The Relationship between

Electricity Prices and Economic Output

Presentation of Draft Working Paper

Developed by the

Kentucky Energy and Environment Cabinet

Department for Energy Development and Independence

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Executive Summary

Purpose – This model estimates the responsiveness of state Gross Domestic Product (GDP) to changes in real electricity prices, while controlling for the numerous factors inherently affecting GDP, including population, education, health, employment, and other fuel prices.

Results – This study indicates that higher electricity prices, holding all other factors constant, are associated with lower levels of economic output. Specifically, a 10% increase in the real price of electricity, would, on average, be associated with a 1.1% reduction in state GDP, and with robust 95% confidence, between 0.6 and 1.6%.

Accuracy – The preliminary version of this model has an absolute mean error of ±0.43% and was able to predict historical GDP within ±1% over 94% of the time, within ±2% of GDP 99.99% of the time, and always within ±3.34%.

Limitations – This model is intended estimate the relationship between electricity prices and economic output and has no way to predict major economic events including recessions or recoveries, since these may be determined by other exogenous factors. While the model is able to explain past variations in economic output, some of its inputs, such as employment, are difficult to extrapolate into the future and therefore decrease the predictive ability of the model forwards in time.

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Kentucky Electricity Portfolio Model v.2.0 Design Plan

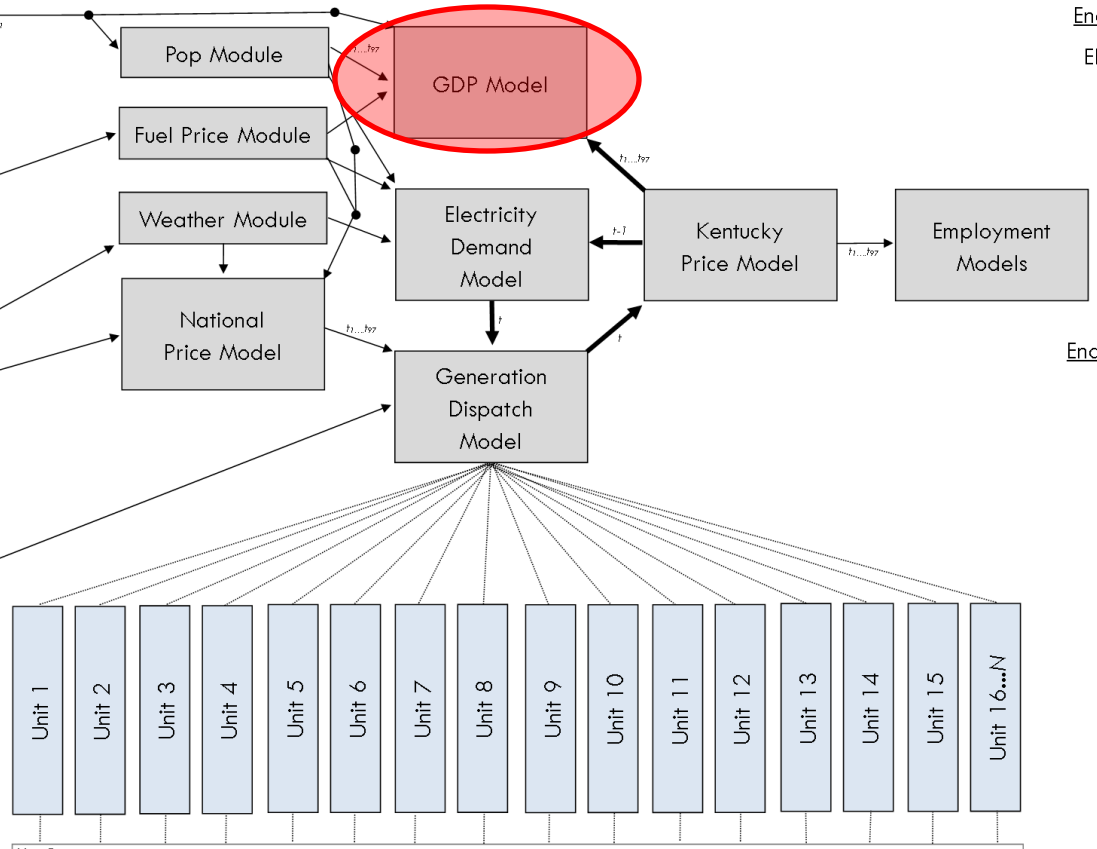
Historical Data Inputs, 1895-2013

Socioeconomic Factors
- Gross Domestic Product (GDP)
- Educational Achievement
- Population
- Employment
- Public Health

Fuel Prices
- Natural Gas Prices
- Coal Prices
- Petroleum Prices

Weather Data
- Temperature
- Rainfall
- Cooling Degree Days
- Heating Degree Days

Policy Options
- Portfolio Standards (Min / Max)
- Portfolio $CO2_e$ Limits
- Portfolio CO2, SO2, NOX, Pricing
- Unit-Level Emission Standards
  - CO2, SO2, HG, NOX, PM



LEGEND
- *Complete One-Time Data Transfer*
- *Annual Data Loop*
- *Control*
- *Programming or Statistical Module*
- *Generating Unit*

Unit Parameters
Nameplate Capacity (MW)—Maximum rated full-load output.
Online Year—The year the unit began generating.
Retirement Year—The expected year the unit is to be retired, if already known.
System Life (Years)—Number of years the system is expected to remain in operation beyond the online year.
Capacity Factor (%)—The maximum technically achievable annual output of rated nameplate capacity.
Capital Costs ($ per kW)—Fixed one-time expenses incurred to purchase and install per 1 kilowatt of capacity.
FOM ($ per kW-yr)—Annual Fixed Operations and Maintenance (FOM) costs per kilowatt of install capacity.
VOM ($ per MWh excluding Fuel)—Annual Variable Operations and Maintenance (VOM) per megawatt-hour, excluding fuel and emissions penalties.
Heat Rate (BTU/kWh)— The average annual amount of heat measured in BTU's required to produce one kilowatt-hour of electricity.
Emissions Rates (Lbs per MWh)—The annual average rate of CO_2, NO_x, SO_2, Hg, N_2O, CO, and PM emissions in pounds per megawatt-hour.
Lead Time—The number of years required to construct the unit.

WORKING DRAFT

Forecast Outputs, 2013-2100

Endogenous Electric Power Factors
- Electricity Consumption by Sector
- Electricity Prices by Sector
- Electricity Expenditures
- Electricity Generation by Unit
- Electric Power Emissions
- Natural Gas Consumption
- Coal Consumption

Endogenous Socioeconomic Factors
- Gross Domestic Product (GDP)
- Per Capita Personal Income
- Manufacturing Employment
- Retail Employment
- Hospitality Employment
- Electric Power Employment
- Coal Mining Employment
- Other Employment

Exogenous Independent Factors
- Temperature
- Cooling Degree Days
- Heating Degree Days
- Rainfall
- Population
- Educational Attainment
- Natural Gas Prices
- Coal Prices

Data Analyzed

Data Analyzed

Unit of Observation: 49 States and the District of Columbia (Alaska Excluded)

Timeframe: Annual Data from 1970 to 2010

Dependent Variable: Total State Economic Output (GDP)

Independent Variable of Interest: Real Electricity Prices

Control Variables Included
Natural Gas and Petroleum Price as a Fuel Substitutes
Population
Education (Composite of Percent of Population with High School Education and Bachelors Degree)
Employment (as Percent of Population)

All prices converted to real 2010 $US, i.e. inflation adjusted using the Bureau of Labor Statistic's Consumer Price Index.

All included variables were converted to their natural logarithms such that their coefficients may be interpreted as elasticities.

All of the coefficients in this model were derived from historical federal data using statistical procedures and there are no user-specified estimates.

GDP Model

Logged Variables	Proposed Model	Other Models Evaluated 1	2	3	4	5	6	7	8
Real Electricity Price	**-0.111*** **	-0.111***	-0.199***	-0.183***	-0.453***	-0.424***	-0.436***	-0.367***	-0.769***
	(0.0255)	(0.0249)	(0.0267)	(0.0281)	(0.059)	(0.537)	(0.0585)	(0.0496)	(0.107)
Population	**1.185*** **	1.181***	1.115***	1.169***	1.485***	1.510***	1.538***	1.631***	
	(0.0514)	(0.0486)	(0.0539)	(0.0616)	(0.126)	(0.128)	(0.122)	(0.123)	
Real Petroleum Price		0.0963***	0.0725***	0.0955***	0.106**		0.156***		
		(0.0170)	(0.0230)	(0.0218)	(0.0378)		(0.0369)		
Real Natural Gas Price		-0.0810***	-0.0916***	-0.0891***	0.0871**	0.133***			
		(0.0151)	(0.0177)	(0.0182)	(0.0308)	(0.0307)			
Education Index	**0.370*** **	0.421***	0.7776***	0.791***					
	(0.0604)	(0.0577)	(0.0568)	(0.0642)					
Health Index			-0.4021***						
			(0.0890)						
Employment	**1.312*** **	1.297***							
	(0.129)	(0.0577)							
Constant	**-7.963*** **	-8.187***	-7.205***	-8.511***	-9.974***	-10.21***	-10.75***	-11.89***	13.44***
	(0.659)	(0.636)	(0.7962)	(0.780)	(1.917)	(1.956)	(1.847)	(1.896)	(0.247)
R-Squared (Overall)	**.9801**	.9578	.9512	.9546	.9288	.9313	.9256	.9258	.0045
R-Squared (Within)	**.9536**	.9578	.9470	.9438	.8727	.8673	.8688	.8542	.1953
R-Squared (Between)	**.9839**	.9811	.9530	.9571	.9432	.9470	.9418	.9258	.0351
AIC	**-5237.2**	-5410.4	-4946.8	-4828.3	-3181.7	-3096.6	-3126.4	-2917.1	753.3
N	**2050**	2040	2040	2040	2090	2090	2100	2150	2150

Coefficients with robust standard errors in parentheses at the following significance levels: * p<0.05, ** p<0.01, *** p<0.001

All variables have been 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 after controlling for all other included independent factors. The models were run using robust standard errors, calculated using the Huber-White Sandwich estimator, in order to prevent biased estimation that could be caused by the presence of outliers in the natural logarithm of GDP, such as the District of Colombia, as well as inherent serial autocorrelation and the presence of the residual heteroscedasticity as identified by the Breusch–Pagan post estimation test. The state-specific fixed effects are not listed above.

Foundations in Economic Theory

Neoclassical Growth Model

$$Y = F(K, T \cdot L)$$

- Benefits: First flexible model that identified the basic determinants of growth; Includes diminishing returns to scale
- Drawbacks: Assumes productivity growth as exogenous; Combines factors
- Important: The Solow Residual (~50% of growth)
- Major Contributors: Robert Solow and T.W. Swan

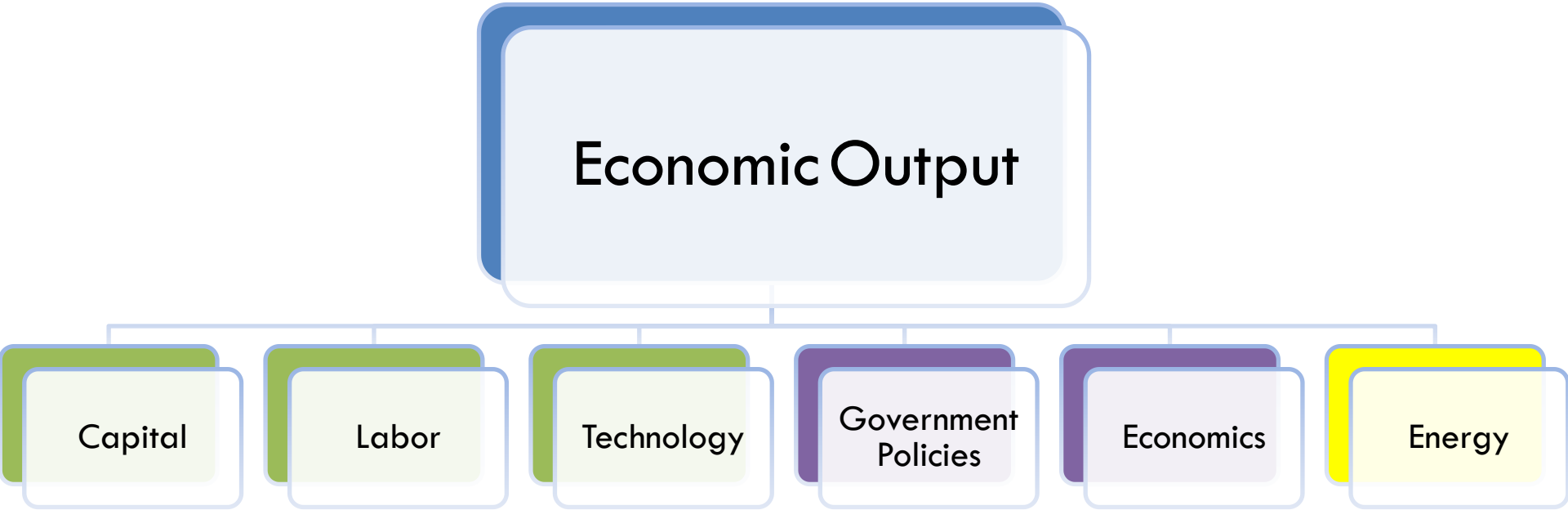
Endogenous Growth Model

- Benefits: Addition of positive spillover effects; Technological change is endogenous
- Drawbacks: Multitude of Variables included; Growth is considered perpetual
- Major Contributors: Paul Romer

Energy and Efficiency Growth Theory

- Includes first and second laws of thermodynamics (conservation of energy and entropy) to understand the role of electricity power consumption and energy in an economy
- Major Contributors: Robert Ayres and Ben Warr

Determinants of Economic Output (non-exhaustive)



