The Vulnerability of Kentucky's Manufacturing Economy to Increasing Electricity Prices

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Executive Summary

Kentucky's low electricity prices have fostered the single-most electricity-intensive manufacturing economy in the United States, a manufacturing economy that is now threatened by future electricity price increases. This study builds upon the notion that low energy costs are a catalyst for commercial growth by quantifying the specific vulnerability of the largest economic sectors of the Commonwealth, in terms of total employment, to future electricity price increases. Using a statistical analysis technique called *multiple regression of panel data with fixed effects*, this study modeled the responsiveness of employment across the United States to changes in the price of electricity from 1990 to 2010 for the top five employment sectors in Kentucky: manufacturing, retail services, hospitality, healthcare, and government. *Elasticities* were developed for each of these economic sectors to calculate changes in employment, given a specific change in the price of electricity, and can be generally applied to the 48 contiguous United States.

Given a 25% forecasted increase in the real price of electricity in Kentucky between 2011 and 2025, this study estimates the Commonwealth will likely lose, or fail to create, approximately 30,000 full-time jobs in the long-term. Manufacturing establishments were found to be most responsive to changes in electricity prices and can be expected to permanently shed 17,500 full-time jobs. The other largest employment sectors in Kentucky, retail stores, restaurants, and hotels, were less than half as responsive as the manufacturing sector to increasing electricity prices, and combined, can be expected to fail to create 12,500 full-time jobs. However, in the fourth and fifth largest employment sectors, healthcare and government, no statistically significant relationship could be identified between electricity prices and total employment.

While total employment in Kentucky is expected to continue to rise in other sectors, **the Commonwealth should develop strategies to mitigate vulnerability to energy price increases, volatility, and risk exposure. Additionally, Kentucky should maintain focus on education and workforce development in emerging industries that are less reliant on energy-intensive manufacturing processes**. These forecasted electricity price increases, in addition to the current trend towards off-shoring and automation of manufacturing processes, have the potential to transform the economies of manufacturing states like Kentucky.

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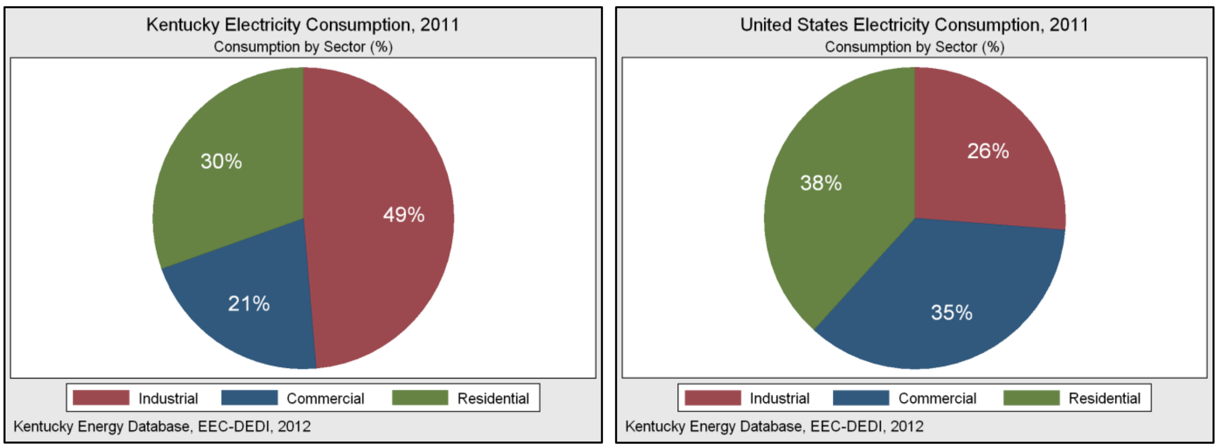
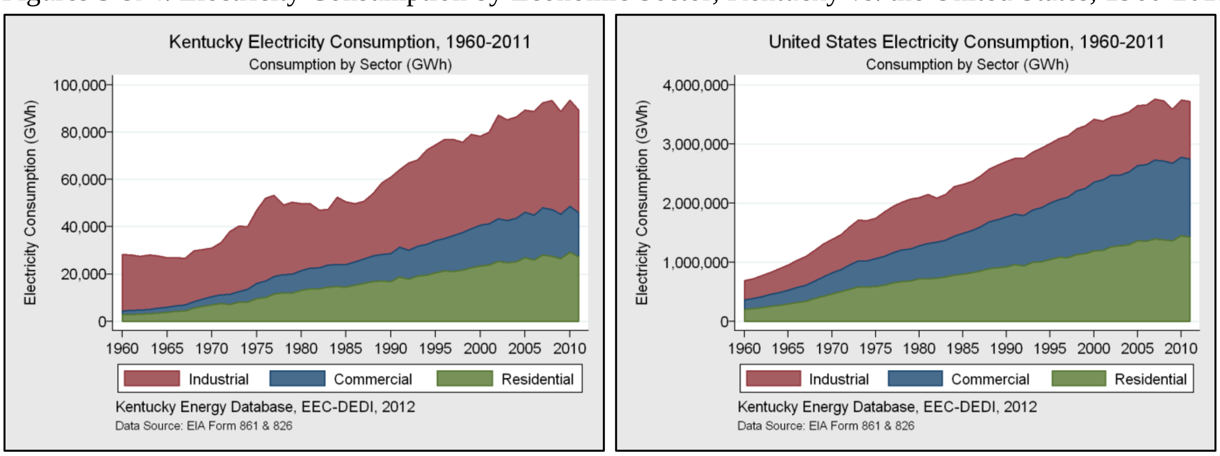
Kentucky's Energy-Intensive Economy

In 2011, 49% of all electricity consumed in Kentucky went to industrial users, compared with 26% for the United States as a whole, as illustrated in Figures 1 and 2 below. The reason for this is obvious—industries requiring large amounts of electricity for production have an incentive to locate in states where they can anticipate that electricity costs will remain low. The industrial nature of Kentucky's electricity load is by no means a recent development. Ever since the first power plants were built in the Commonwealth, most of the electricity produced went to large factories. Over the past 50 years for which there is reliable data, industrial users have consumed an average of 60% of all electricity generated in Kentucky annually, as illustrated in Figure 3 below. These proportions for the United States as a whole have historically been far more balanced, as illustrated in Figure 4 below.

Figures 1 & 2: Electricity Consumption by Economic Sector, Kentucky vs. the United States, 2011



Figures 3 & 4: Electricity Consumption by Economic Sector, Kentucky vs. the United States, 1960-2011



Coal has historically provided the Commonwealth both low-cost electricity and energy security. Nominal electricity prices in Kentucky have increased since 1970 at about 2% annually, which is less than the average rate of inflation during this same period. When adjusted for inflation,[1] as illustrated in Figure 5 on page 3, real electricity prices actually fell in Kentucky from 1980 to 2003, and have risen over the past decade with increases in the price of all fossil fuels. Since 1992, Kentucky has maintained one of the lowest four electricity prices in the nation, running neck and neck with the coal and hydroelectric states of Idaho, Wyoming, Washington, and West Virginia.

Figure 6 on page 3 illustrates that Kentucky is home to the most electricity-intensive economy in the United States. Simply stated, *this means that Kentucky industries use more kilowatt-hours of electricity to produce one dollar of GDP than any other state and are, therefore, more sensitive to changes in electricity prices than any other state.*

In 2009, the most-electricity-intensive sectors nationally were aluminum smelting, iron & steel mills, paper mills, chemical production, and glass manufacturing, which required on average between 0.5 and 4.5 kilowatt-hours of electricity to produce $1 worth of goods. At current Kentucky industrial electricity prices, each dollar of shipments from these industries required between $0.025 and $0.222 worth of electricity. In other words, up to a quarter of total revenues in these industries go to electricity costs. In Kentucky, the most-intensive of these manufacturing processes, which require more than 0.5 kilowatt-hours of electricity to produce $1 of goods, directly contributed $5 billion, or 3.2%, to the Commonwealth's total 2009 GDP and employed 12,685 Kentuckians.[2] The national average electricity-intensity of each NAICS manufacturing sector present in Kentucky is summarized in Table 1 on page 4 along with the total number of employees and the contribution of each industry to Kentucky's 2009 State GDP based on data provided by the U.S. Census Bureau's Annual Survey of Manufactures and the U.S. Bureau of Economic Analysis.[3] This table provides an approximate rank ordering of sensitivity to electricity prices between types of manufacturing operations present in Kentucky.

