years; smaller that with the pooled U.S. based estimates. The simulated effect using the similar states estimates, in columns 6 and 7, shows larger effects than the Kentucky-specific estimates and for the overall estimates. After 20 years the difference between the baseline and the similar states model (comparing in columns 1 and 7) is the difference of 2,436.62 thousand and 1,939.63 thousand; a reduction of about 497,000.

Table 14: Policy Scenarios and Employment, 10% and 25% Price of Electricity Increase

Panel A: Employment Growth.
Relative to 1.0% Growth

	U.S.	KY	Group
10% Price Incr., SR	0.96	0.98	0.94
10% Price Incr., LR	0.89	0.95	0.84
25% Price Incr., SR	0.89	0.95	0.84
25% Price Incr., LR	0.73	0.88	0.61

Panel B: Employment Level
Relative to 1900 thousands

	U.S.	KY	Group
10% Price Incr., SR	1897.8	1899.7	1897.0
10% Price Incr., LR	1831.1	1889.2	1806.4
25% Price Incr., SR	1894.5	1899.1	1892.5
25% Price Incr., LR	1727.8	1873.0	1666.1

Panel C: Employment Over Time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
10% price increase	1% gth.	0.89%	Less level	0.95%	less level	0.84%	less level
5 years	1996.92	1986.07	1914.07	1991.98	1980.65	1981.15	1883.59
10 years	2098.78	2076.04	2000.77	2088.42	2076.53	2065.77	1964.04
20 years	2436.62	2371.14	2186.15	2406.64	2392.95	2341.93	2226.60
25% price increase	1% gth	0.73%	Less level	0.88%	less level	0.61%	less level
5 years	1996.92	1970.37	1791.80	1985.08	1956.85	1958.66	1717.50
10 years	2098.78	2043.35	1858.17	2073.98	2044.48	2019.13	1770.53
20 years	2436.62	2278.90	1998.36	2365.27	2331.63	2211.99	1939.63

Notes: The estimates used to develop policy scenarios were extracted from Tables 9 and 10.

Conclusion

This report looks at the relationship between electricity prices and two measures of economic conditions, GSP and employment. We reviewed the two major types of models for conducting this type of analysis, computable general equilibrium (CGE) models and capital, labor, energy and materials models (CLEM). We determined that the CGE models were too complex and required too many assumptions for our purposes. Therefore, we estimated an autoregressive distributed lag (ARDL) model, an approach implied by a CLEM-type model for the long-run analysis.

Before conducting that analysis, we first studied the demand equation for electricity and other energy sources. As expected, we found that our results were consistent with the law of demand. The price elasticity of demand is negative: quantity demanded for energy decreases with increases in the price, all else equal. Furthermore, energy is a normal good, in that income elasticity of demand is expected to be positive; accordingly, increases in income result in increases in energy consumption, all else equal. Long-run price elasticities are higher (in absolute values) as consumers have greater flexibility in adopting more energy-efficient technologies and avoiding price increases. Likewise, income elasticity is greater in the long run than in the short run.

After confirming the expected results for electricity demand, we turn to our preferred ARDL model for examining the relationship between energy prices and four measures of economic output: GSP levels, GSP growth, employment levels, and employment growth. We look at this relationship across states nationally, and we also study whether the effect differs for Kentucky and for energy-reliant states. We consider models that include lagged values of growth in order to allow partial adjustments of energy prices. Across the models and outcomes, we find an expected negative relationship between electricity prices and economic output.

To summarize and illustrate our results, we conduct policy scenarios based on either a 10% or 25% permanent increase in electricity prices. We focus on the effect for the pooled U.S. states estimates, the Kentucky-specific estimates, and the similar, energy-reliant states estimates. Because these policy scenarios look only the price shock and assume no changes in other factors such as technological innovations, these scenarios are simple simulations of future economic output under these assumptions rather than our forecast of expected future conditions. In terms of GSP, we find that a 10% increase in electricity prices would decrease GSP growth from our baseline value of 3% annual growth (without the shock) to 2.88% in the short run and 2.83% in the long run based on the U.S.-wide estimates. The drop in growth is more pronounced for the Kentucky-based and energy-reliant states based estimates. Turning to employment growth, a 10% increase in electricity prices decreases employment growth rate from the baseline value of 1% annual growth (without the shock) 0.96% in the short run and 0.89% in the long run, base on U.S.-wide estimates. The resulting reduction in the long-run growth rate in employment growth is not as large for the Kentucky-based estimate (0.95%) but is larger for energy-reliant states based estimates (0.84%).

These policy scenarios provide valuable information on the possible effects of electricity price increases. These scenarios illustrate that price increases will have sizable negative effects on Kentucky's GSP and employment growth if the price increases are not accompanied by other policy changes, technological advances, or other factors that might mitigate (or possibly exacerbate) the consequences of electricity price increases.

Our reliance on coal-based electricity suggests that policy makers should focus future research on mitigation of the adverse economic consequences illustrated in the policy scenarios. If the status quo fails to change, the policy scenarios suggest that Kentucky and other energy-reliant states will suffer in the event of substantial electricity price increases.