Neoclassical Growth Model

Endogenous Growth Model

Energy and Efficiency Growth Theory

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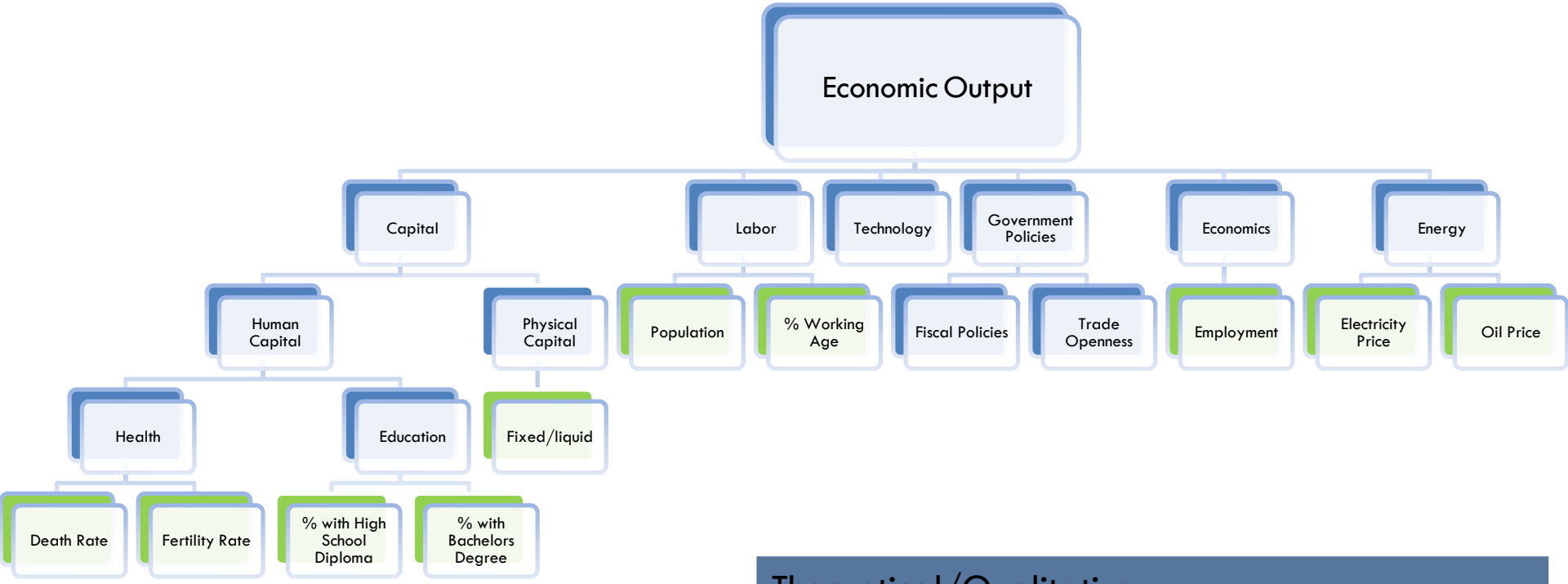
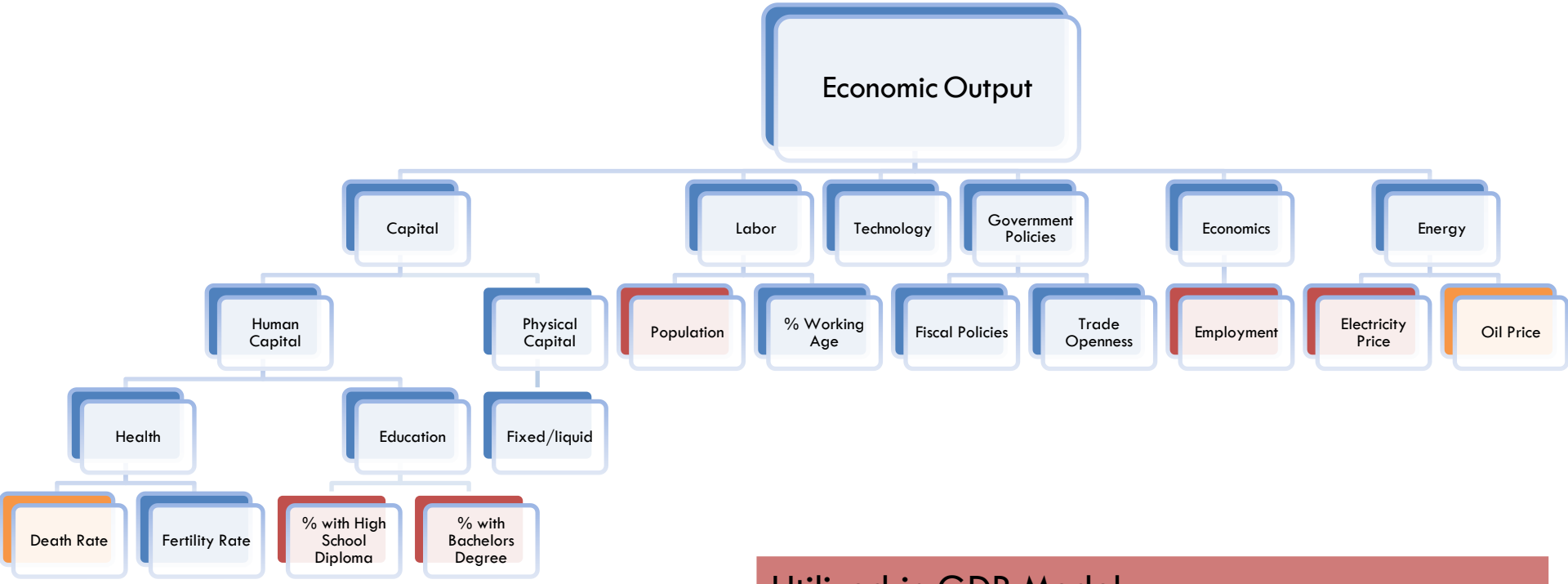


Theoretical/Qualitative

Measureable/Quantitative

Determinants of Economic Output (non-exhaustive)



Utilized in GDP Model

Included in Preliminary GDP Model, Discarded

Other Components of GDP

Fixed Effects Model

Fixed Effects Model

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

$$i = 1, \ldots, 48 \ (state)$$
$$t = 1970, \ldots, 2010 \ (year)$$
$$k = 8$$

Where *i* and *t* index states and years, such that y_{it} is the dependent variable of interest, Gross Domestic Product, in state *i* in year *t*, β_0 is the constant *y* intercept across all states, *X* is a *k* x 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.

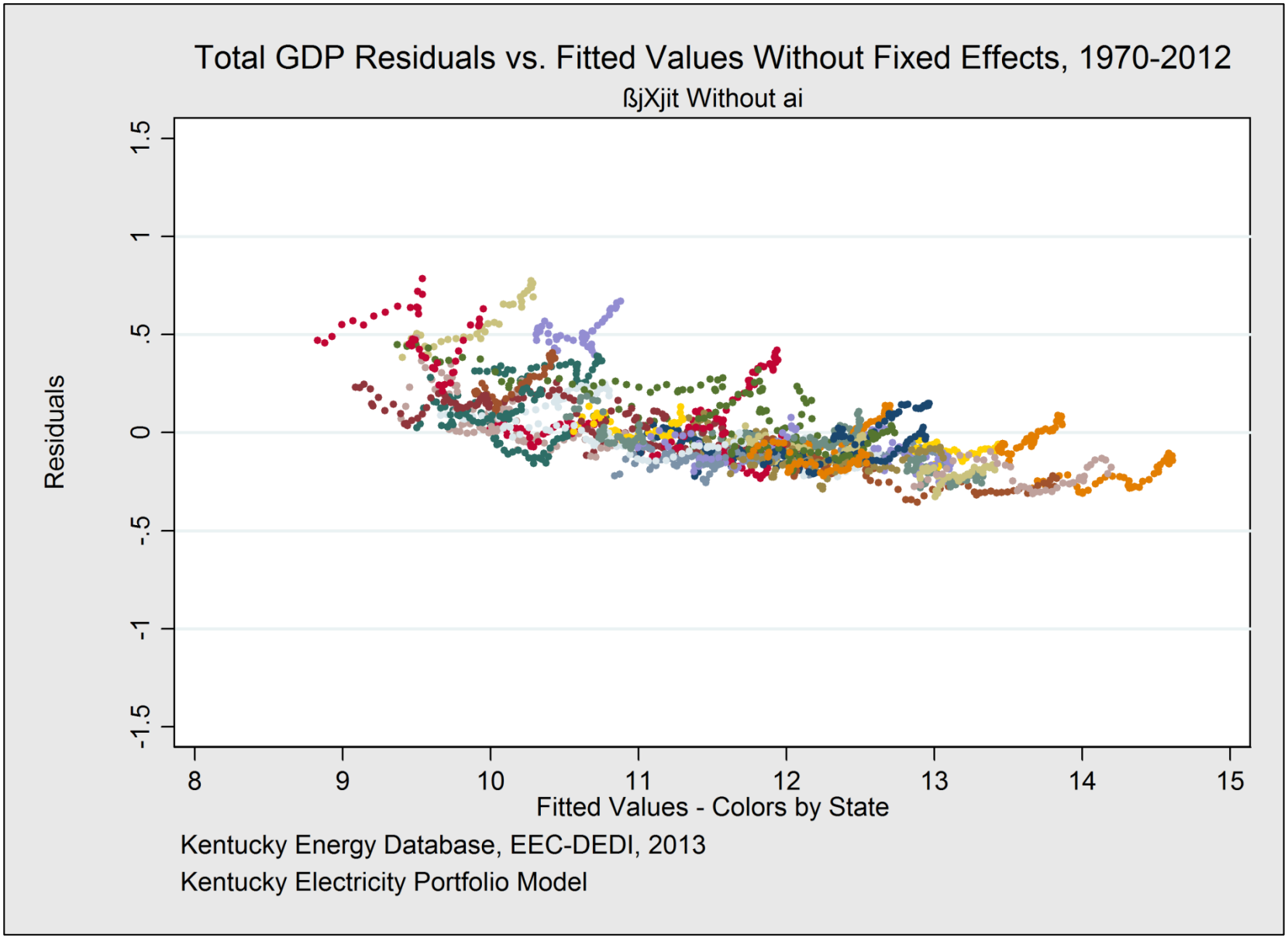
Fixed Effects Model

This model uses a statistical analysis technique called multiple regression of panel data with fixed effects, which builds upon Ordinary Least Squares (OLS) regression by isolating the time-independent constant difference in Gross Domestic Product (y_{it}) between cross-sectional units (states or *i*) that are correlated with the explanatory variables (X_{jit}).

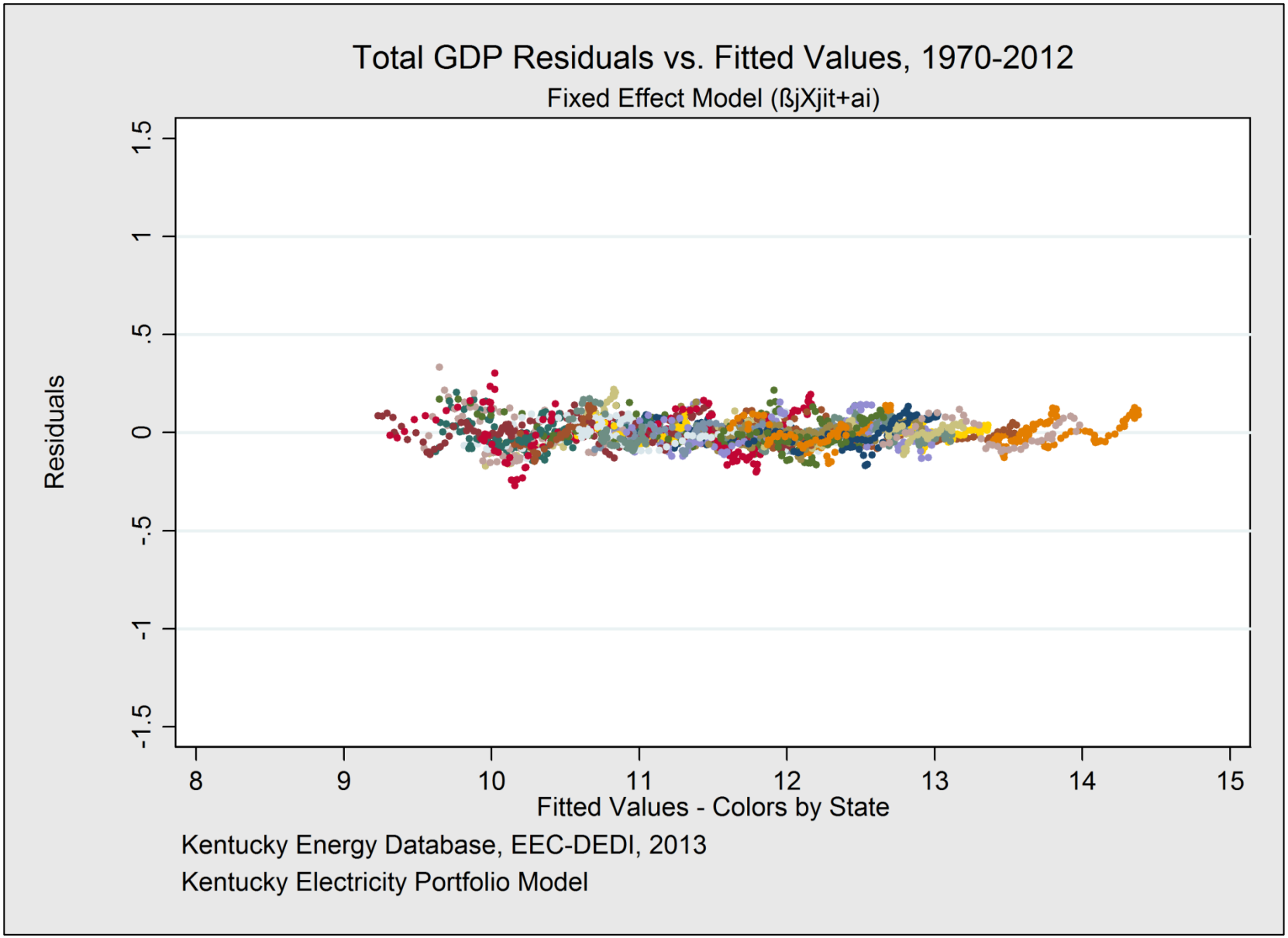
A fixed effects model specifically assumes the existence of unobserved time-invariant heterogeneity between states, often referred to as unobserved variable bias, which in addition to the included independent variables, are affecting the dependent variable (GDP). The fixed effects model then attempts to control for these missing or unobserved between unit (interstate) factors, the fixed effects (α_i), to isolate the specific net effect of the independent variables (β_j)on all cross-sections (nationally).

Therefore, as with OLS, the resulting coefficients are homogenous—uniform across all states and times. However, since a custom fixed effect for GDP is calculated for each state, GDP forecasts are significantly improved versus OLS by adjusting to best fit the model to historical data.

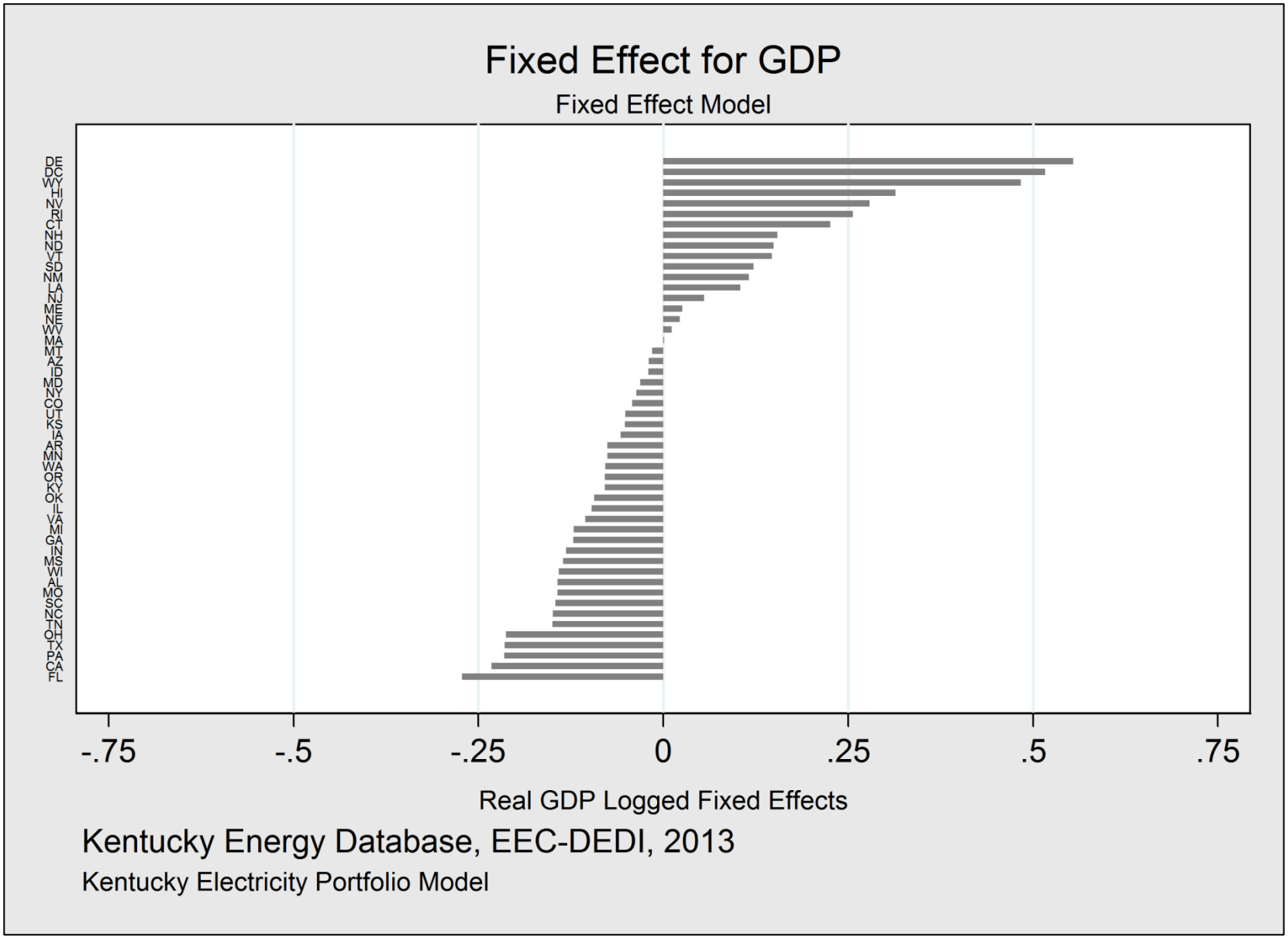
Residuals vs. Fitted Values (without Fixed Effects)