Figure 5: Total Real Electricity Prices, 1970-2010, Kentucky vs. the United States

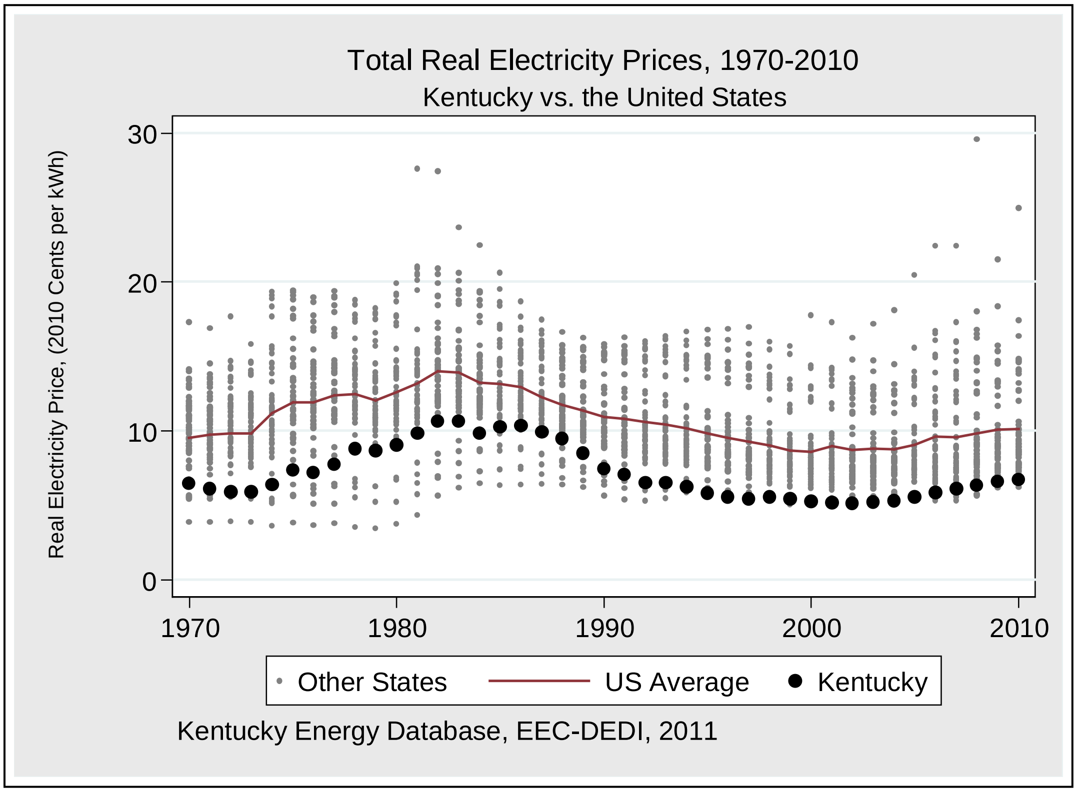


Figure 6: Total Electricity Intensity of Production, 1963-2010, Kentucky vs. the United States

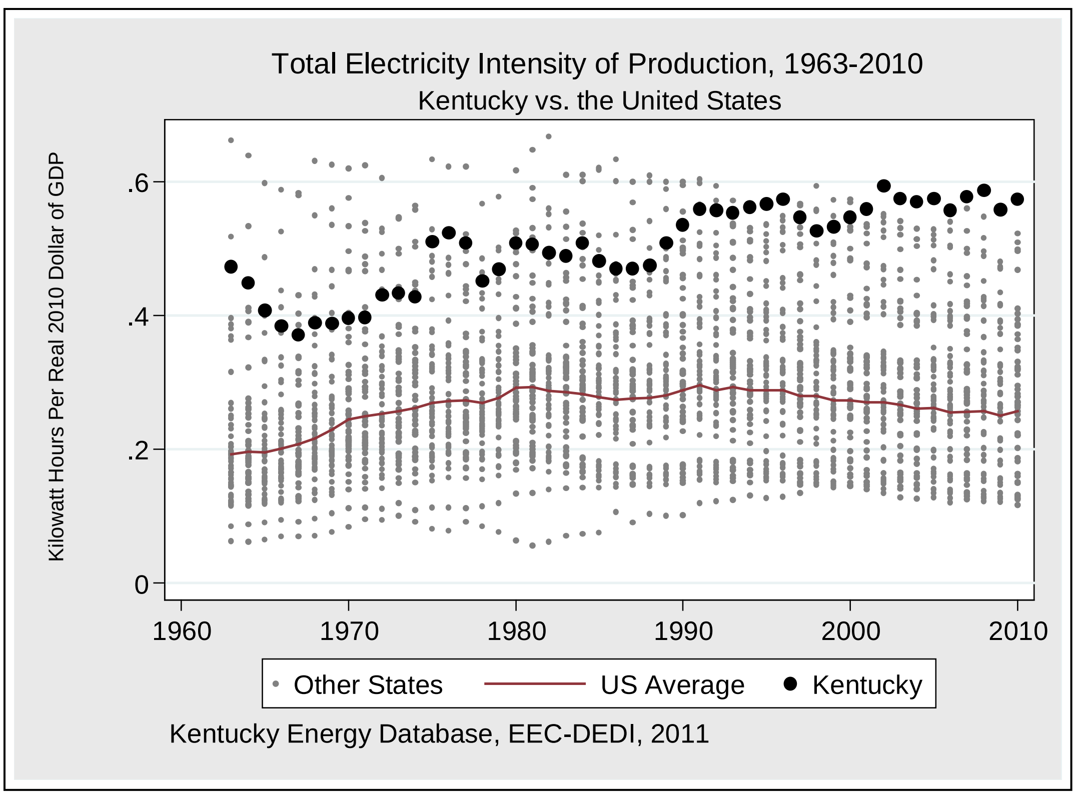


Table 1: National Manufacturing Sector Electricity-Intensity and Kentucky Employment by NAICS, 2009

NAICS 4	NAICS Description	National Electricity Intensity of Production (kWh per $ of Shipment)	Kentucky Average Workers	Kentucky Production Worker Hours (1,000)	Kentucky Value added ($1,000)
3313	Aluminum Production & Processing	4.37313	3,482	6,930	1,083,373
3311	Iron & Steel Mills & Ferroalloy	1.57640	2,954	6,083	232,537
3221	Pulp, Paper, & Paperboard Mills	1.11598	1,192	2,382	1,142,732
3251	Basic Chemical	0.71269	3,043	6,000	2,245,950
3272	Glass & Glass Product	0.60508	2,015	4,151	287,908
3315	Foundries	0.39152	1,595	3,403	104,152
3252	Resin, Syn Rubber, & Artificial Syn Fibers & Filaments	0.35947	1,845	3,799	544,965
3273	Cement & Concrete Product	0.34890	1,688	2,996	236,878
3279	Other Nonmetallic Mineral Product	0.32072	755	1,352	82,074
3132	Fabric Mills	0.30503	857	1,299	
3328	Coating, Engraving, Heat Treating, & Allied Activities	0.29064	730	1,434	62,744
3261	Plastics Product	0.28636	9,552	19,369	1,369,277
3121	Beverage	0.23187	1,941	3,563	
3211	Sawmills & Wood Preservation	0.21894	1,743	3,387	173,367
3359	Other Electrical Equipment & Component	0.21885	1,237	2,283	256,187
3321	Forging & Stamping	0.21571	1,462	2,883	200,502
3262	Rubber Product	0.21049	1,161	2,209	130,931
3116	Animal Slaughtering & Processing	0.17398	8,233	17,208	1,126,612
3114	Fruit & Vegetable Preserving & Specialty Food	0.16088	3,214	6,478	466,909
3118	Bakeries & Tortilla	0.16008	4,018	6,983	740,444
3222	Converted Paper Product	0.15944	5,636	10,950	1,167,297
3344	Semiconductor & Other Electronic Component	0.15703	707	1,315	44,721
3326	Spring & Wire Product	0.14747	2,359	4,496	246,093
3363	Motor Vehicle Parts	0.14719	16,660	31,037	2,942,269
3259	Other Chemical Product & Preparation	0.14596	915	1,965	184,767
3231	Printing & Related Support Activities	0.14519	8,092	15,155	846,289
3327	Machine Shops, Turned Product, & Screw, Nut, & Bolt	0.14463	2,772	5,570	336,332
3329	Other Fabricated Metal Product	0.14187	2,699	4,948	456,340
3219	Other Wood Product	0.14074	5,764	10,705	413,340
3324	Boiler, Tank, & Shipping Container	0.13796	885	1,701	196,781
3336	Engine, Turbine, & Power Transmission Equipment	0.13598	1,209	2,138	127,183
3335	Metalworking Machinery	0.13253	1,331	2,250	139,843
3241	Petroleum & Coal Products	0.13014	740	1,456	
3371	Household & Institutional Furniture & Kitchen Cabinet	0.12103	1,597	2,765	
3115	Dairy Product	0.11755	1,531	3,136	321,496
3364	Aerospace Product & Parts	0.11584	1,257	2,322	420,386
3372	Office Furniture (Including Fixtures)	0.11478	1,017	2,017	
3399	Other Miscellaneous	0.10128	2,006	3,913	325,240
3352	Household Appliance	0.09877	1,576	2,858	
3339	Other General Purpose Machinery	0.09456	3,307	6,293	758,199
3119	Other Food	0.09371	1,570	2,906	579,615
3255	Paint, Coating, & Adhesive	0.09362	907	1,777	537,129
3366	Ship & Boat Building	0.09142	980	2,081	
3334	Ventilation, Heating, Ac, & Commercial Refrigeration	0.08948	2,071	3,765	376,925
3323	Architectural & Structural Metals	0.08879	3,402	6,355	436,994
3353	Electrical Equipment	0.08174	1,107	1,977	293,203
3331	Agriculture, Construction, & Mining Machinery	0.07432	1,407	2,201	209,643
3391	Medical Equipment & Supplies	0.07185	1,242	2,395	165,180
3362	Motor Vehicle Body & Trailer	0.06701	808	1,622	76,925
3256	Soap, Cleaning Compound, & Toilet Preparation	0.05454	957	2,136	442,283
3122	Tobacco	0.04605	593	1,095	
3361	Motor Vehicle	0.03654	11,384	22,724	