References

Bernstein, M.A., and J. Griffin. "Regional Differences in Price-Elasticity of Demand for Energy." The Rand Corporation Technical Report, 2005.

Bohi, D.R. and M.B. Zimmerman. "An Update on Econometric Studies of Energy Demand and Behavior." *Annual Review of Energy*, 1984,9, 105-54.

Bovenberg, A.L. and L.H. Goulder. "Optimal Environment Taxation in the Presence of Other Taxes: General-Equilibrium Analyses." *American Economic Review,* 86:4, 1996, 985-1000.

Dahl, C. and C. Roman. "Energy Demand Elasticties-Fact or Fiction: A Survey Update. Unpublished Manuscript, 2004.

Davis, S. J., and J. Haltiwanger. "Sectoral Job Creation and Destruction Responses to Oil Price Changes." *Journal of Monetary Economics*, 48, 2001, 465–512.

Francois, J.F. "General Equilibrium Studies of Multilateral Trade Negotiations: Do They Really Help?" paper presented at the Murphy Institute Conference on the Political Economy of Policy Reform, Tulane University, 2001, 9-10 November.

Goulder, L. *Environmental Policy Making in Economies with Prior Tax Distortions*. 2002, Northampton MA: Edward Elgar.

Gunning, J.W. and M. Keyzer. "Applied General Equilibrium Models for PolicyAnalysis." in J. Behrman and T.N. Srinivasan (eds.) Handbook of Development Economic Vol. III-A, Amsterdam: Elsevier, 1995, 2025-2107.

Hamilton, J. D. "Oil and the Macroeconomy Since World War II." *Journal of Political Economy*, 91, 1983, 228–248.

Hamilton, J. D. "Historical Oil Shocks." *National Bureau of Economic Research*, 2011, NBER Working Paper No. 16790.

Hooker, M. A. ''What Happened to the Oil Price-Macroeconomy Relationship?'' *Journal of Monetary Economics*, 38, 1996, 195–213.

Houthakker, H .S., Philip K. Verleger, Jr., and Dennis P. Sheehan, "Dynamic Demand Analyses for Gasoline and Residential Electricity," *American Journal of Agricultural Economics*, 1974, 56(2), 412–418.

Kennedy, P. *A Guide to Econometrics*, 2003, Cambridge Massachusetts: The MIT Press.

Killian, L., "The Economic Effects of Energy Price Shocks," *Journal of Economics Literature,* 2008, 46(4), 871-909.

Li, P., and A. Rose. "Global Warming Policy and the Pennsylvania Economy: A Computable General Equilibirum Analysis." *Economic Systems Research,* 7, 1995, 151-71.

Panagariya, A. and R. Duttagupta. "The "Gains" from Preferential Trade Liberalization in the CGE Models: Where do they Come From?" in S. Lahiri (ed.), Regionalism and Globalization: Theory and Practice, 2001, London and New York: Routledge: 39-60.

Perry, G., J. Whalley and G. McMahon, eds. *Fiscal Reform and Structural Change in Developing Countries*, 2001, New-York: Palgrave-Macmillan.

Taylor, L.D. "The Demand for Electrcity: A Survey." *The Bell Journal of Economics,* 1975, 74-110.

Weyant, J., "The Costs of the Kyoto Protocol: a Multi-Model Evaluation." *Energy Journal* special issue, 1999.

Whalley, J., and I. Trela. *Regional Aspects of Confederation*. Buffalo: University of Toronto Press, 1986.

Wing, I. S. "Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis." MIT Joint Program on the Science and Policy of Global Change Technical Note No. 6, September 2004.

Appendix A

Throughout this report we use the term elasticity to describe the consumer response to a change in a variable of interest (e.g. energy). For example, own-price elasticity measures the degree of consumer response to a change in the price of that product (e.g. energy); cross-price elasticity measures the degree of consumer response to a change in the price of a substitute (or complement) good; and income elasticity measures the degree of consumer response to a change in the consumer's income. Elasticities are calculated as follows:

$$\eta^{own-price} = \frac{\%\Delta Q}{\%\Delta P}$$

$$\eta^{cross-price} = \frac{\%\Delta Q}{\%\Delta P^S}$$

$$\eta^{income} = \frac{\%\Delta Q}{\%\Delta I}$$

where Δ indicates change; Q is energy consumption; P is price of energy; P^S is the price for the substitute good; and I is consumer income. These values describe the demand curve. For instance, a high value (in absolute terms) indicates a more elastic demand curve which means consumers are more responsive to price changes. One reason for high elastic demand curves is the availability of substitutes. The cross-price elasticity describes the relationship between two goods (e.g., the substitutability between electricity and natural gas). A high positive value for cross-price elasticity indicates a high degree of substitutability and a negative sign indicates the two good are complements. Income elasticity is expected to be positive if the good is normal, meaning the consumer purchases more of the good as income rises.