Residuals vs. Fitted Values (with Fixed Effects)

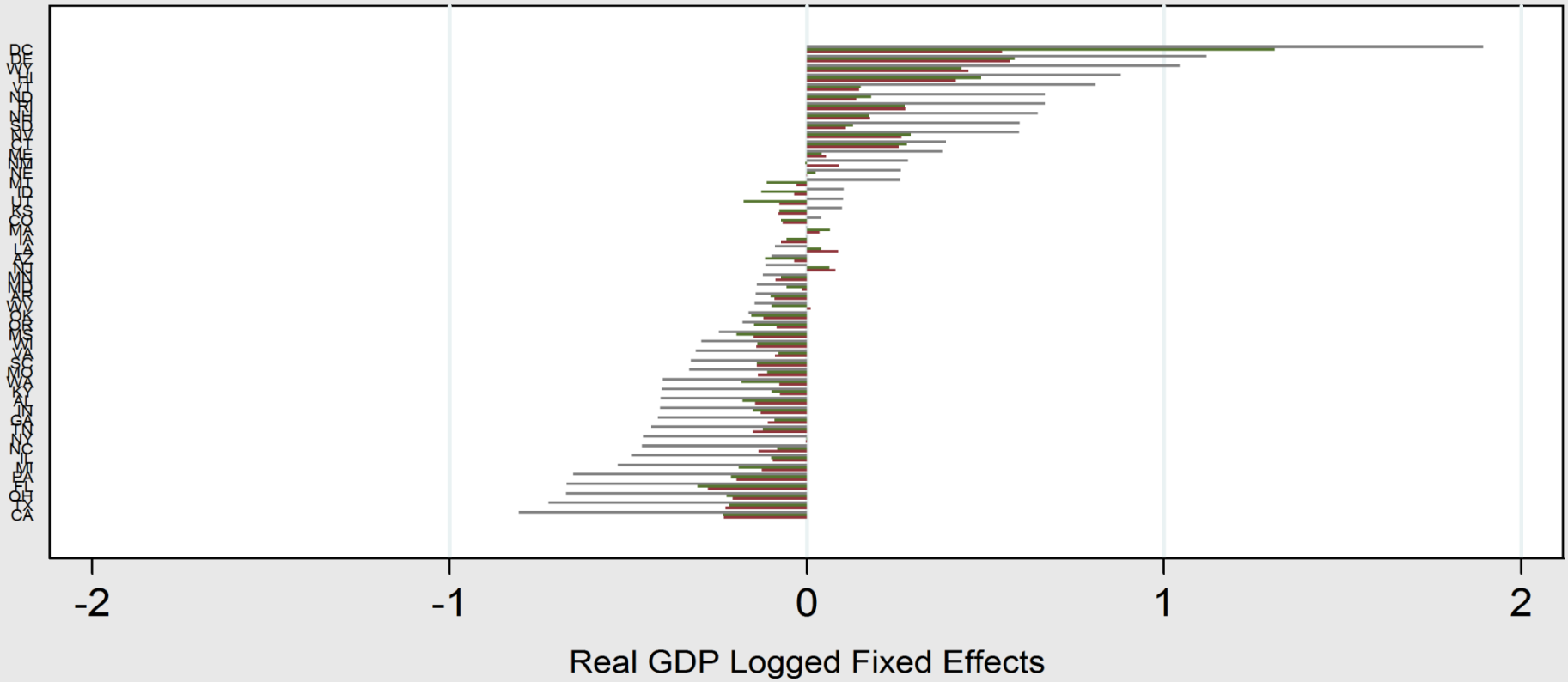


Fixed Effects for Demand (α_i)



Unobserved Variable Bias Explained by Education and Employment

Fixed Effect Model



Without Education Index and Percent Employed

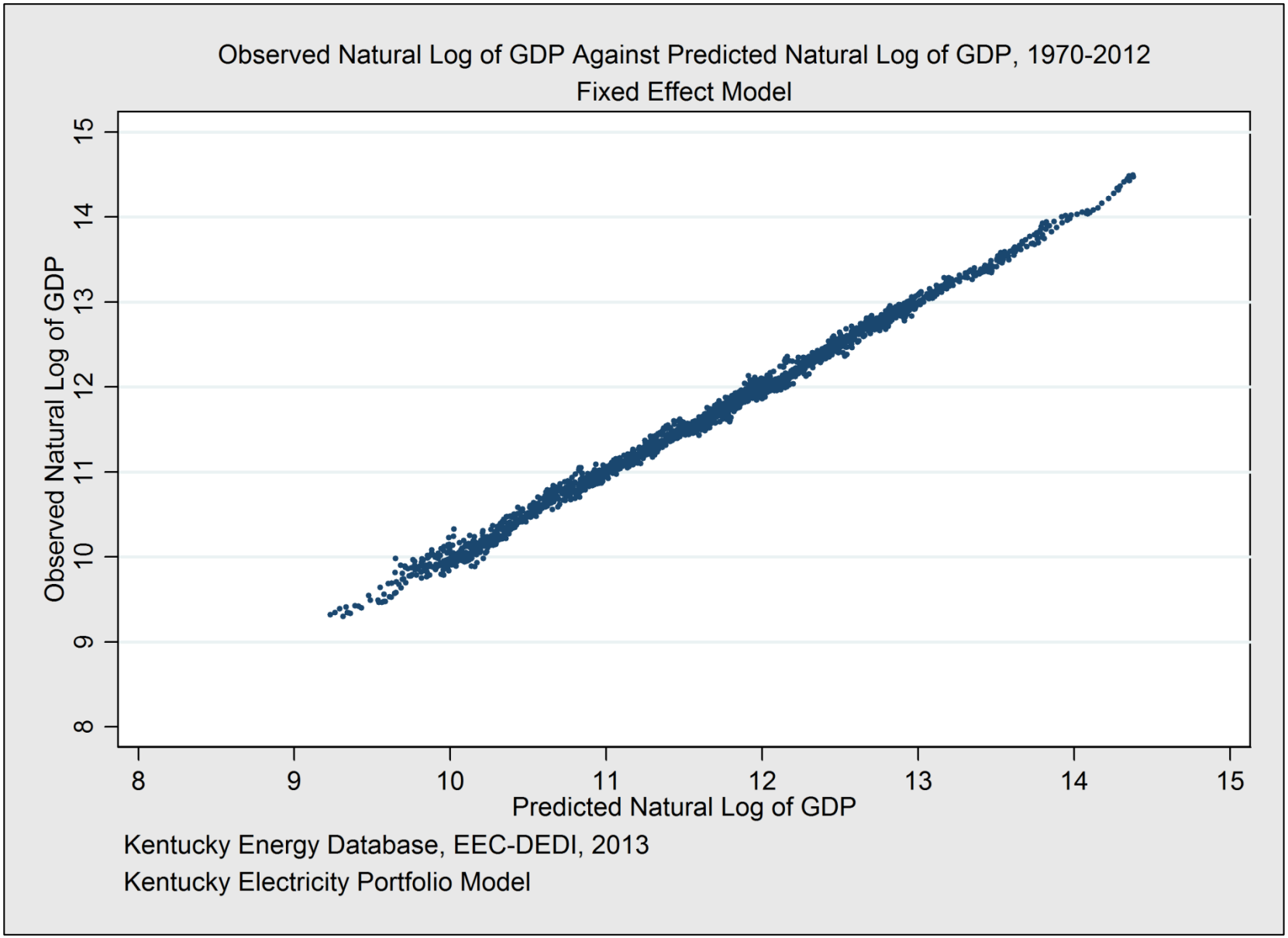
With Education Index

With Education Index and Percent Employed

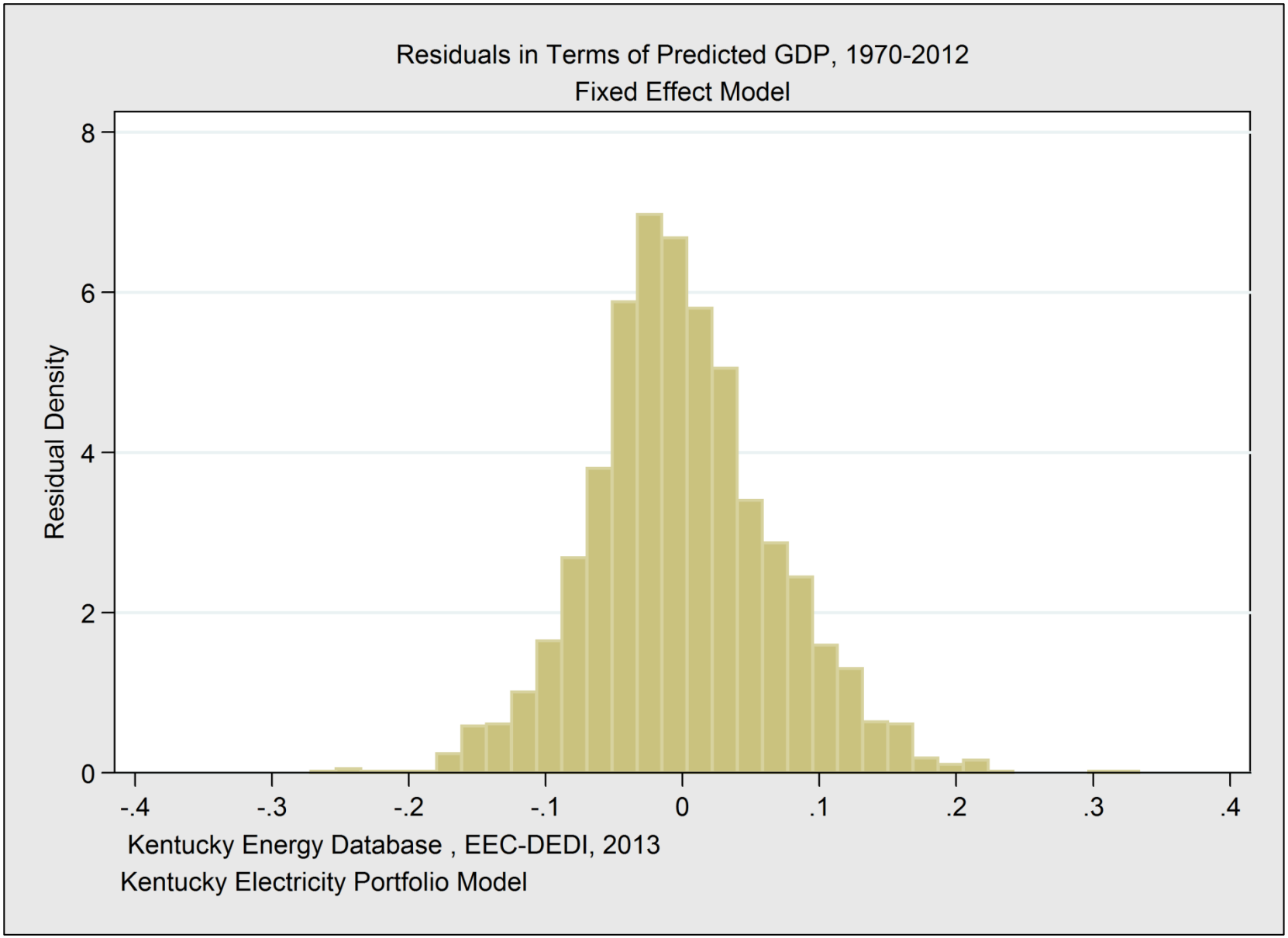
Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