Figure 7: Kentucky Gross Domestic Product by Economic Sector, 2009 [4]

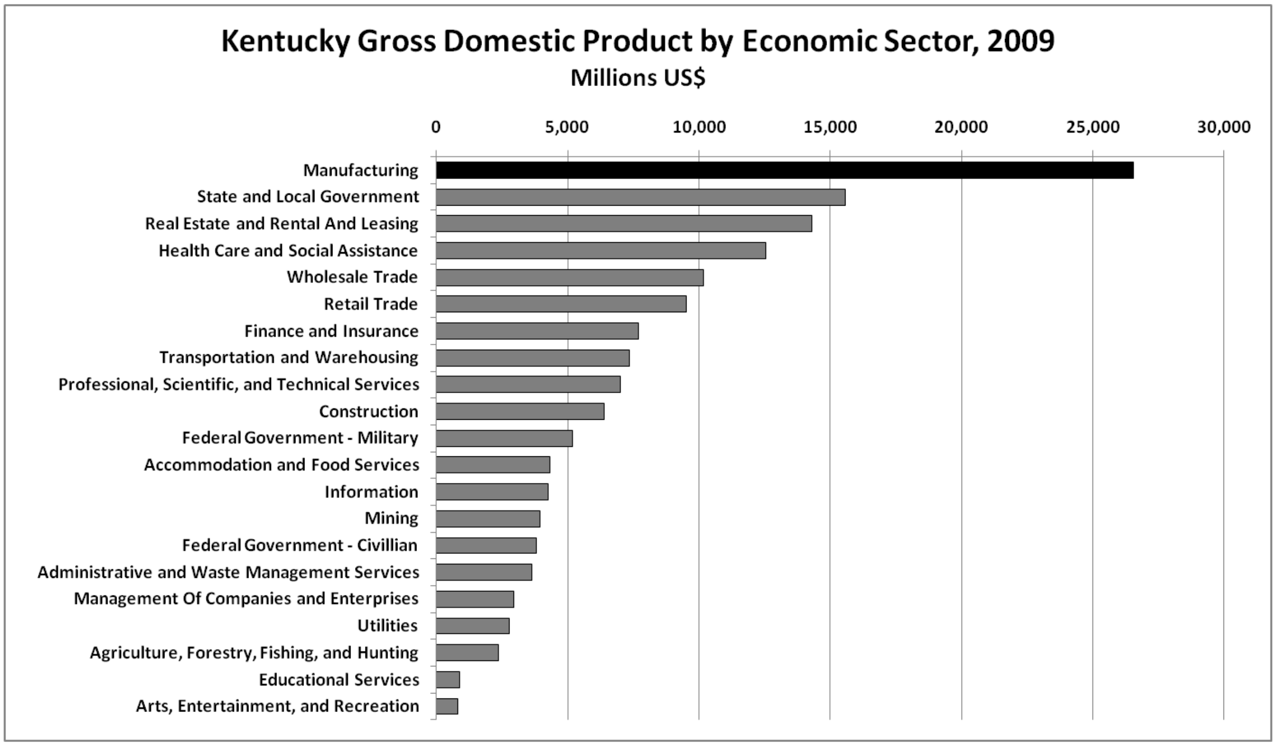
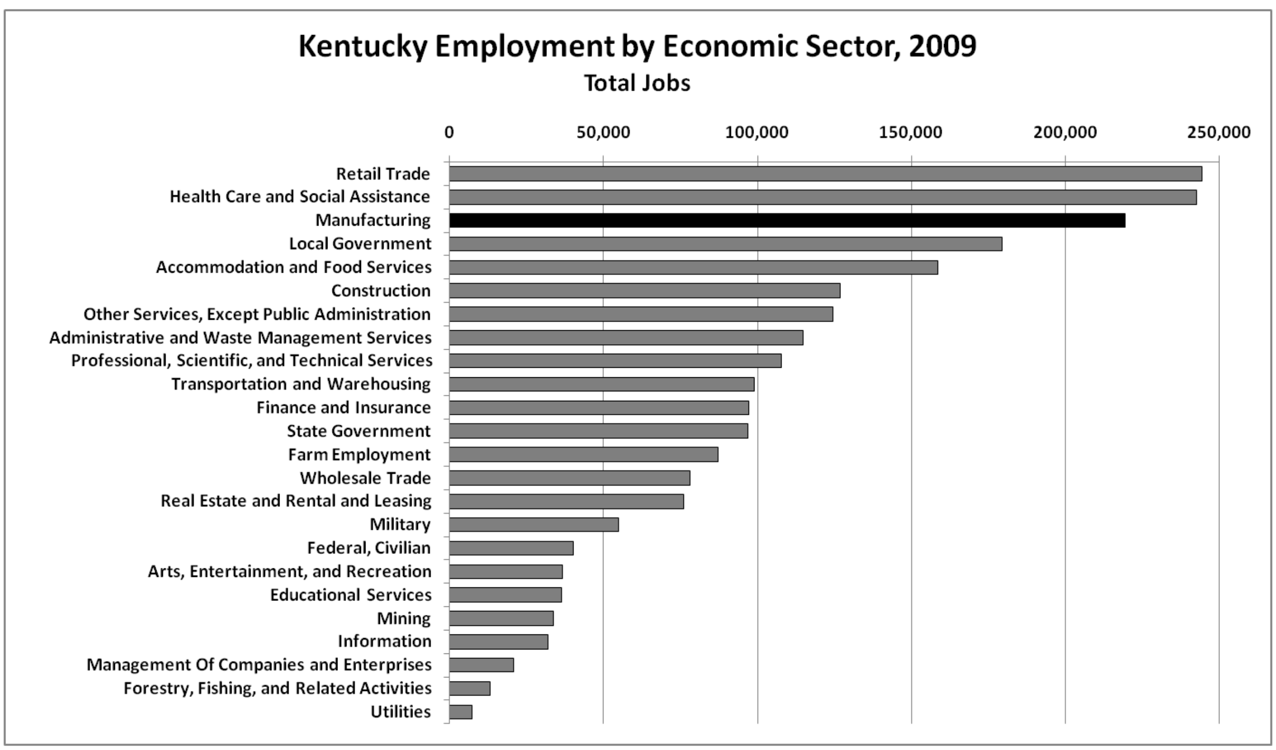


Figure 8: Kentucky Employment by Economic Sector, 2009



Kentucky's electricity-intensive manufacturing economy is threatened by increasing electricity prices. While the price of electricity is only one of several factors influencing industrial location decisions, Kentucky's historically low and stable electricity prices have fostered the most electricity-intensive economy in the United States. In the twenty-first century, the bulwark of the Kentucky economy is clearly manufactured goods—the Commonwealth’s single largest source of economic activity. Even mid-recession, as illustrated in Figures 6 and 7 on page 5, manufacturing in Kentucky accounted for more than $26.6 billion in 2009, or 17% of State GDP, and directly employed 213,330 Kentuckians—2.5 times more than were employed as farmers and 11 times more than were employed as coal miners. In addition to being Kentucky’s largest source of revenue and a leading source of employment, manufacturing is *sui generis*, fulfilling a unique economic function in that most goods are exported, bringing revenue to the Commonwealth from other economies. This is in contrast to the other top employment opportunities in Kentucky: retail services, health care, local government, food service, and construction, which principally depend upon local sources of revenue. Employment opportunities in manufacturing pay more than the two larger employment sectors, retail and hospitality. Large manufacturers, such as General Electric, Toyota, and Ford Motor in Kentucky, also have a more significant multiplier effect on a regional economy because they encourage suppliers to collocate with manufacturing facilities.[5]And this may well be the greatest significance of coal for the Commonwealth: not the number of persons employed in coal mining operations, nor the direct revenue generated from coal exports, *but rather the sheer size of the manufacturing industry that has located in Kentucky because of low energy costs*.

A variety of econometric studies[6,7] have been conducted to estimate the relationship between electricity prices and employment, also finding that increased electricity prices are associated with reductions in employment. However, none of these studies have taken into account the regional disparities in both the forecasted electricity price increases as well as distribution of electricity-intensive manufacturing as a percentage of total employment or state gross domestic product (GDP). Furthermore, none of these existing studies have specifically analyzed the impact of increasing prices on the most relevant employment sectors in the Commonwealth of Kentucky: manufacturing, retail, hospitality, healthcare and government.

A 2011 report prepared for the Kentucky state government found that increases in the price of electricity are associated with decreases in overall levels of employment. Specifically, the authors posit that a onetime increase of 25% in the price of electricity would reduce the long-run growth rate in total employment from an average of 3.0% to 2.49% per annum.[8] This current study builds upon the their work by using sector-specific employment as the dependent variable rather than total employment in all sectors to identify particular vulnerabilities within the Kentucky economy.