These elasticities can change overtime as well; therefore it is important to examine elasticities in both the short run and long run. Especially while doing policy analysis, the consumers have a considerable amount of flexibility in the long run compared to the short run so that any price change could result in very different elasticity estimates overtime.

Appendix B

The stock-flow model developed by Houthakker et al. (1974) is used to estimate short-run and long-run elasticities. Specifically, we develop an energy demand equation to estimate own-price elasticity, cross-price elasticity, and income elasticity. The model we estimate is:

$$Q_{i,t}^{D} = \beta Q_{i,t-1}^{D} + \gamma_1 P_{i,t} + \gamma_2 P_{i,t-1} + \delta_1 P_{i,t}^{S} + \delta_2 P_{i,t-1}^{S} + \theta_1 I_{i,t} + \theta_2 I_{i,t-1} + \varphi_1 X_{i,t}' + \varphi_2 X_{i,t-1}' + \phi_t + \alpha_i + \varepsilon_{i,t}$$

where i and t index state and time, respectively. α_i are state-specific intercepts and ϕ_t are annual time dummies. The variable $Q_{i,t}^{D}$ is total energy consumption. $P_{i,t}$ is the average real price of energy and $P_{i,t}^{S}$ is the real price of energy's substitute (i.e. natural gas). The income variable is denoted by $I_{i,t}$ and the variable $X_{i,t}'$ is a vector of control variables including the climate index and population. All variables are measured as the natural logarithm.

Because the variables are converted to natural logarithms, the estimated coefficients are interpreted as elasticities. Therefore, estimates of the short-run own-price elasticity is represented by γ_1 and the cross-price elasticity is given by δ_1. Finally, the income elasticity is given by θ_1.

In the long-run it is assumed that equilibrium is reached and thus the above equation is transformed into a steady-state equation. In the steady-state: $Q_{i,t}^{D} = Q_{i,t-1}^{D}$, $P_{i,t} = P_{i,t-1}$, $P_{i,t}^{S} = P_{i,t-1}^{S}$, $I_{i,t} = I_{i,t-1}$ and $X_{i,t} = X_{i,t-1}$. Thus, to estimate the long-run elasticities, the following calculations were made:[9]

$$\eta^{own-price} = \frac{(\gamma_1 + \gamma_2)}{(1-\beta)}$$

$$\eta^{cross-price} = \frac{(\delta_1 + \delta_2)}{(1-\beta)}$$

$$\eta^{income} = \frac{(\theta_1 + \theta_2)}{(1-\beta)}$$

[9] Standard errors for the long-run elasticity estimates are calculated using the delta method.

Appendix C

For our analysis of the relationship among energy prices and economic conditions, we rely on a partial adjustment mechanism, similar to that of the energy demand equations. The partial adjustment is given by the following equation:

$$Y_{i,t} - Y_{i,t-1} = \lambda(Y^* - Y_{i,t-1})$$

where subscripts i and t indicate state and time, respectively. The variable Y is our macroeconomic variable of interest, either production or employment, and Y^* is the equilibrium level of production or employment. The parameter λ represents the adjustment coefficient. When $\lambda = 1$ there is instantaneous adjustment and when $\lambda = 0$ there is no adjustment, so that $Y_{i,t} = Y_{i,t-1}$.

Solving for $Y_{i,t}$ we get:

$$Y_{i,t} = (1 - \lambda)Y_{i,t-1} + \lambda Y^*$$

From here, we assume that the equilibrium value of production and employment is a function of energy prices, in particular, crude oil, electricity, and natural gas. So if we let $Y^* = \alpha_i + \beta X_{i,t}$, where $X_{i,t}$ are energy prices and α_i are state-specific intercepts, then we get the following:

$$Y_{i,t} = \lambda\alpha_i + (1 - \lambda)Y_{i,t-1} + \lambda\beta X_{i,t} = \delta_0 + \delta_1 Y_{i,t-1} + \delta_2 X_{i,t}$$

We then modify this equation to allow for short-run dynamics in energy prices by adding a lagged value of energy prices. We further augment this model to include state and time dummies to provide us with the model to be estimated.

$$Y_{i,t} = \delta_1 Y_{i,t-1} + \delta_2 X_{i,t} + \delta_3 X_{i,t-1} + \sum_i \theta_i \alpha_i + \sum_t \mu_t T_t$$

In order to decompose the effect of energy prices on production and employment for Kentucky and other energy-reliant states we interact each energy price variable by a binary variable equal to one if the state is Kentucky (or an energy-reliant state) and zero otherwise. For example, the following model decomposes the total effect of energy prices into the effect of energy prices for all states and a Kentucky-specific effect:

$$Y_{i,t} = \delta_1 Y_{i,t-1} + \delta_2 X_{i,t} + \delta_3 (KY * X_{i,t}) + \sum_i \theta_i \alpha_i + \sum_t \mu_t T_t$$

Here the combination $\delta_2 + \delta_3$ gives the total contemporaneous effect of energy price change on $Y_{i,t}$, where δ_3 provides the Kentucky-specific effect in addition to δ_2.