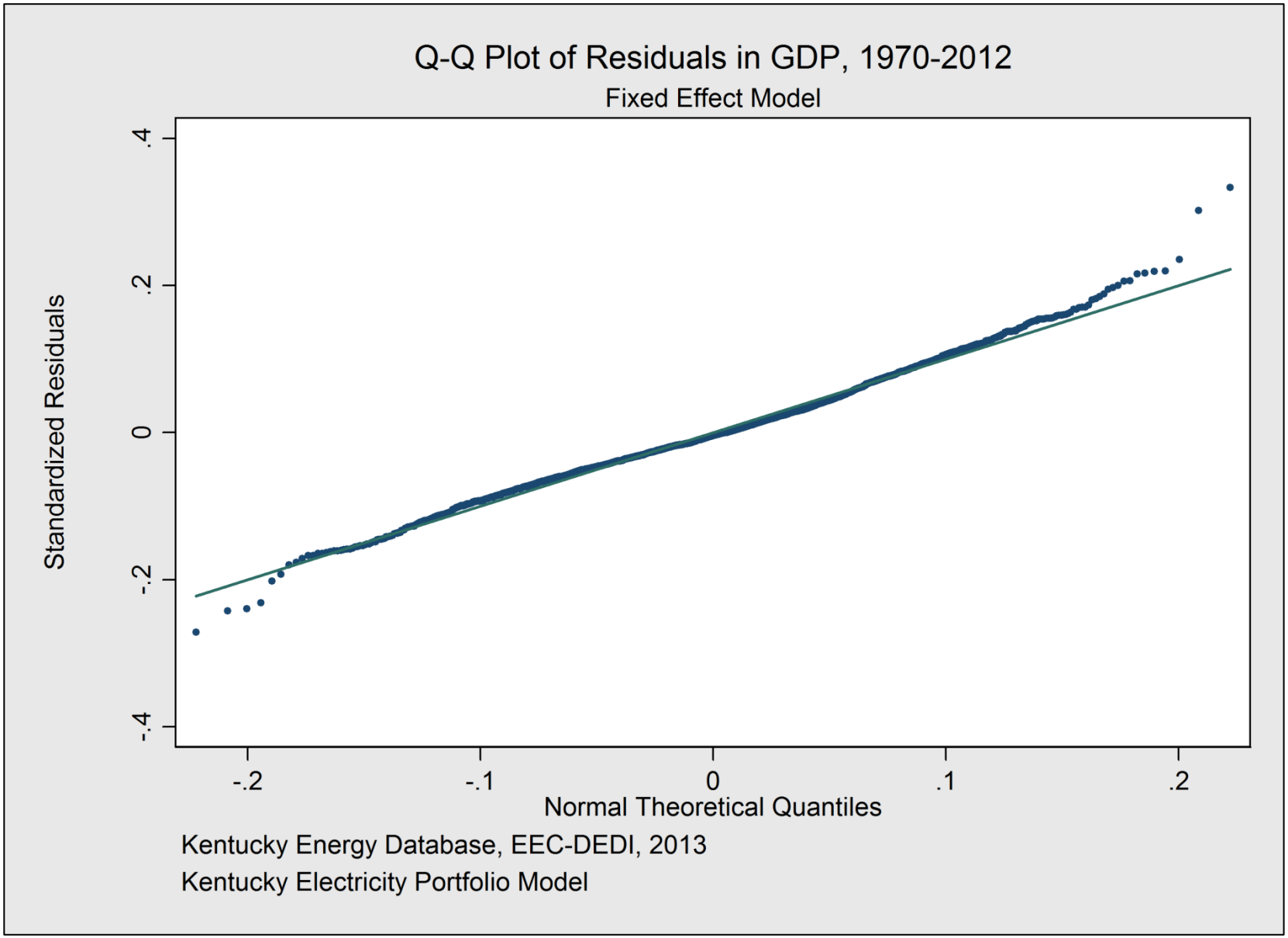
Observed vs. Predicted



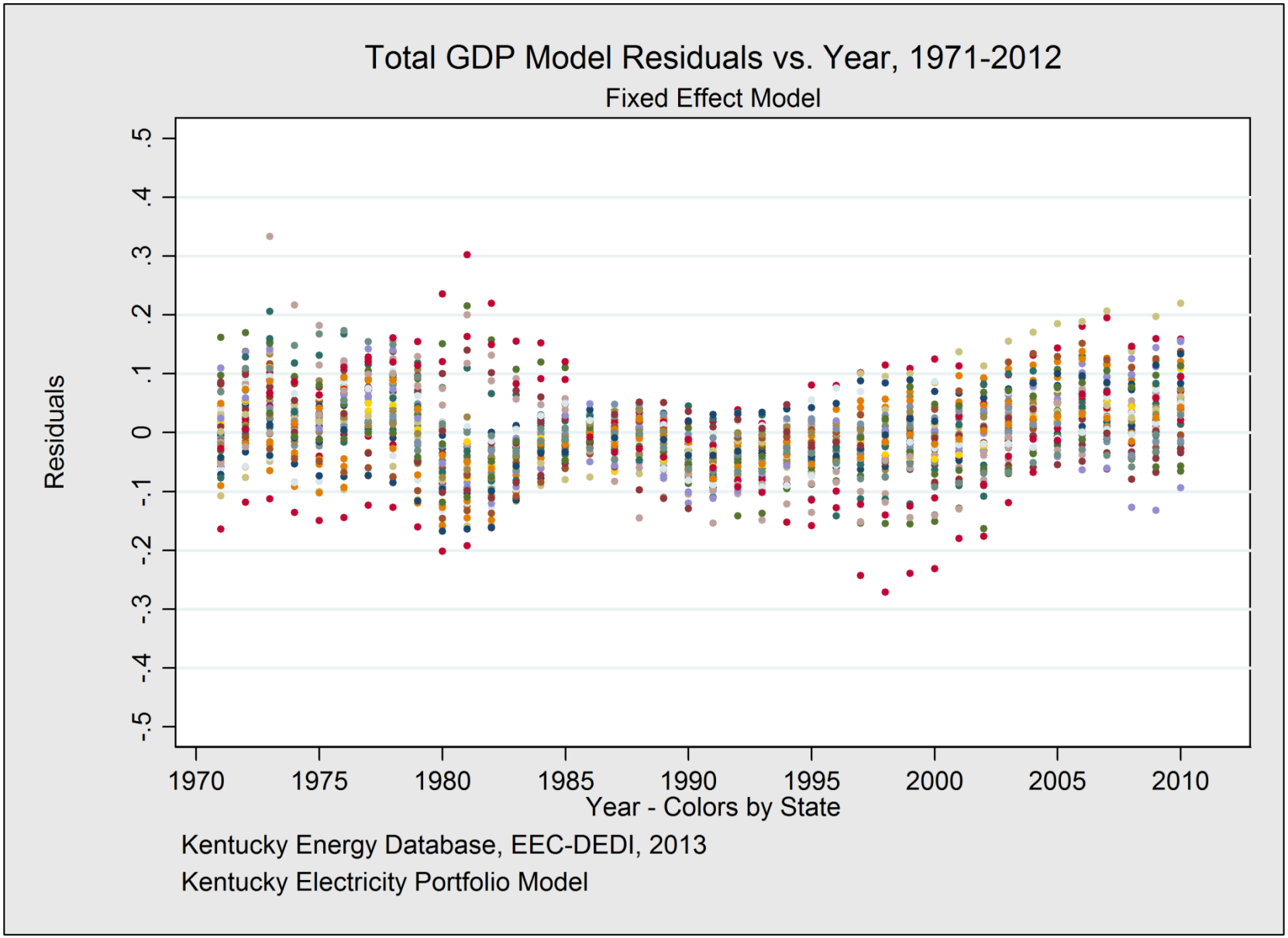
Distribution of Residuals



GDP Model Q-Q Plots

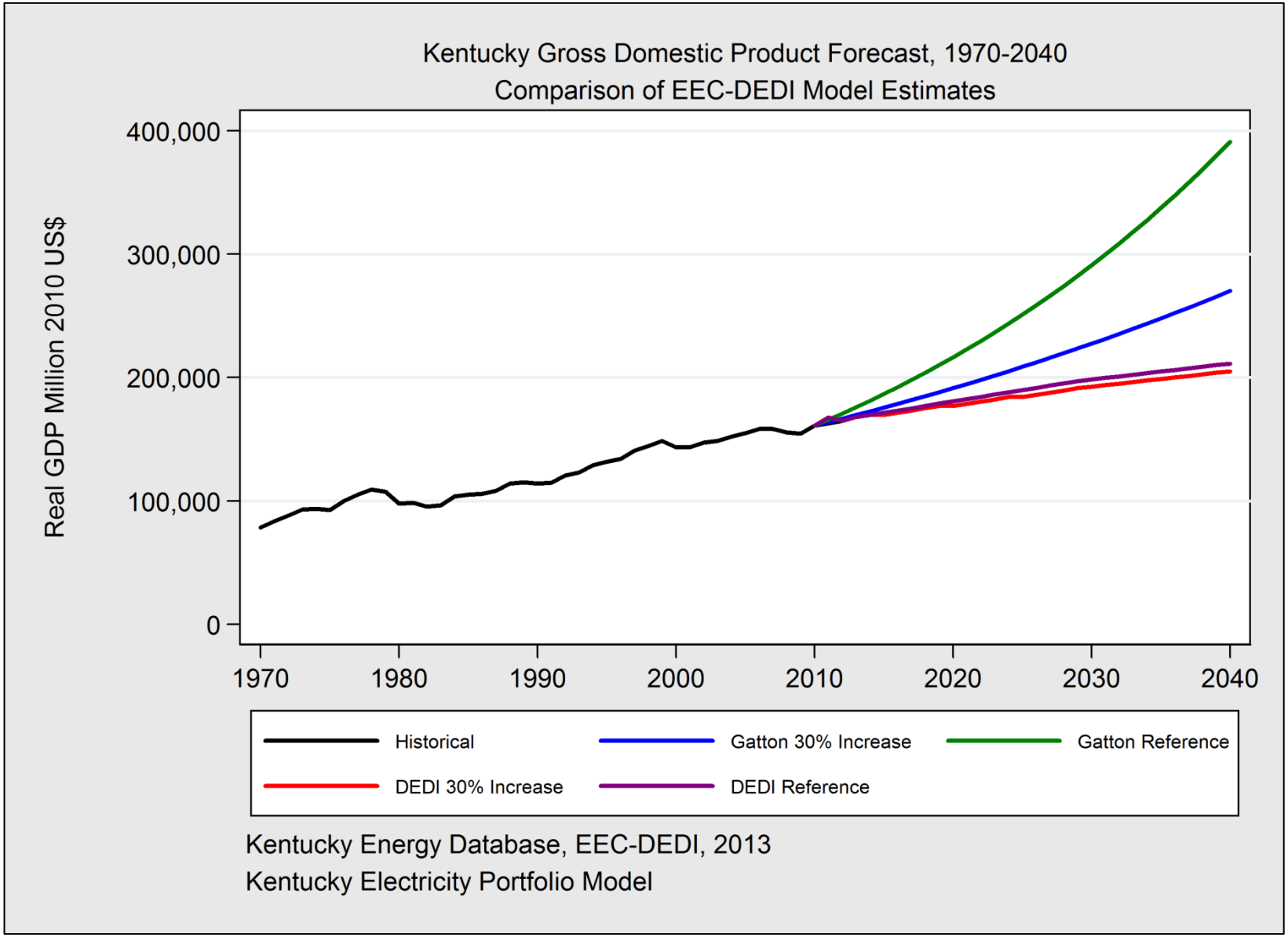


Residuals vs. Time



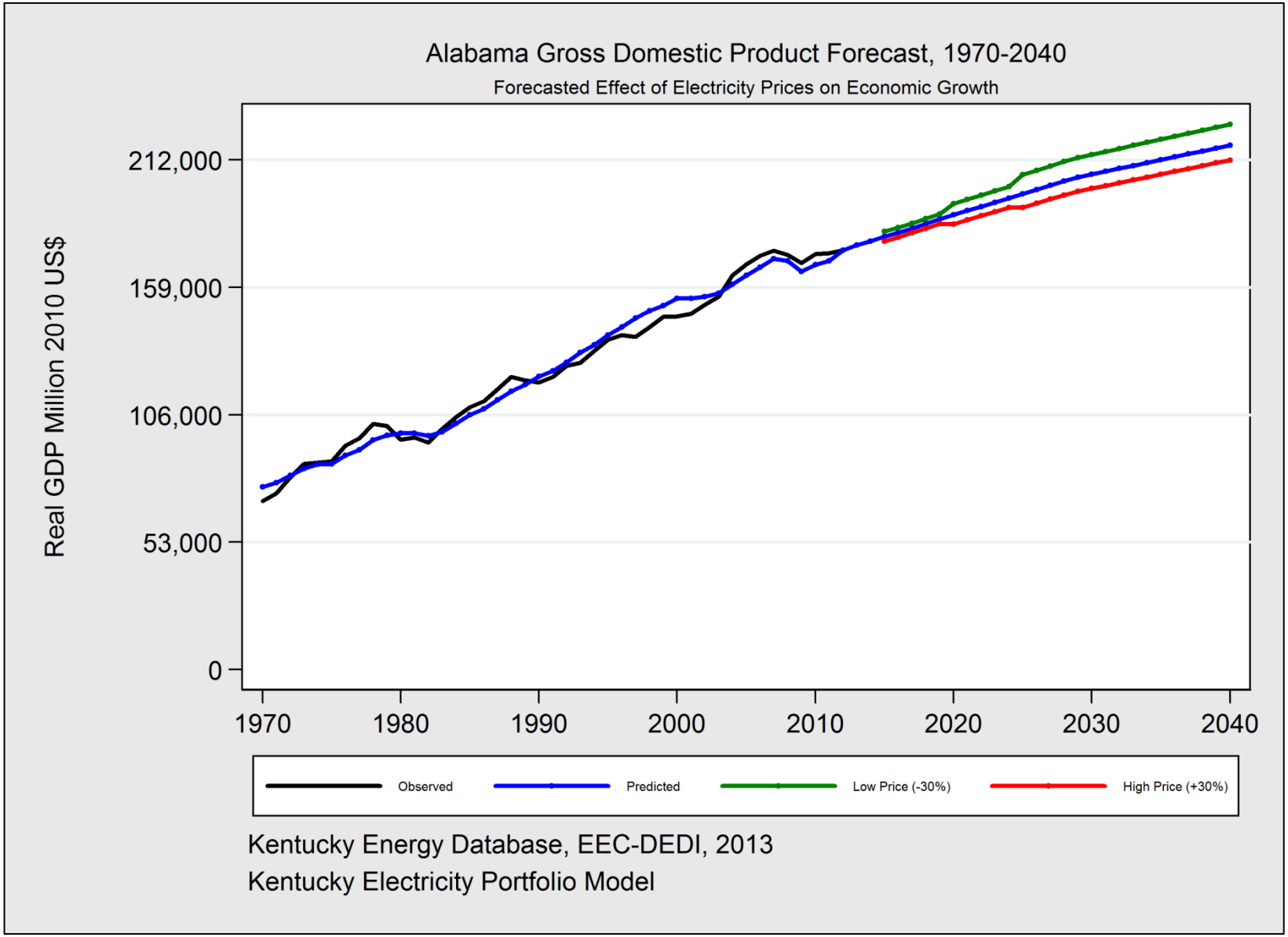
Comparison to Previous Research

Model Comparison



Model Validation by State

Model Validation



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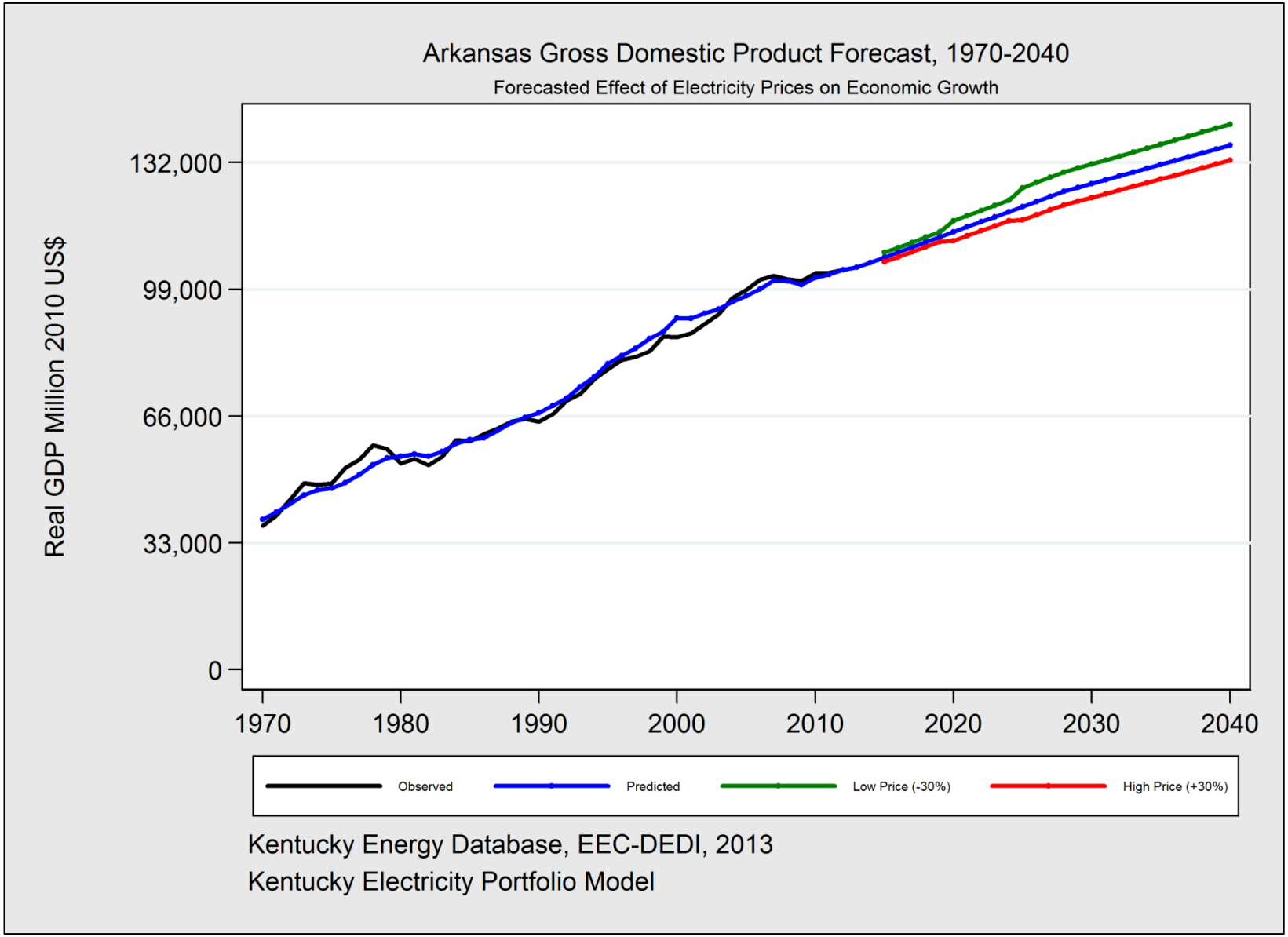