Beyond absolute price, the mere presence of price volatility may make it difficult for electricity-intensive manufacturing businesses to plan ahead and may also discourage capital investment in these engines of economic growth. Electricity price volatility could be included as an independent variable in future studies. For example, one could surmise that during a period of electricity price increases, companies would leave or not expand their existing operations, and this would not necessarily be recovered during periods of declining electricity prices.

Business Response Options to Increasing Electricity Prices

Faced with increasing electricity prices, energy-intensive businesses have the following response options.

1. Pass the price increase directly to consumers, in non-competitive markets.
2. Ignore the price increase and accept a reduction in profit margins.
3. Implement energy efficiency measures to lower total electricity consumption.
4. Substitute electricity with alternative energy sources, where available and competitively priced.
5. Seek government incentives or intervention.
6. Implement efficiency in other areas, including labor costs.
7. Relocate to an area where costs of production will be lower.
8. Close.

Option 1, passing the price increases directly to product end users, will only be a viable option if that industry has a captive or non-competitive market. If market competition is tight or if there are already lower-cost alternatives available to consumers, manufacturers may have limited room to increase prices. Electricity-intensive industries will not likely be able to choose option 2, since electricity expenditures are such a significant portion of their costs of doing business. In such cases, businesses have probably also already implemented energy efficiency measures, option 3, to increase profit margins. However, as much as possible, more efficient use of electricity is preferable under most conditions.

The use of energy substitutes, option 4, for energy-intensive industries in Kentucky may mean substituting direct natural gas combustion for electricity. However, natural gas price volatility, supply, and pipeline access may be prohibiting factors to large scale natural gas substitution.

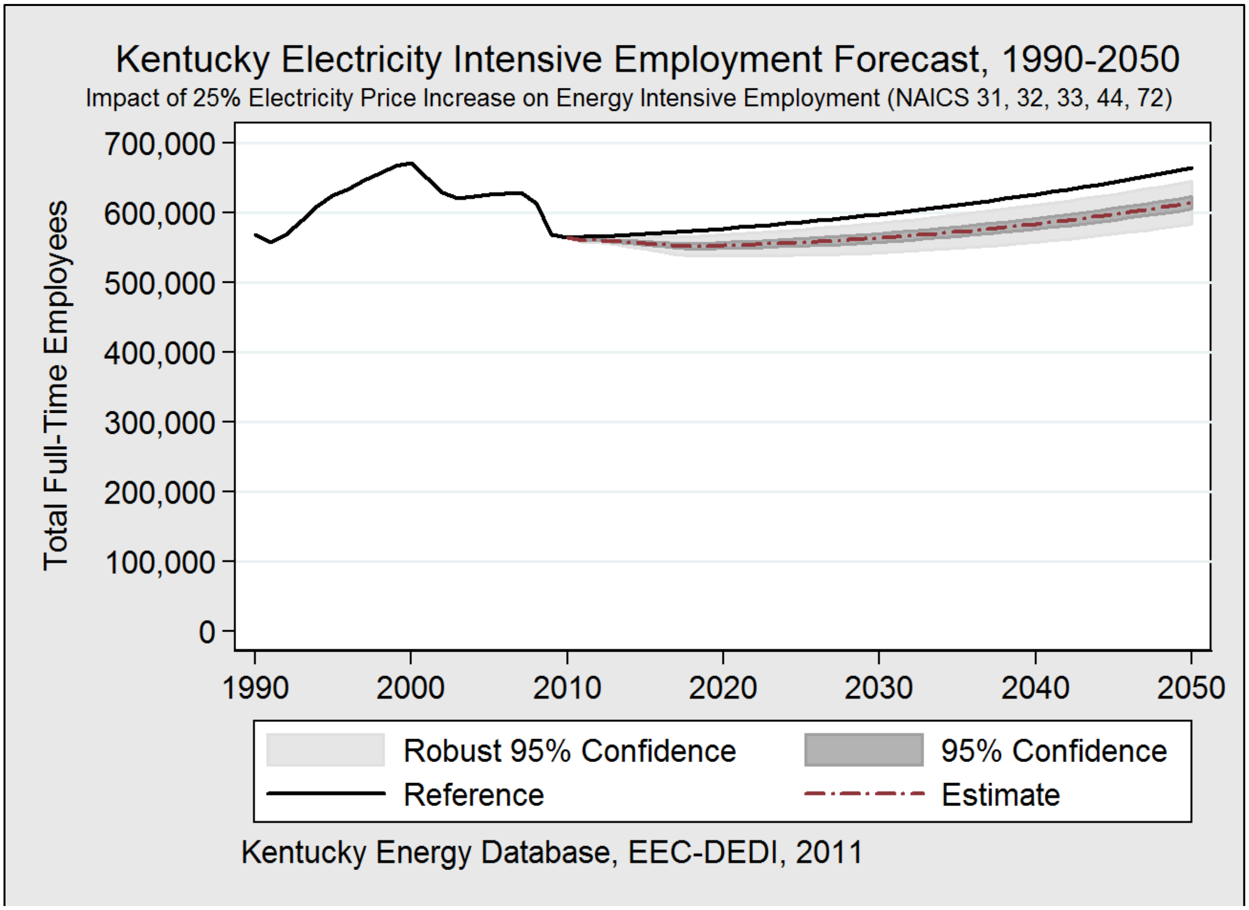
Businesses may also turn to government to either subsidize increasing electricity costs or offset them through taxpayer or ratepayer-funded incentives, option 5. Indeed, many other state governments already offer such incentives to electricity-intensive industries; however, in practice, the long-term affordability of such subsidies must be part of the government’s evaluation criterion.

Whenever a business chooses options 6, 7, or 8, there should be a negative impact on total employment. Options 7 and 8 could be measured in total number of employees, whereas option 6 would be better measured using total labor hours or wage data.

Findings

This study builds upon the notion that low energy costs are a catalyst for commercial growth by quantifying the precise vulnerability of the largest economic sectors of the Commonwealth, in terms of total employment, to future electricity price increases. Using a statistical analysis technique called *multiple regression of panel data with fixed effects,* discussed in greater detail in the Statistical Appendix on pages 13 to 19, this study modeled the responsiveness of employment across the United States to changes in the price of electricity from 1990 to 2010 for the top five employment sectors in Kentucky: manufacturing, retail services, hospitality, healthcare, and government. *Elasticities* were developed for each of these economic sectors to calculate changes in employment, given a specific change in the price of electricity, and can be generally applied to the 48 contiguous United States.

Figure 9: Kentucky Electricity Intensive Employment Forecast, 1990-2050



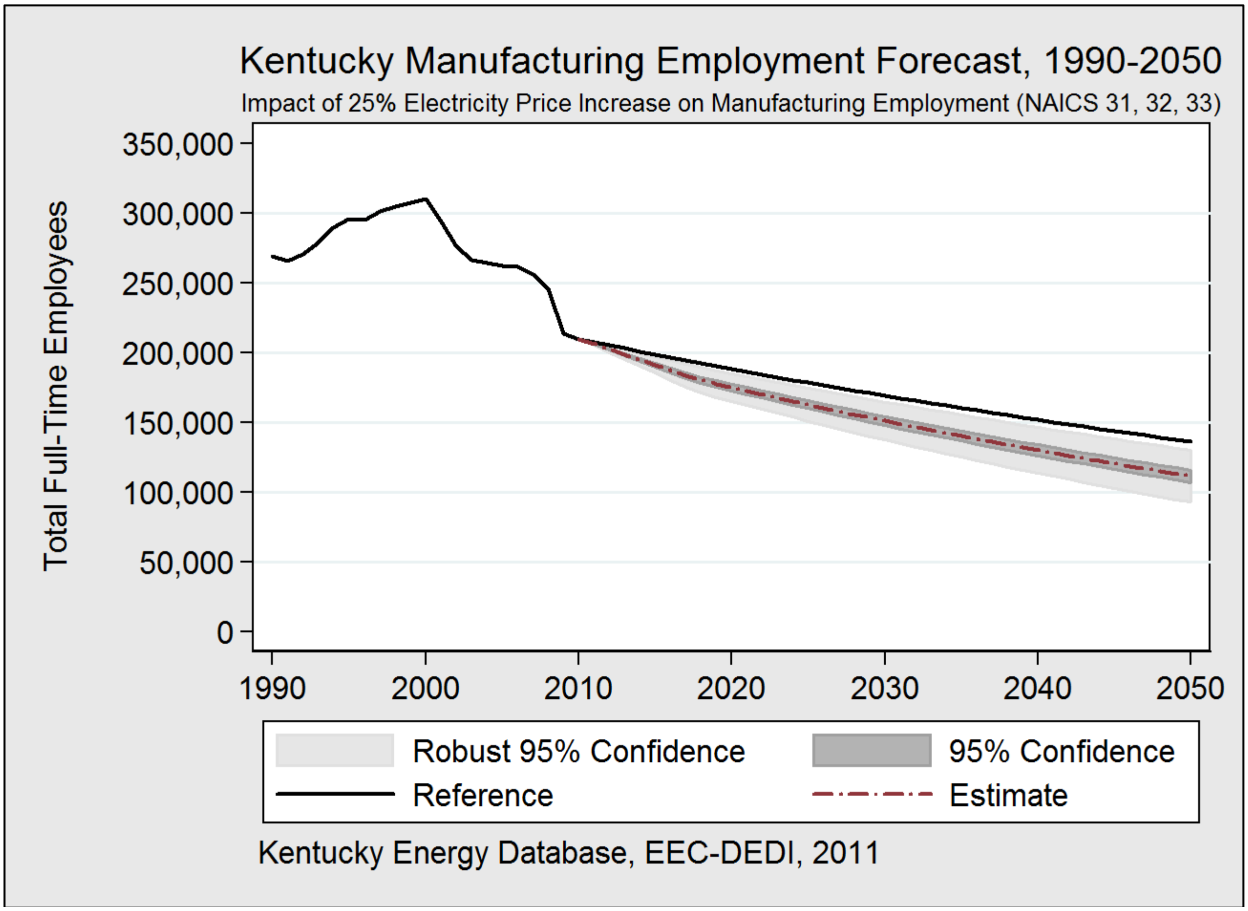
Given the potential cumulative increase of 25% in real electricity prices between 2011 and 2025, this multiple regression model estimates that Kentucky will likely lose, or fail to create, 30,000 full-time jobs long-term. Manufacturing establishments were the most vulnerable to electricity price increases and can be expected to permanently shed 17,500 full-time jobs. Evidence suggests that, once lost, similar manufacturing employment opportunities will never return. The relative extent of this finding is intuitive given that there are 12,685 jobs in the most-electricity intensive manufacturing sectors alone.

Retail stores, restaurants, and hotels were less than half as responsive as the manufacturing sector to increasing electricity prices, and combined, can be expected to fail to create 12,500 full-time jobs. However, in the fourth and fifth largest employment sectors, healthcare and government, no statistically significant relationship between electricity prices and total employment could be identified.

The employment forecast illustrated in Figure 9 above is an aggregation of each of the sector-specific forecasts for the energy-intensive sectors, manufacturing, retail, and hospitality (NAICS 31, 32, 33, 44, & 72). The estimated electricity-related job losses were subtracted from a reference forecast for each sector that simply extrapolated the 20-year average annual growth rate (AGR). The 95% confidence intervals, both with and without robust standard errors, are displayed in gray surrounding the single-point estimations. The delta between the estimate and reference case is the isolated effect of electricity price increases on employment.

Impact on Manufacturing Employment

Figure 10: Kentucky Manufacturing Employment Forecast, 1990-2050

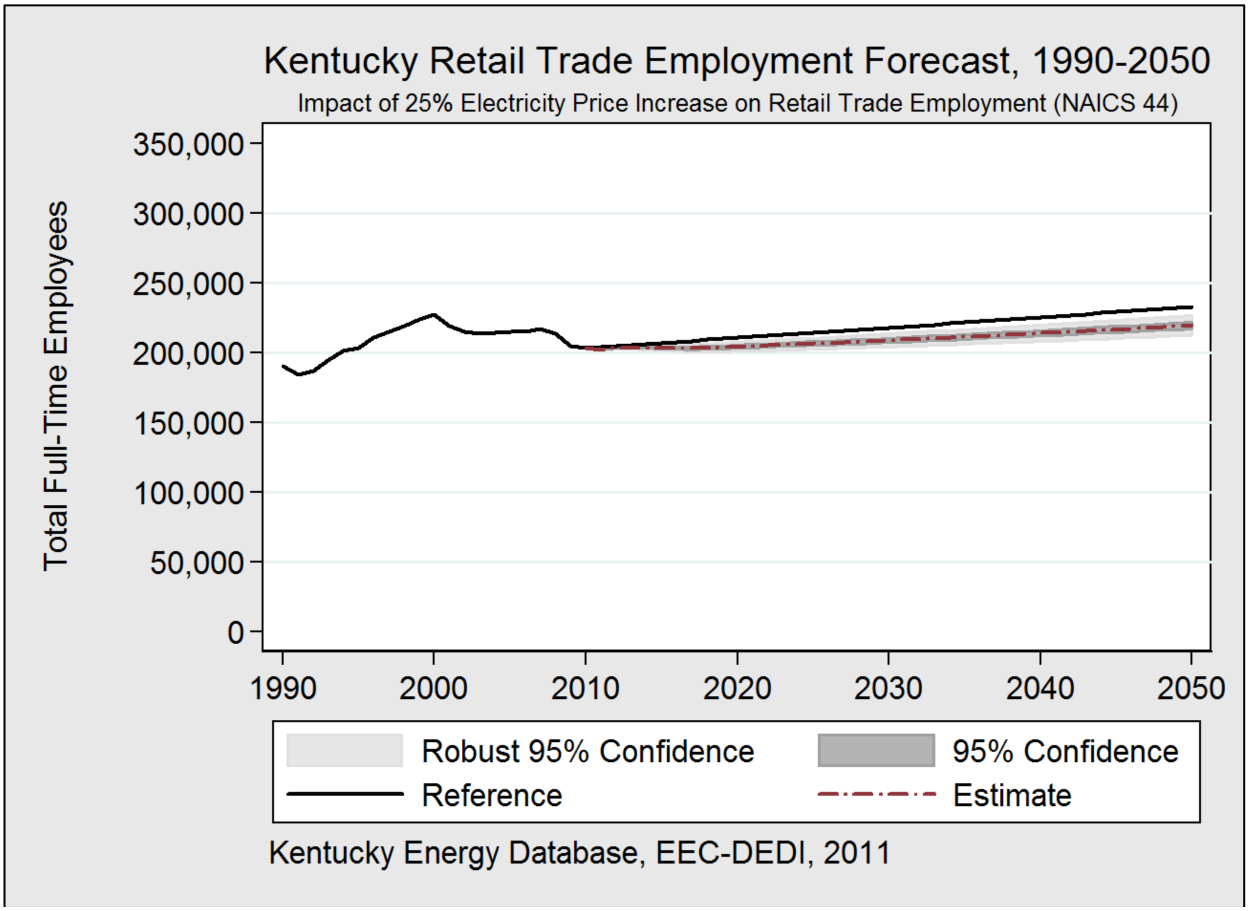


Of the sectors analyzed, manufacturing, Kentucky's largest economic sector, was the most-responsive sector to changes in electricity prices. Specifically, an increase of 10% in real electricity prices was associated with a reduction of 3.37% in absolute manufacturing employment, and with 95% confidence, between -2.77% and -3.97%. This finding was statistically significant below the 0.001 level. When using robust standard errors, however, the 95% confidence interval widened to between -0.83% and -5.92% and the significance level dropped to 0.01. Overall economic activity and time were also significant factors in predicting employment in the manufacturing sector; however, educational attainment as well as the total population levels were not. Time had a statistically significant negative coefficient, reflecting the general trend of contraction of manufacturing both in Kentucky and nationally. Given a 25% increase in real electricity prices by 2025, manufacturing establishments in Kentucky would be expected to permanently shed an additional 17,660 full-time jobs long-run as a direct result of price increases, and with 95% confidence using robust standard errors between 5,764 and 31,022 full-time jobs, *ceteris paribus*.

The manufacturing employment forecast, illustrated in Figure 10 above, was developed by applying the elasticities for the manufacturing sector to the electricity price forecast to estimate electricity price-related job losses, which were subtracted from a baseline forecast developed using the 20-year AGR of -1.16%, and then subtracting predicted historical electricity-related losses, for a net reference AGR of -1.07%.