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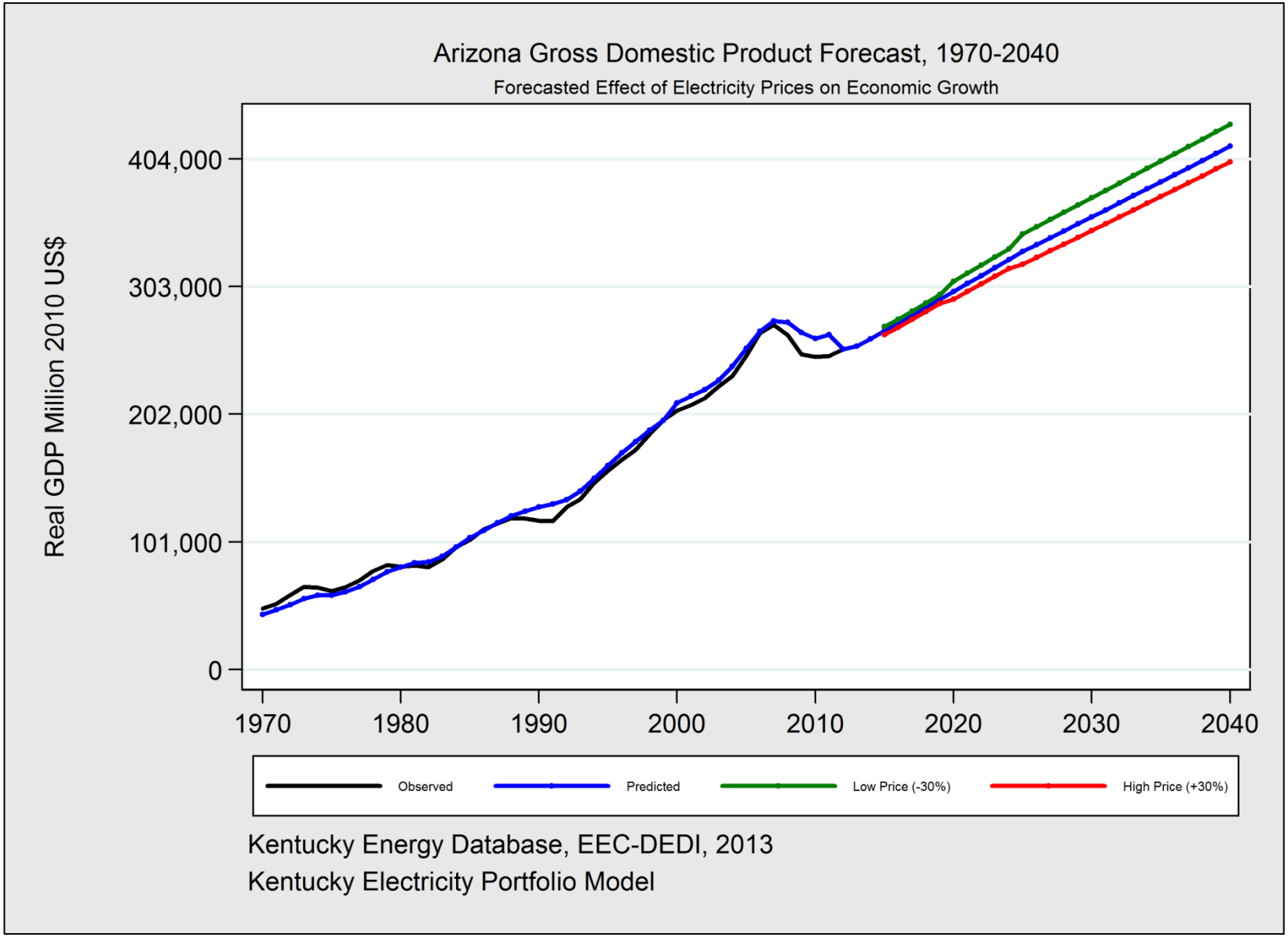

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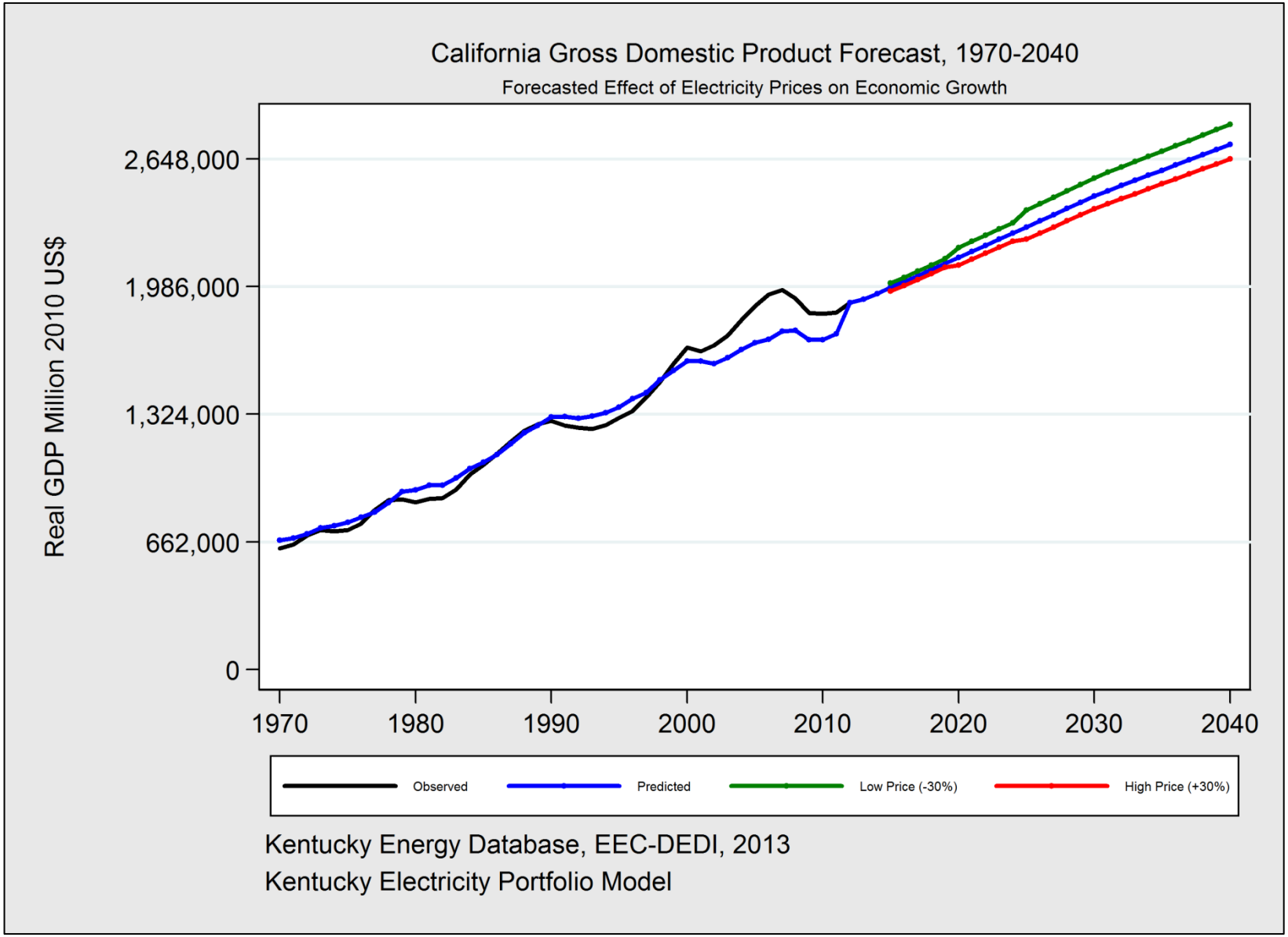

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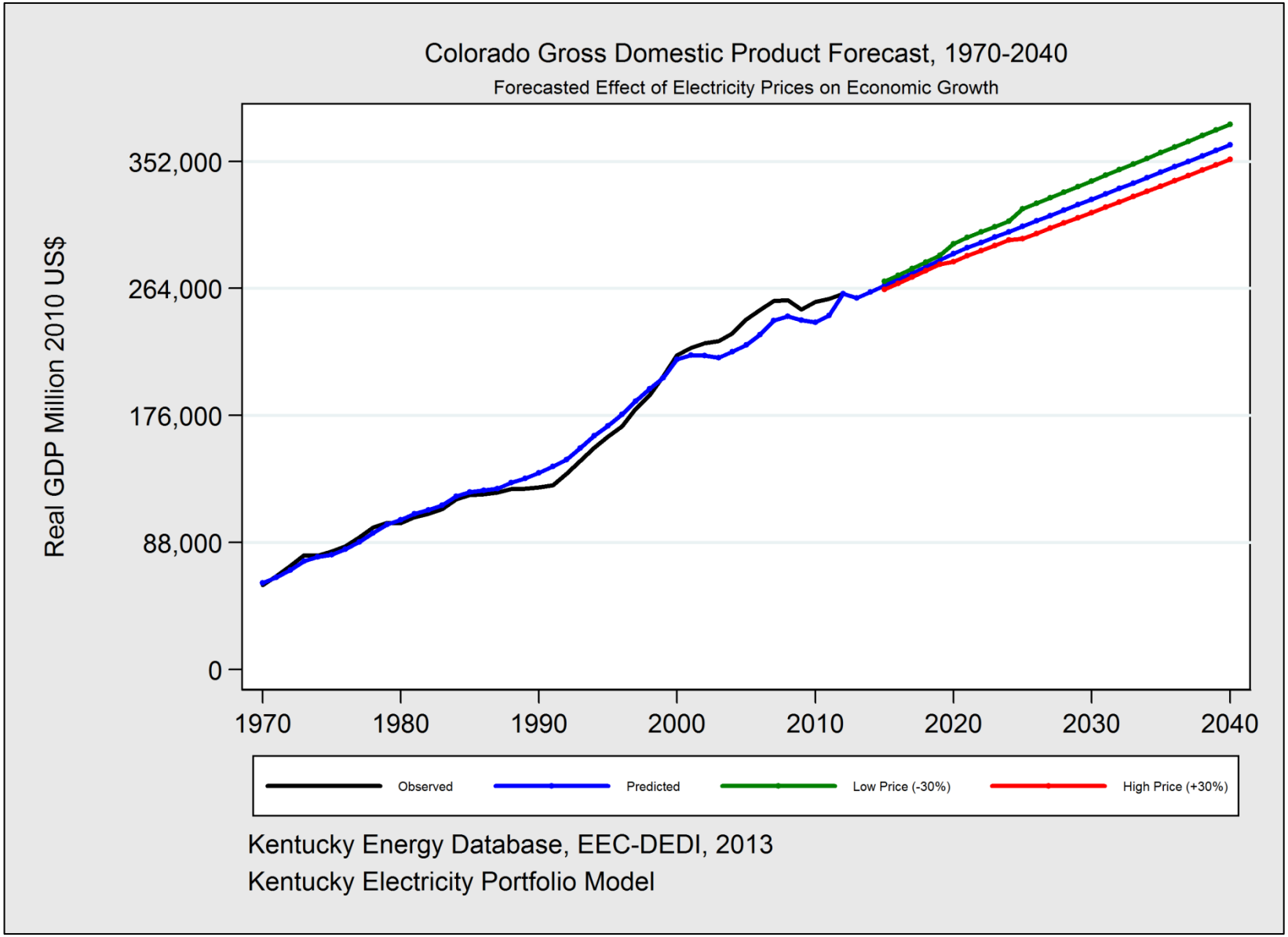

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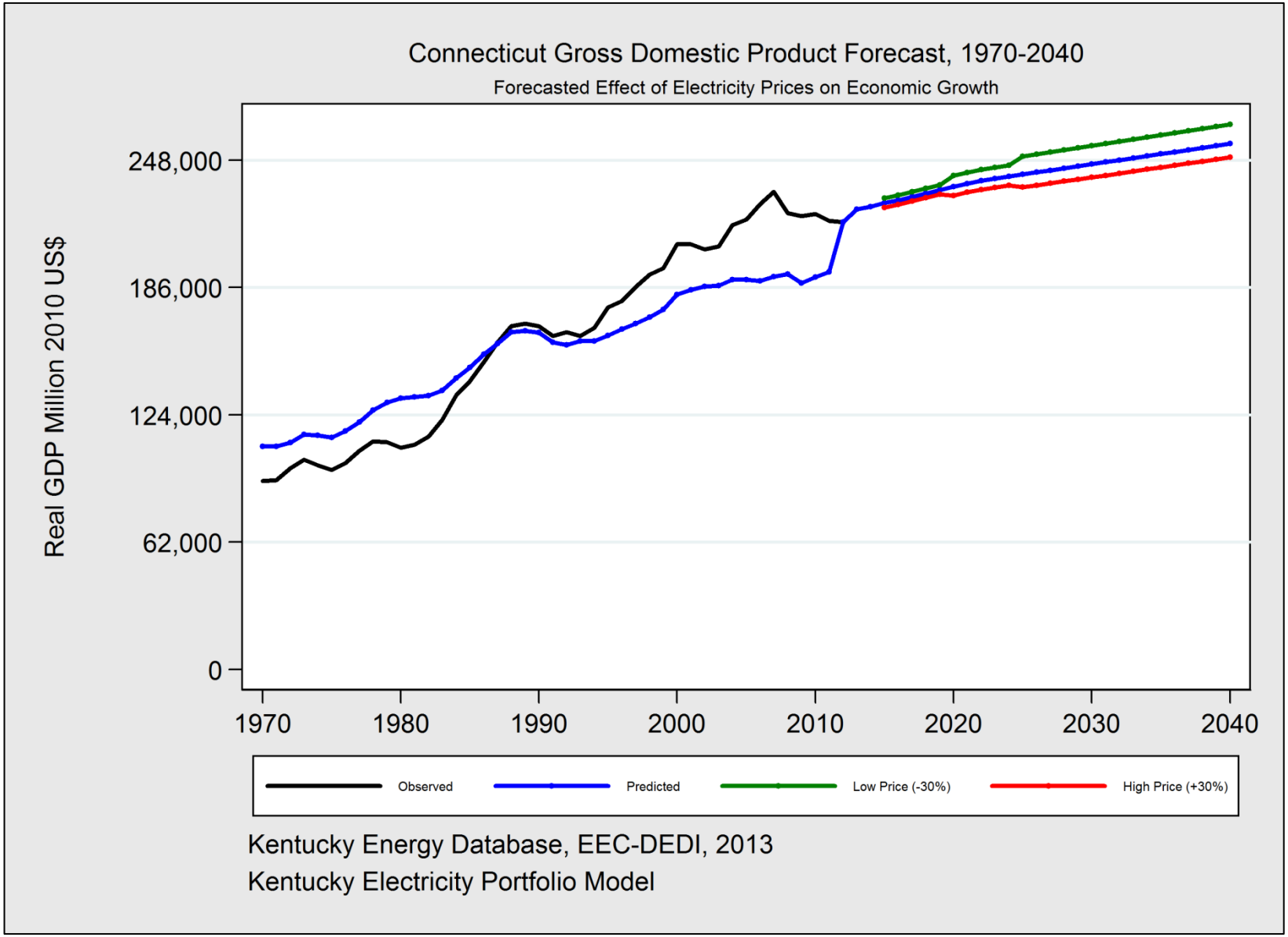