Impact on Retail Trade Employment

Figure 11: Kentucky Retail Trade Employment Forecast, 1990-2050

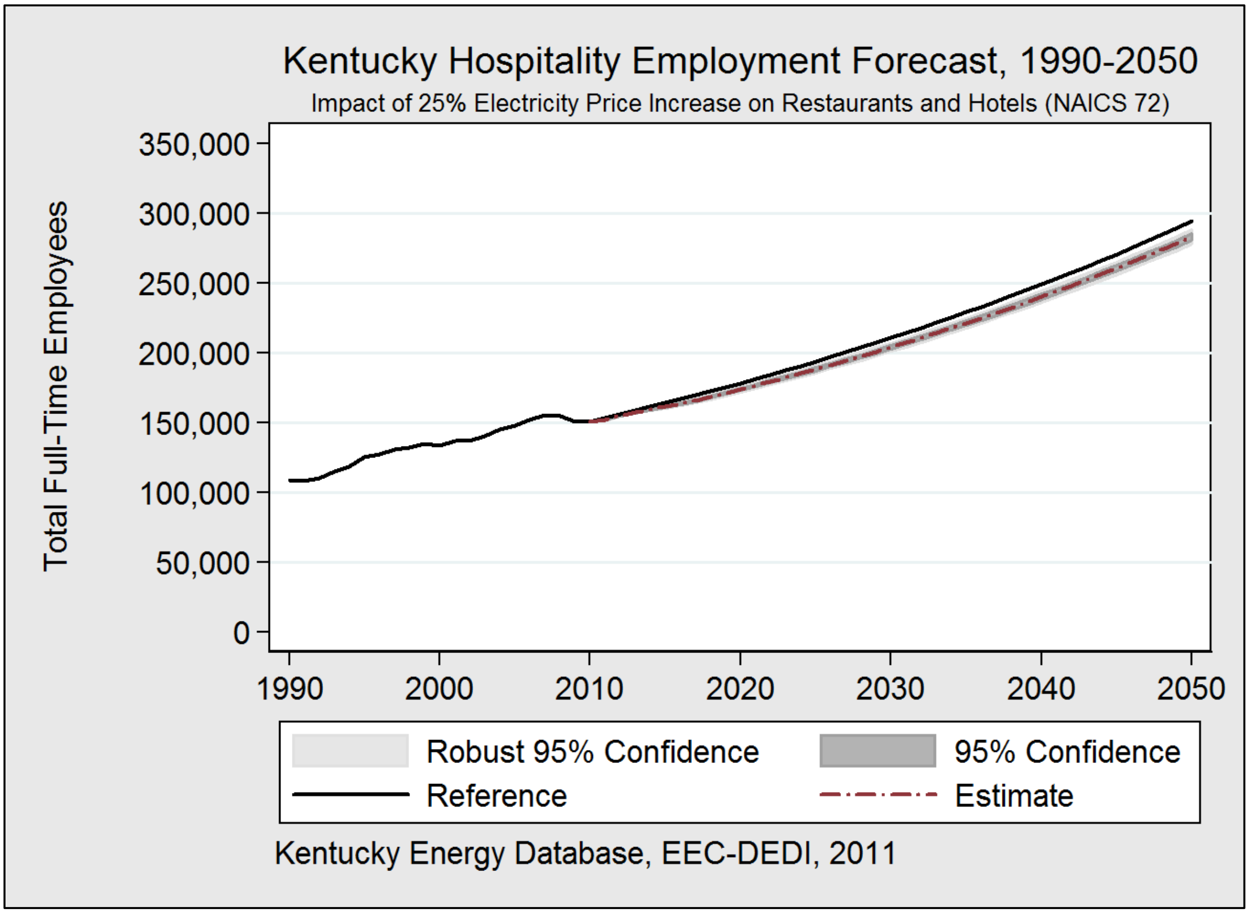


Retail trade, Kentucky's largest employment sector in terms of total employment, was less than half as responsive as the manufacturing sector to increasing electricity prices. Specifically, an increase of 10% in real electricity prices was associated with a reduction of 1.57% in total employment, and with 95% confidence between -1.30% and -1.84%. When using robust standard errors, however, the 95% confidence interval widened between -0.77% and -2.39%. These findings were statistically significant below the 0.001 level. Education was not a significant factor in determining retail employment; whereas economic activity and total population levels were. Given a 25% increase in real electricity prices by 2025, retail establishments in Kentucky would be expected to fail to create 7,225 full-time jobs long-run, and with 95% confidence using robust standard errors, between 3,916 and 12,160 full-time jobs, *ceteris paribus*.

The retail employment forecast, illustrated in Figure 11 above, was developed by applying the elasticities for the retail sector to the electricity price forecast to estimate electricity price-related job losses, which were subtracted from a baseline forecast developed using the 20-year AGR of 0.3584%, and then subtracting predicted historical electricity-related losses, for a net reference AGR of 0.3393%.

Impact on Hospitality Employment

Figure 12: Kentucky Hospitality Employment Forecast, 1990-2050



Employment in hospitality industries such as restaurants and hotels demonstrated a similar, but weaker, responsiveness as retail employment. Specifically, an increase of 10% in real electricity prices was associated with a reduction of 1.42% in total employment, and with 95% confidence between -1.12% and -1.71%. When using robust standard errors, however, the 95% confidence interval widened between -0.78% and -2.06%. This finding was statistically significant below the 0.001 level. Education and total population do not appear to be significant factors in determining hospitality sector employment; whereas economic activity and time were both significant. Given a 25% increase in real electricity prices by 2025, restaurants and hotels in Kentucky would be expected to shed 5,352 full-time jobs long-run, and with 95% confidence using robust standard errors, between 2,940 and 7,765 full-time jobs, *ceteris paribus*.

The retail employment forecast, illustrated in Figure 12 above, was developed by applying the elasticities for the retail sector to the electricity price forecast to estimate electricity price-related job losses, which were subtracted from a baseline forecast developed using the 20-year AGR of 1.6857%.

Impact on Healthcare Employment

Employment in the healthcare industry was much less sensitive to increases in electricity prices, and responsiveness was not statistically significant when using robust standard errors. Specifically, a 10% increase in the price of electricity appears to be associated with a 0.43% reduction in overall healthcare employment. However, with 95% confidence and robust standard errors, these effects are not necessarily distinguishable from zero. Healthcare employment was better predicted by educational attainment of the population, overall economic activity, total population levels, and time. Given that the independent variable of interest, real electricity prices, was not significant when using robust standard errors, no forecast for this sector was developed.

Impact on Government Employment

In government employment, no relationship between electricity prices and total employment could be identified, whereas educational attainment of the population, overall economic activity, and total population levels appeared to have statistically significant effects. Given that the independent variable of interest, real electricity prices, was not significant in any model, no forecast for this sector was developed.

Conclusion

This study demonstrated that electricity price increases alone may force businesses to seek ways to reduce costs or close, causing substantial job losses in Kentucky's electricity-intensive manufacturing sector, and slowing overall long-term job creation in other sectors. The timing of this transition could exacerbate high unemployment and slow economic growth in the near-term. The Commonwealth's vulnerability to these dynamics could also be worsened if leadership is unaware of them and inadequately prepared for the transition. Kentucky's neighboring states of Indiana, Ohio, and West Virginia exhibit similar vulnerabilities due to the potential for increasing electricity costs and the relative size of their manufacturing sectors.

While total employment in the Commonwealth is expected to continue to rise in other sectors, the Commonwealth should maintain focus on education and workforce development in emerging industries that are less reliant on energy-intensive manufacturing processes as well as consider strategies to mitigate vulnerability to price increases and risk exposure.

Data Analyzed

Total employment in Kentucky's top five economic sectors, in terms of number of employees as illustrated in Figure 8 on page 5, served as the dependent variables of interest in this study. Total employment by industry was collected from the Bureau of Economic Analysis (BEA) for all 51 entities and all years from 1990 to 2010. [9] Data was collected for each state as well as the District of Columbia, in each year, and for each industry, organized by North American Industry Classification System (NAICS) codes.

The primary explanatory variable of interest in this study was the natural logarithm of total real electricity price in each state and year expressed in 2010 US$ per kWh. Electricity prices are defined here as the quotient of the total revenue received by electric utilities in state *i* and in year *t* divided by the total kilowatt-hours of electricity sold in that state and year. Electricity *prices* differ from electricity *rates*, which are only a subset of the total cost and often do not include taxes, environmental surcharges, and fuel costs that vary substantially across time and geography. Thus, electricity prices more accurately reflect the cost for one kilowatt-hour of electricity paid by consumers in a given state and year. This variable was assembled using a variety of datasets from the Energy Information Administration (EIA), including data from the State Energy Data System (SEDS) for years 1990 to 2009 for all states,[10] and where certified data was not yet available using Form EIA-861[11] and Form EIA-826 for the year 2010.[12] The correlation between historical electricity prices derived from Form EIA-861 and EIA-826 to the corresponding certified variables was 0.999; thus, there is almost no difference between the historical data and the 2010 update other than it has not yet been certified and included in SEDS.

The following control variables were used: educational attainment, defined as the percentage of the adult population (age 25 years and older) with a bachelor's degree (or higher), collected from the United States Census American Community Survey; population, also collected from the United States Census; state Gross Domestic Product (GDP), collected from the BEA; and year. The following control variables were also tested but ultimately excluded because their effects were not statistically significant: labor force unionization, Standard & Poor's 500 Index, and per capita personal income.

There were a total of 51 states included (*N*=51), the 50 United States as well as the District of Columbia. However, the model's performance would have been improved by ~5% if the District of Columbia had been excluded. All currency variables, namely the price of electricity and State Gross Domestic Product, were adjusted for inflation to 2010 US$ using the Bureau of Labor Statistics (BLS) Consumer Price Index (CPI), which is intended to account for the generally rising cost of goods during this time period.

Analytical Method

Using a statistical analysis technique called *multiple regression of panel data with fixed effects*, this study modeled the responsiveness of employment across the United States to changes in the real price of electricity from 1990 to 2010 for the top five employment sectors in Kentucky: manufacturing (NAICS 31, 32, & 33), retail services (NAICS 44), hospitality (NAICS 72), healthcare (NAICS 62), and government (NAICS 92). Elasticities were developed for each sector to calculate changes in employment given a specific change in the electricity prices and can be generally applied to any state and year.