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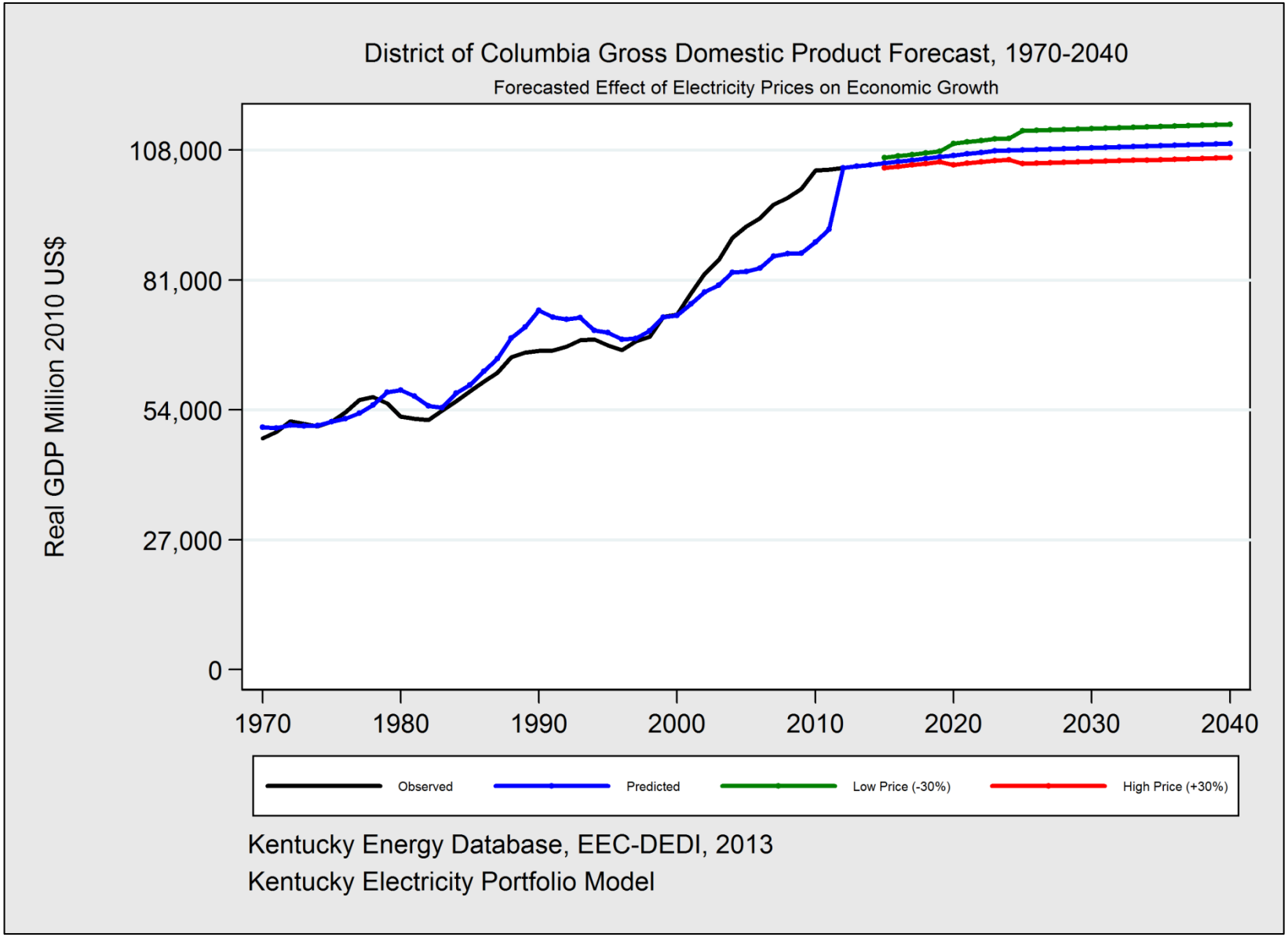

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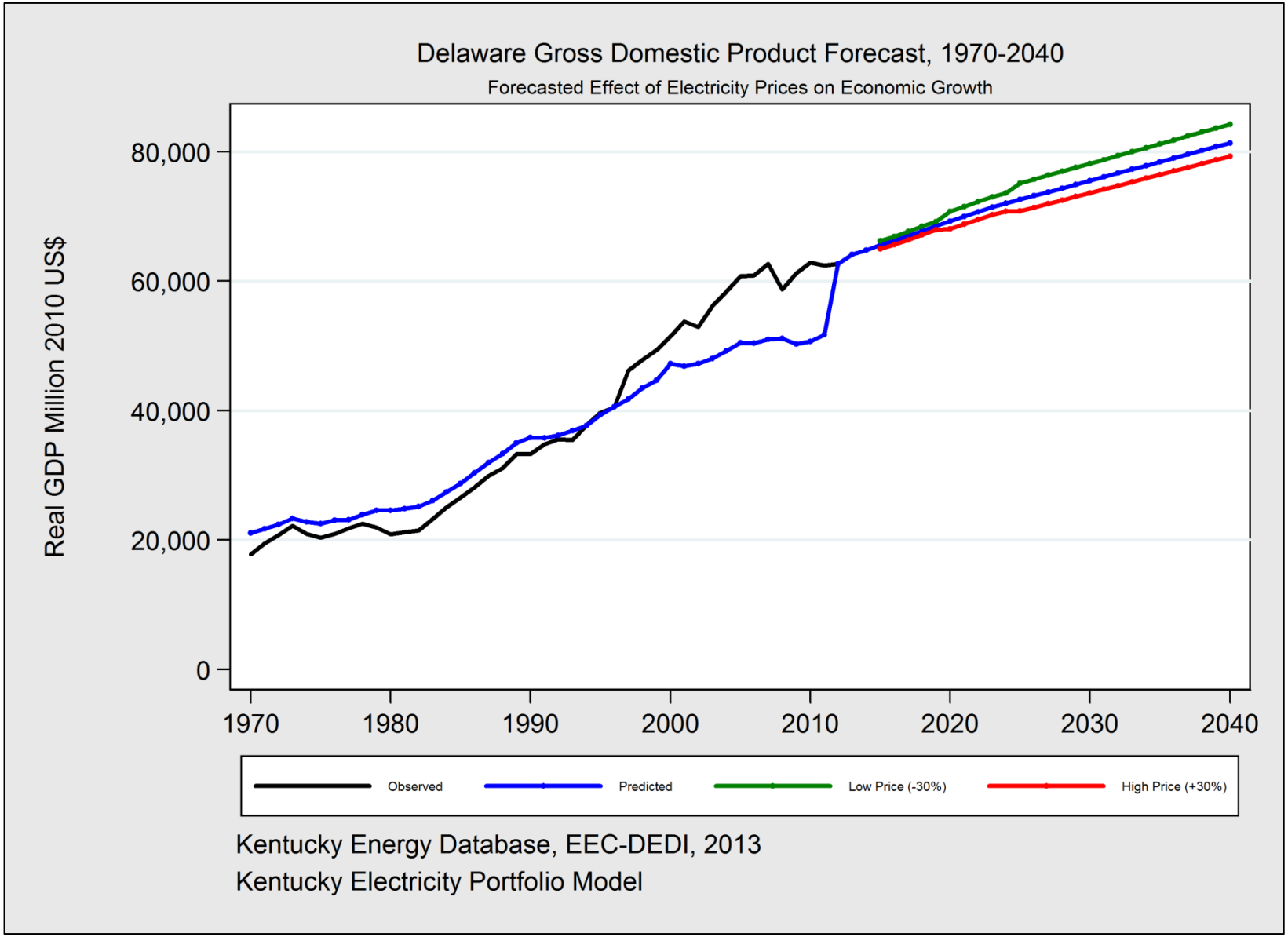

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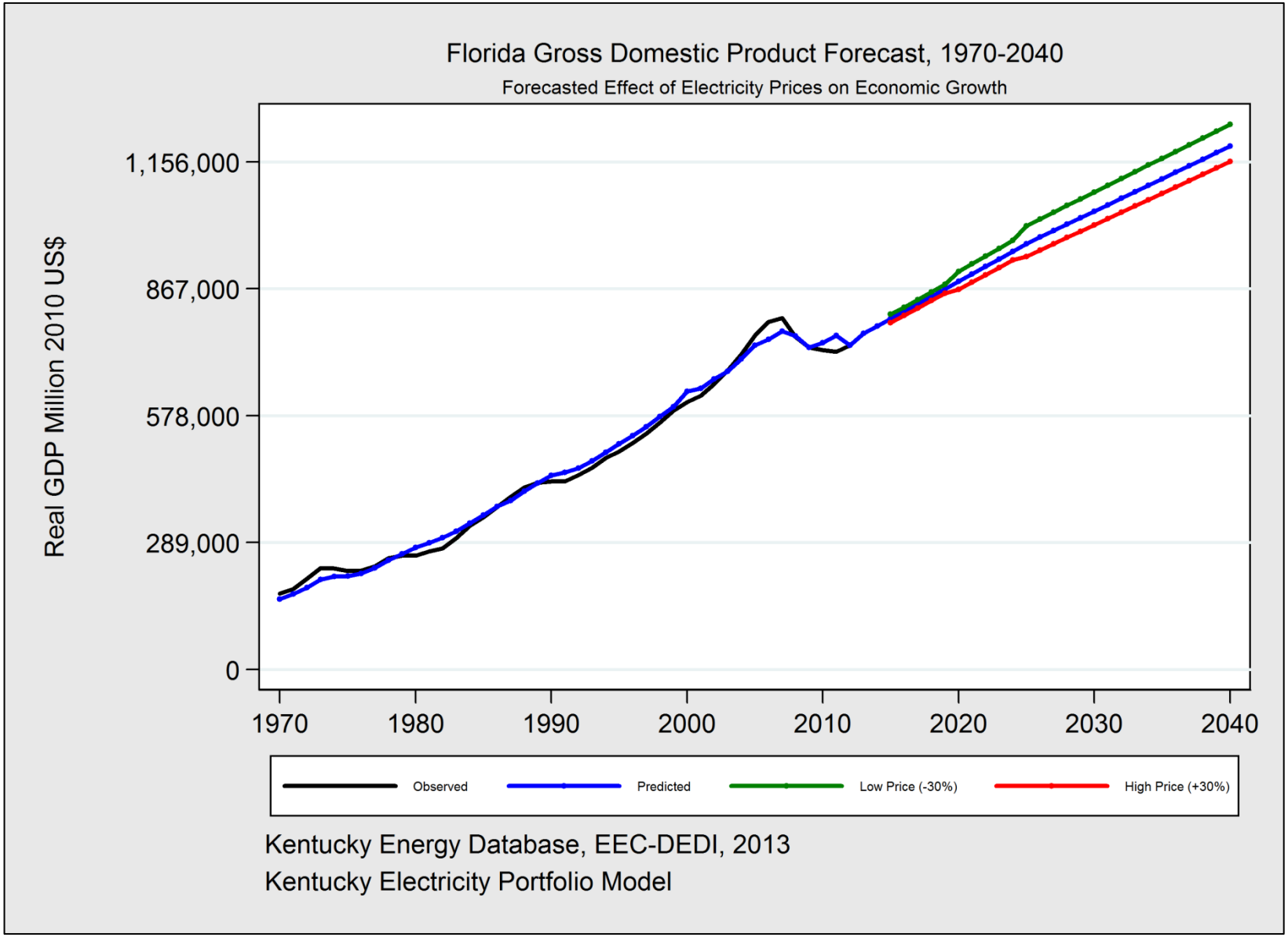

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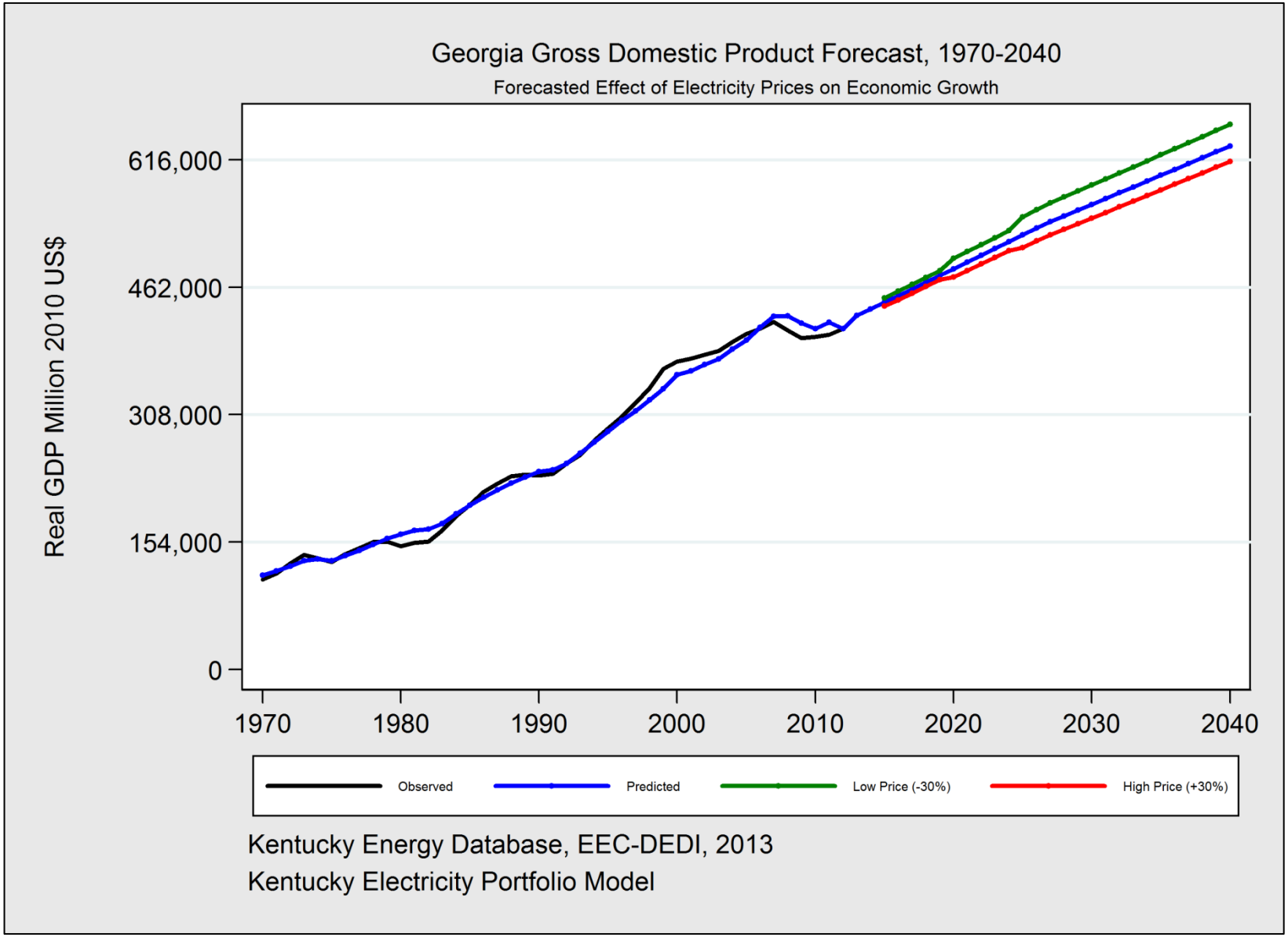

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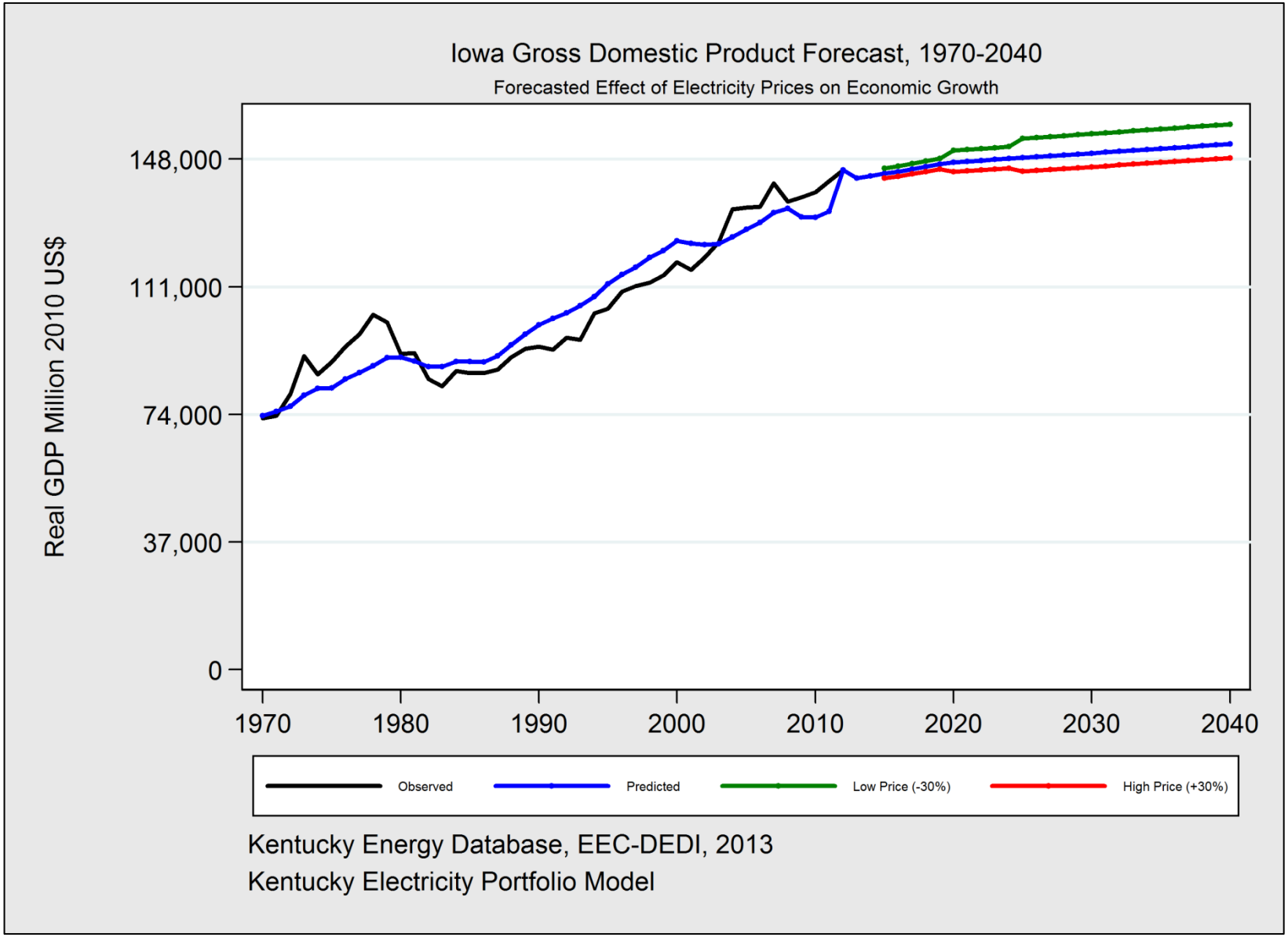

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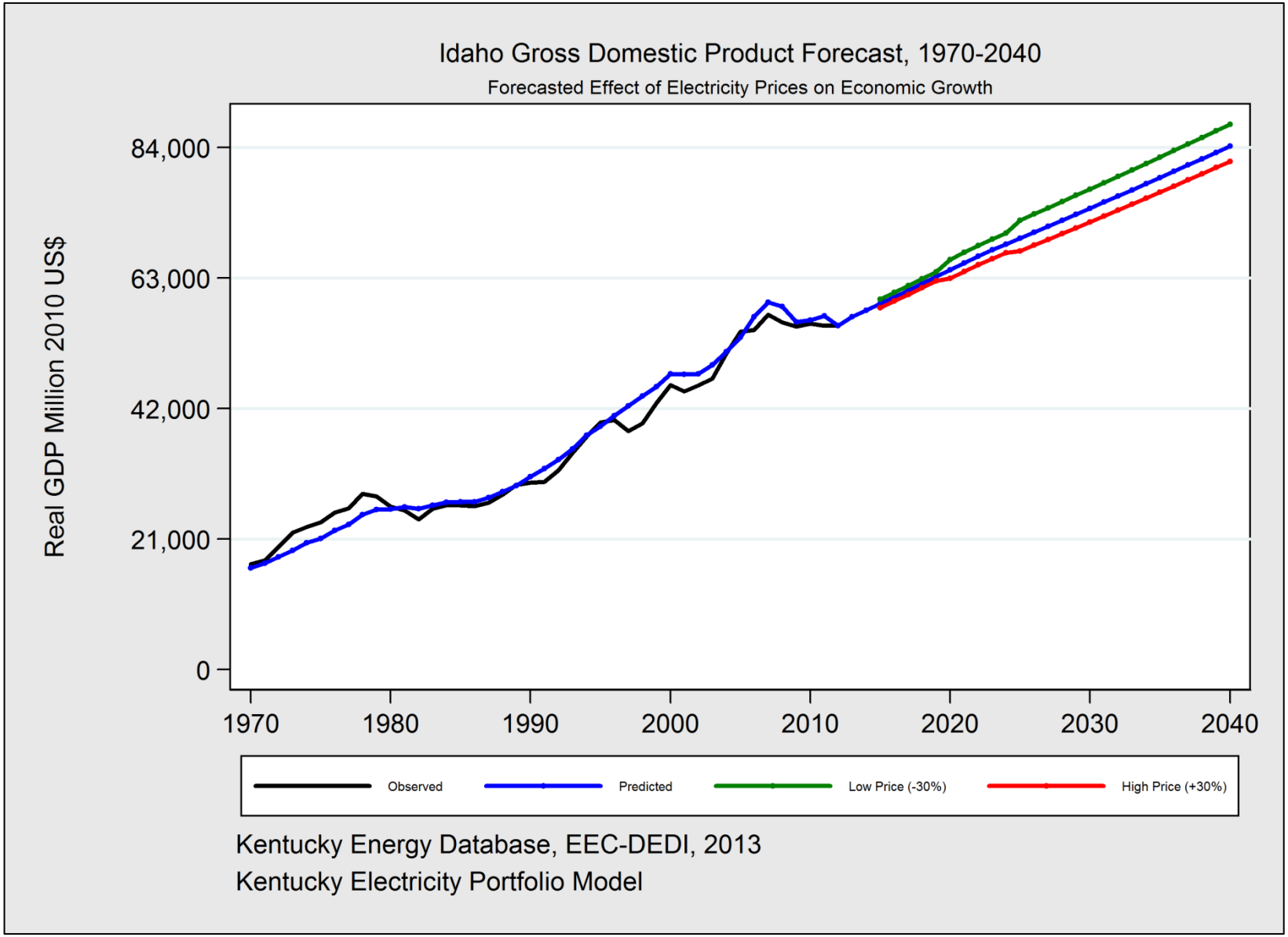

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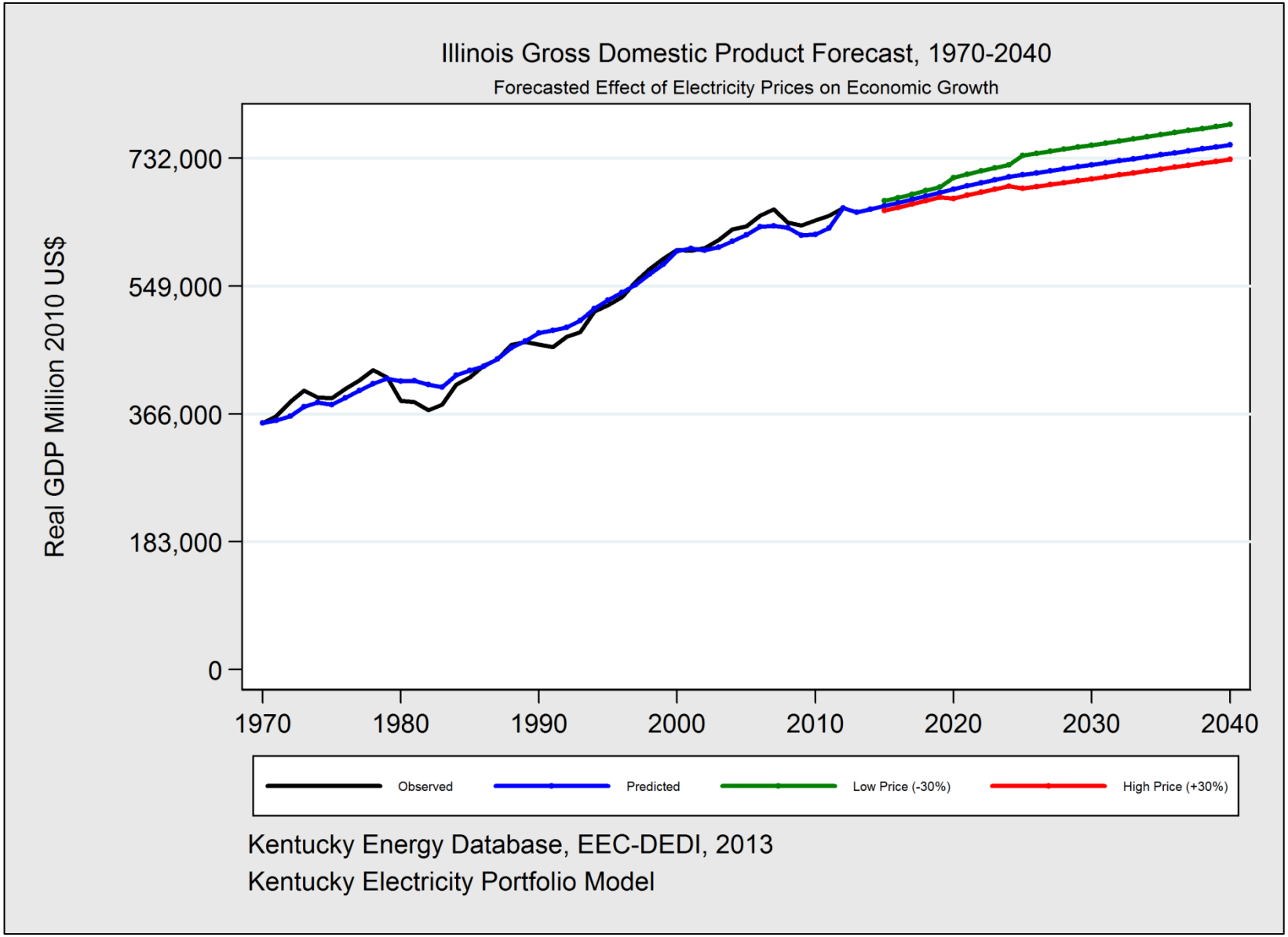

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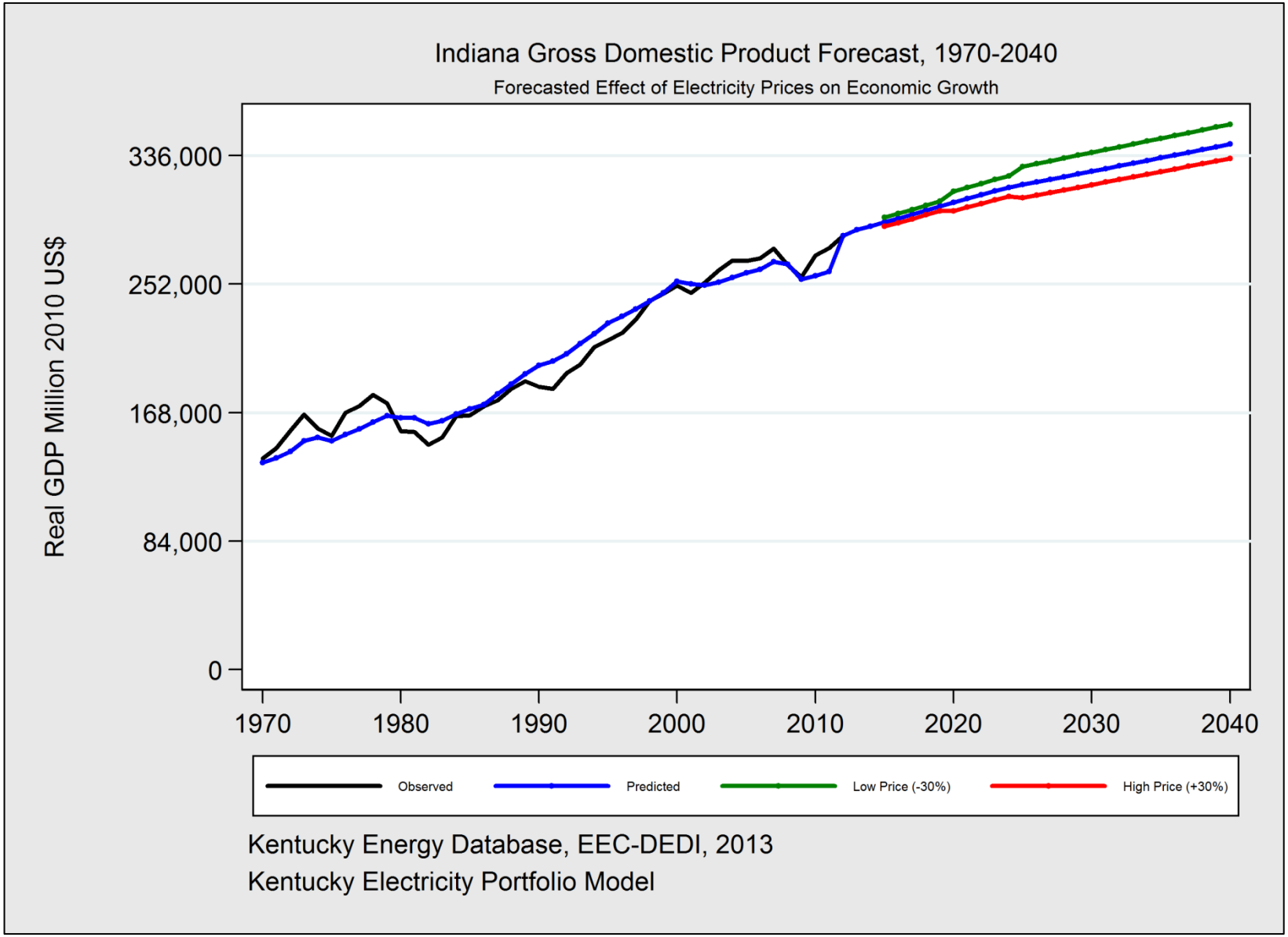