To develop these elasticity coefficients, data were organized into a multidimensional panel, i.e. both time series and cross sectional, enabling simultaneous modeling of the relationships of multiple statistics across both space and time (N x t). Since each observation is non-random, and not independent, for example electricity prices in state i and year t are not independent of prices in state i in year t-1, a fixed effects model was used, which builds upon Ordinary Least Squares (OLS) regression by isolating the time-independent constant difference between states that is correlated with the explanatory variables. Two multiple regression of panel data models with fixed effects, both with and without robust standard errors, were constructed for each of the top five employment sectors in Kentucky, for a total of 10 separate multiple regression models.

The multiple regression of panel data model with fixed effects can be generally given by,

$$Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \alpha_i + \varepsilon_{it}$$

Where i and t index states and years, such that y_{it} is the dependent variable of interest, employment by industry, in state i in year t, β_0 is the constant y intercept across all states, X is a k by 1 vector of explanatory variables, $\beta_j X_{jit}$ is the product of the observation for each independent variable j through k for state i in year t and the coefficient of X, k is the total number of included independent variables, α_i is the time-invariant fixed effect for state i, and ε_{it} are the residuals, and where $\varepsilon_{it} \sim N(0, \sigma^2)$, or are approximately normally distributed with a mean of zero.

Multiple regression of panel data using fixed effects facilitated controlling for the numerous factors inherently affecting sector-specific employment as well as electricity prices from state to state that have not been accounted for in the independent variables included in this study to isolate the primary national effect of the variable of interest, real electricity prices, on each of the dependent variables, employment by industry. Since this study aims to isolate the unique effect of electricity prices on employment, the model was rerun five times to derive the coefficient for each of the industries of interest by NAICS code.

A fixed effects model specifically assumes the existence of unobserved time-invariant heterogeneity, often referred to as unobserved variable bias, which in addition to the included independent variables, is affecting the dependent variable. The fixed effects model will attempt to control for these missing or unobserved between unit (interstate) factors, the fixed effects, to isolate the specific net effect of the independent variables of interest on all units (nationally). The fixed effects model also assumes that these between-unit effects are both time invariant and correlated with the independent variables. A fixed effect model is also functionally, although not computationally, equivalent to assigning an independent indicator variable, or dummy variable (0 or 1), for each state, to isolate the specific effect for each state without having to create the 51 additional independent variables.

The Hausman test, which is often used in econometrics to determine the appropriateness of a fixed effect versus a random effect model, is not required here because this study is modeling the entire population of states (*N*), thus necessitating a fixed effects model and obviating a random effects model. A random effect model is only suitable to model the sample (*n*) of the population that has been selected at random.

Table 2 on page 16 shows the multiple regression models with fixed effects estimated for each of the top five employment sectors. These five models were subsequently rerun using robust standard errors in order to prevent biased estimation that could be caused by the presence of outliers in manufacturing employment, such as the District of Columbia, as well as the presence of the residual heteroscedasticity as identified by the Breusch–Pagan post estimation test. Robust standard errors were calculated using the Huber-White sandwich estimator.[13] The resulting five multiple regression models with fixed effects and robust standard errors are shown in Table 3 on page 17. However, using robust standard errors had little impact on the relationships of interest; the effect of electricity prices on manufacturing employment remained significant with a p-value of 0.010.

Prior to analysis, all variables were converted to their natural logarithms such that the estimated coefficients for each may be simply interpreted as elasticities, which measure the percentage change in the dependent variable given a percentage change in one of the independent variables. For electricity prices specifically, the independent variable of interest in this study, the coefficients summarized in the first row of Tables 2 and 3 are the estimated electricity price elasticity of employment for each specific economic sector, which is the expected percentage change in employment given a percentage change in the price of electricity, *ceteris paribus*, or holding all other included independent variables constant.

Since these elasticities were derived through regression of national historical data, they may be generally applied to any state and year and to the United States as a whole for each respective economic sector. The only difficult math in this process is in the development of the elasticity coefficients themselves. Therefore, assuming a reliable electricity price forecast has already been developed, the long-term change in employment in a given sector for other states and for different changes in the price of electricity can be calculated by simply multiplying the number of employees in that sector currently by the forecasted percentage change in real electricity prices, i.e. inflation adjusted, multiplied by the specified elasticity coefficient for that sector. For example, given that there were 209,609 employees in all manufacturing sectors in Kentucky in 2010, and assuming real electricity prices increased by 25%, and given that the electricity price elasticity of manufacturing employment calculated here is 0.337, then the estimated long-term job losses resulting from the increase in electricity prices would 17,660, as illustrated below.

	209,609	*Number of Employees in NAICS Sectors 31, 32, & 33*
x	0.25	*% Change in Electricity Price*
x	0.337	*Sector-Specific Elasticity Coefficient*
=	17,660	*Resulting Long-Term Job Losses*

The employment forecasts illustrated in Figures 12 through 21 on the following pages were produced by integrating the elasticities developed in this study into the Kentucky Electricity Portfolio Model. This facilitated creating dynamic employment forecasts for different electricity price scenarios that were responsive to the forecasted change in real prices in each future year. No lags have been assumed.

Table 2: Model of Electricity Prices & Employment by Economic Sector

Logged Variables	Manufacturing Employment		Retail Employment		Food & Accommodation Employment		Healthcare Employment		Government Employment	
Price of Electricity (Real 2010 US$)	-0.337	***	-0.158	***	-0.142	***	-0.0426	**	0.00084	
	(-0.0307)		(-0.0136)		(-0.0152)		(-0.0158)		(-0.0101)	
Educational Attainment	0.0249		-0.108		-0.0679		-0.536	***	-0.14	**
	(-0.146)		(-0.065)		(-0.0728)		(-0.0758)		(-0.0482)	
State GDP (Real 2010 US$)	0.744	***	0.509	***	0.318	***	0.17	***	0.253	***
	(-0.0514)		(-0.0228)		(-0.0255)		(-0.0265)		(-0.0169)	
Population	0.166	**	0.26	***	0.129	***	0.37	***	0.258	***
	(-0.0532)		(-0.0236)		(-0.0264)		(-0.0275)		(-0.0175)	
Year	-76.05	***	-11.31	***	21.11	***	55.21	***	3.801	*
	(-5.536)		(-2.457)		(-2.752)		(-2.861)		(-1.819)	
Constant	579.4	**	88.85	***	-153.9	***	-413.5	***	-22.72	
	(-41.38)		(-18.36)		(-20.57)		(-21.39)		(-13.6)	
R-Squared	0.7776		0.956		0.9219		0.8885		0.9344	
Observations (*N x t*)	1069		1071		1069		1071		1071	
Number of States (*N*)	51		51		51		51		51	

Standard Errors in Parentheses
Asterisk Denotes Statistical Significance at the Following Levels: * p<0.05, ** p<0.01, *** p<0.001
All Variables Transformed into their Natural Logarithms

Table 3: Model of Electricity Prices & Employment by Economic Sector With Robust Standard Errors

Logged Variables	Manufacturing Employment		Retail Employment		Food & Accommodation Employment		Healthcare Employment		Government Employment	
Price of Electricity (Real 2010 US$)	-0.337	*	-0.158	***	-0.142	***	-0.0426		0.00084	
	(-0.127)		(-0.0404)		(-0.032)		(-0.0377)		(-0.0285)	
Educational Attainment	0.0249		-0.108		-0.0679		-0.536		-0.14	
	(-0.598)		(-0.23)		(-0.216)		(-0.345)		(-0.155)	
State GDP (Real 2010 US$)	0.744	***	0.509	***	0.318	***	0.17		0.253	***
	(-0.141)		(-0.115)		(-0.0789)		(-0.0939)		(-0.0719)	
Population	0.166		0.26		0.129		0.37	*	0.258	*
	(-0.19)		(-0.134)		(-0.0835)		(-0.155)		(-0.124)	
Year	-76.05	**	-11.31		21.11	*	55.21	***	3.801	
	(-22.38)		(-10.79)		(-9.212)		(-14.23)		(-5.988)	
Constant	579.4	**	88.85		-153.9	*	-413.5	***	-22.72	
	(-166.9)		(-80.3)		(-68.98)		(-106.3)		(-44.06)	
R-Squared	0.7776		0.956		0.9219		0.8885		0.9344	
Observations (*N x t*)	1069		1071		1069		1071		1071	
Number of States (*N*)	51		51		51		51		51	

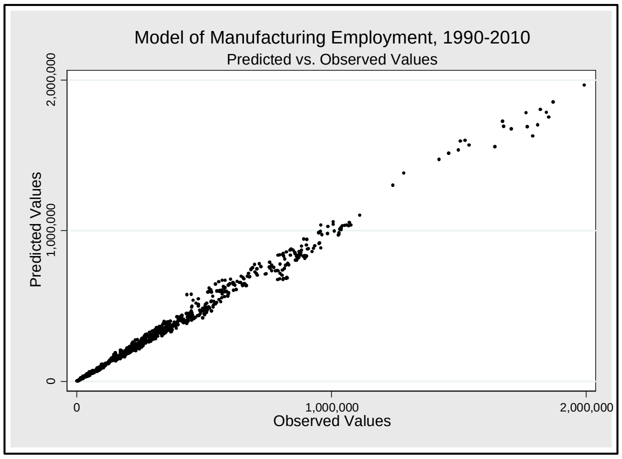
Robust Standard Errors in Parentheses
Asterisk Denotes Statistical Significance at the Following Levels: * p<0.05, ** p<0.01, *** p<0.001
All Variables Transformed into their Natural Logarithms.

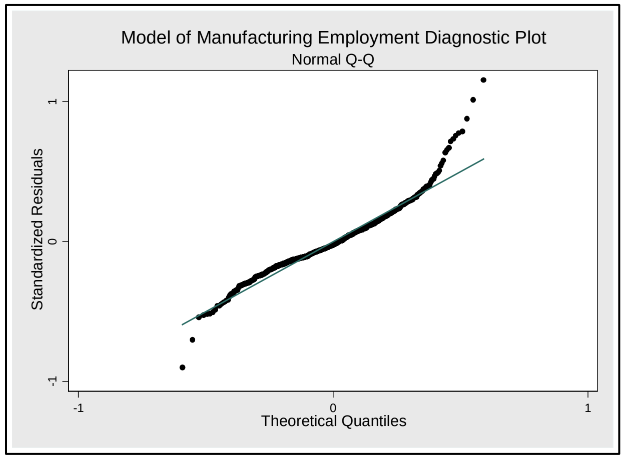
Model Diagnostic Plots

For each economic sector below, the diagnostic plot on the left shows the model's predicted employment versus employment that was actually observed in that state and year, such that all deviations from a perfect line illustrate model error (ε_{it}). The predicted values in all graphics include not only the homogenous, i.e. national, model components, including the constant (β_0) and the product of each variable j to k and the coefficient of each ($\beta_j X_{jit}$), but also the time-invariant interstate fixed effect (α_i) in the response variable, employment, estimated for each state.

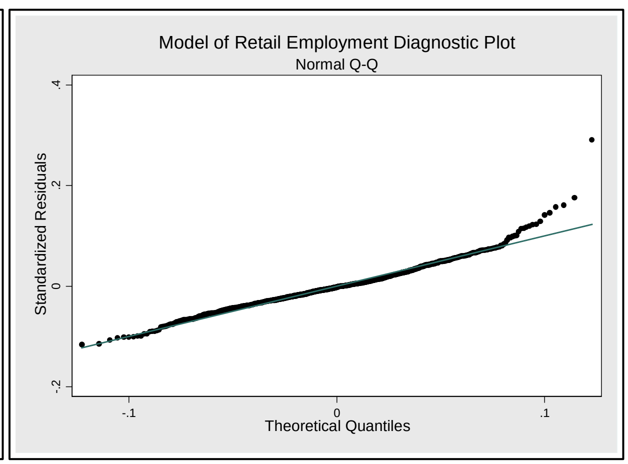
The Q-Q plot on the right illustrates the standardized residuals of the model for each economic sector versus their normal theoretical quantiles and are intended to demonstrate that the residuals are approximately normally distributed with a mean of zero, such that $\varepsilon_{it} \sim N(0, \sigma^2)$.

Figures 13 & 14: Model of Manufacturing Employment Diagnostic Plots

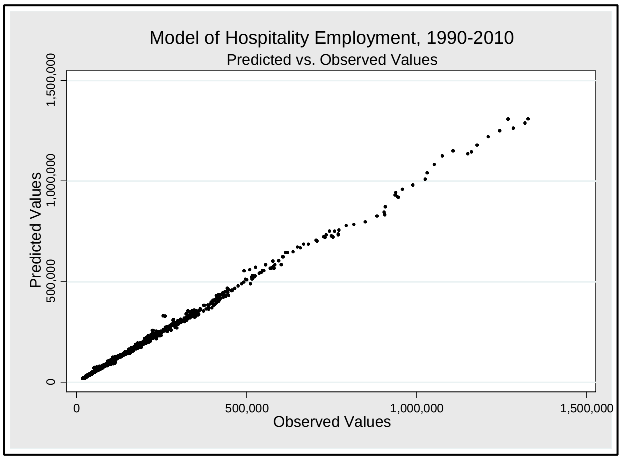


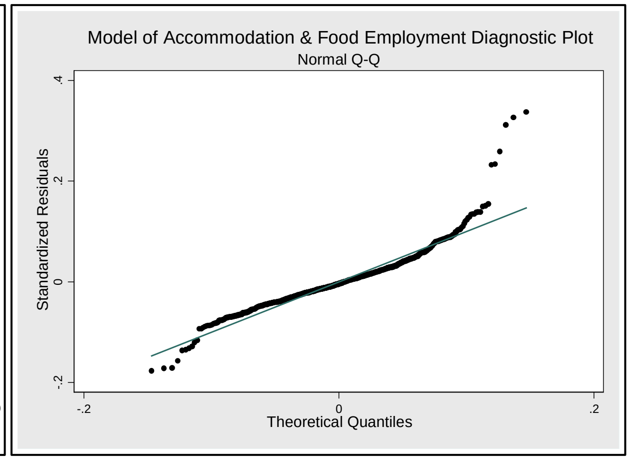


Figures 15 & 16: Model of Retail Employment Diagnostic Plots

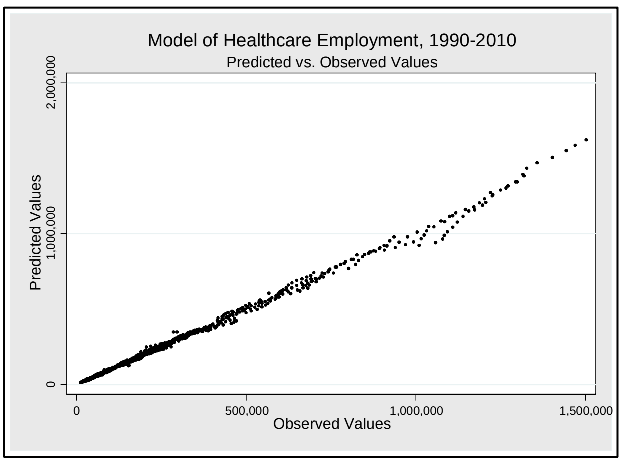


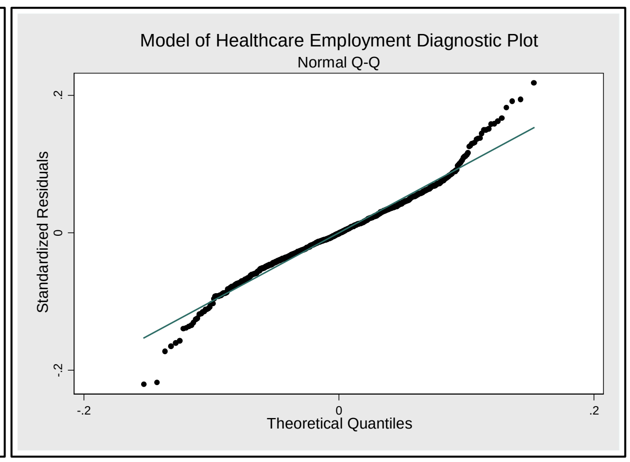
Figures 17 & 18: Model of Food & Accommodation Employment Diagnostic Plots



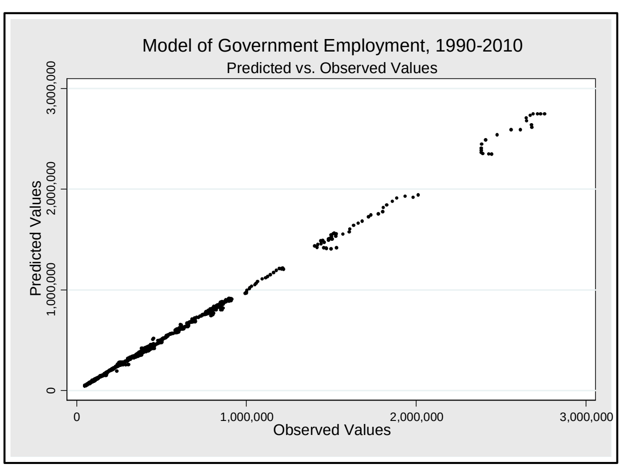


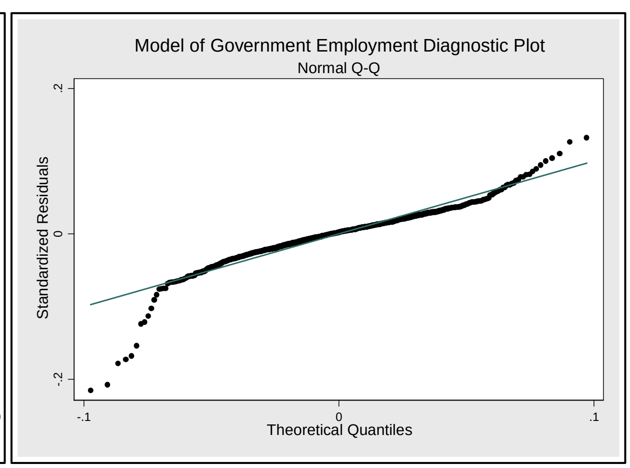
Figures 19 & 20: Healthcare Employment Diagnostic Plots





Figures 21 & 22: Model of Government Employment Diagnostic Plots





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