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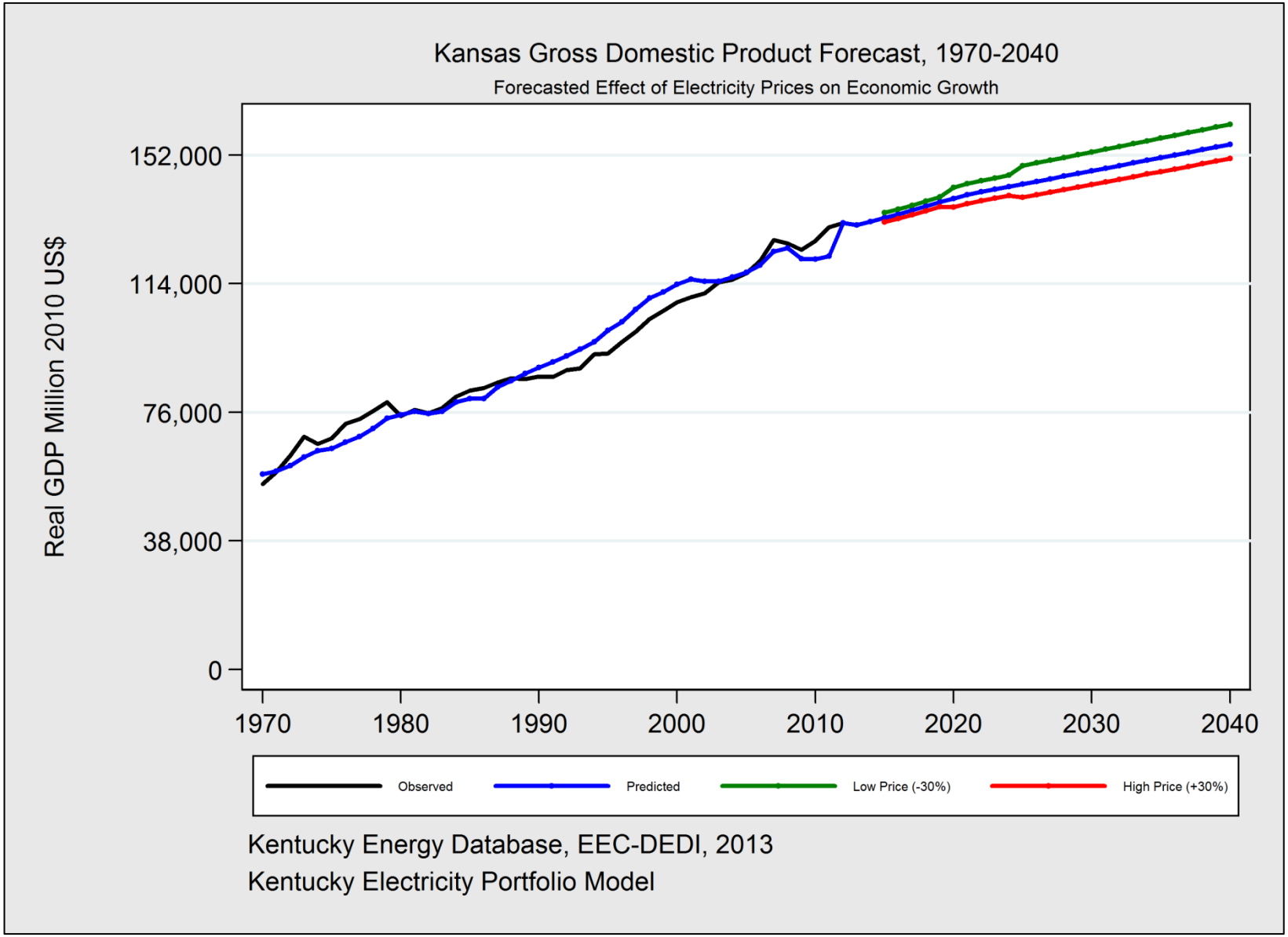

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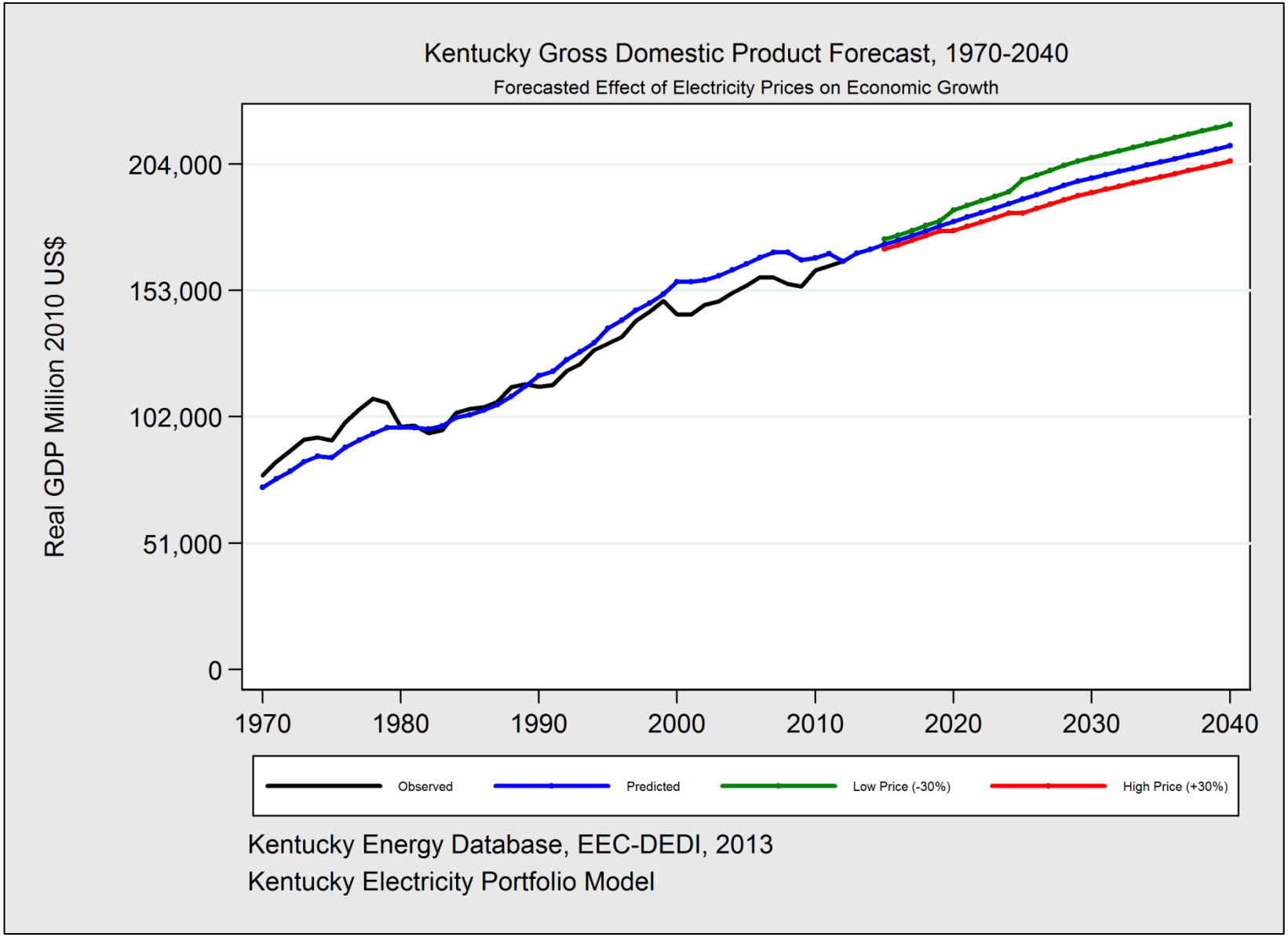

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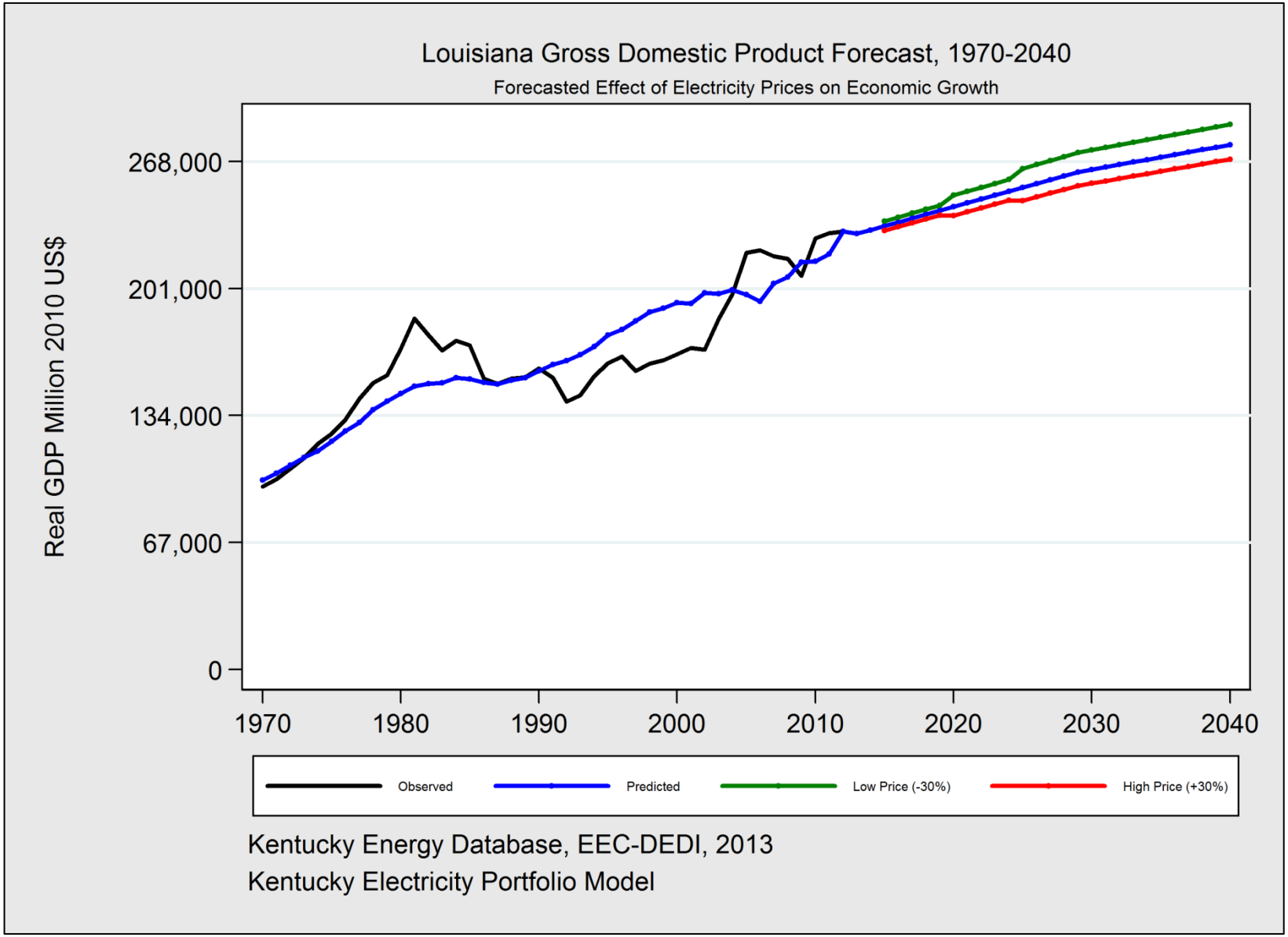

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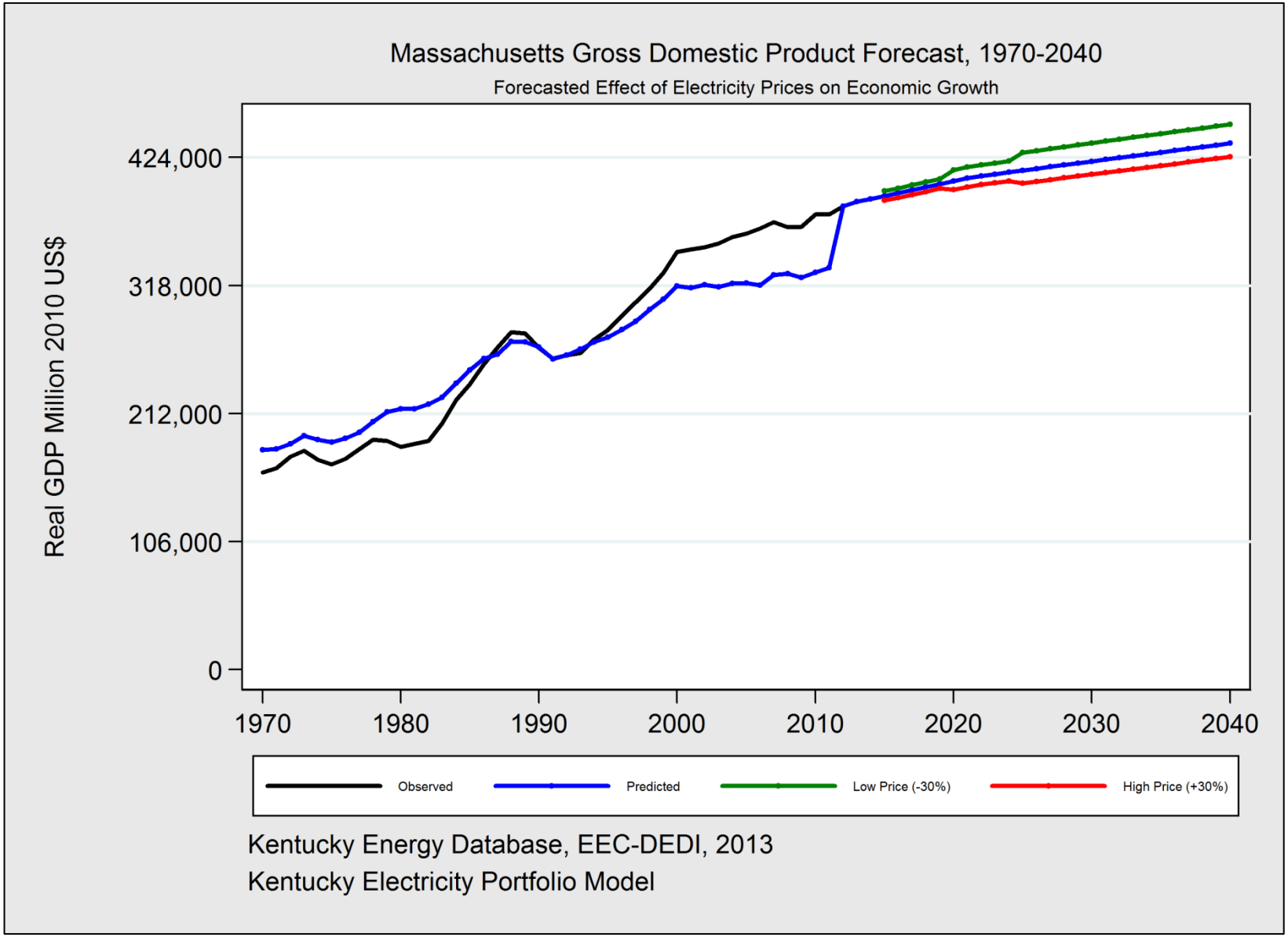

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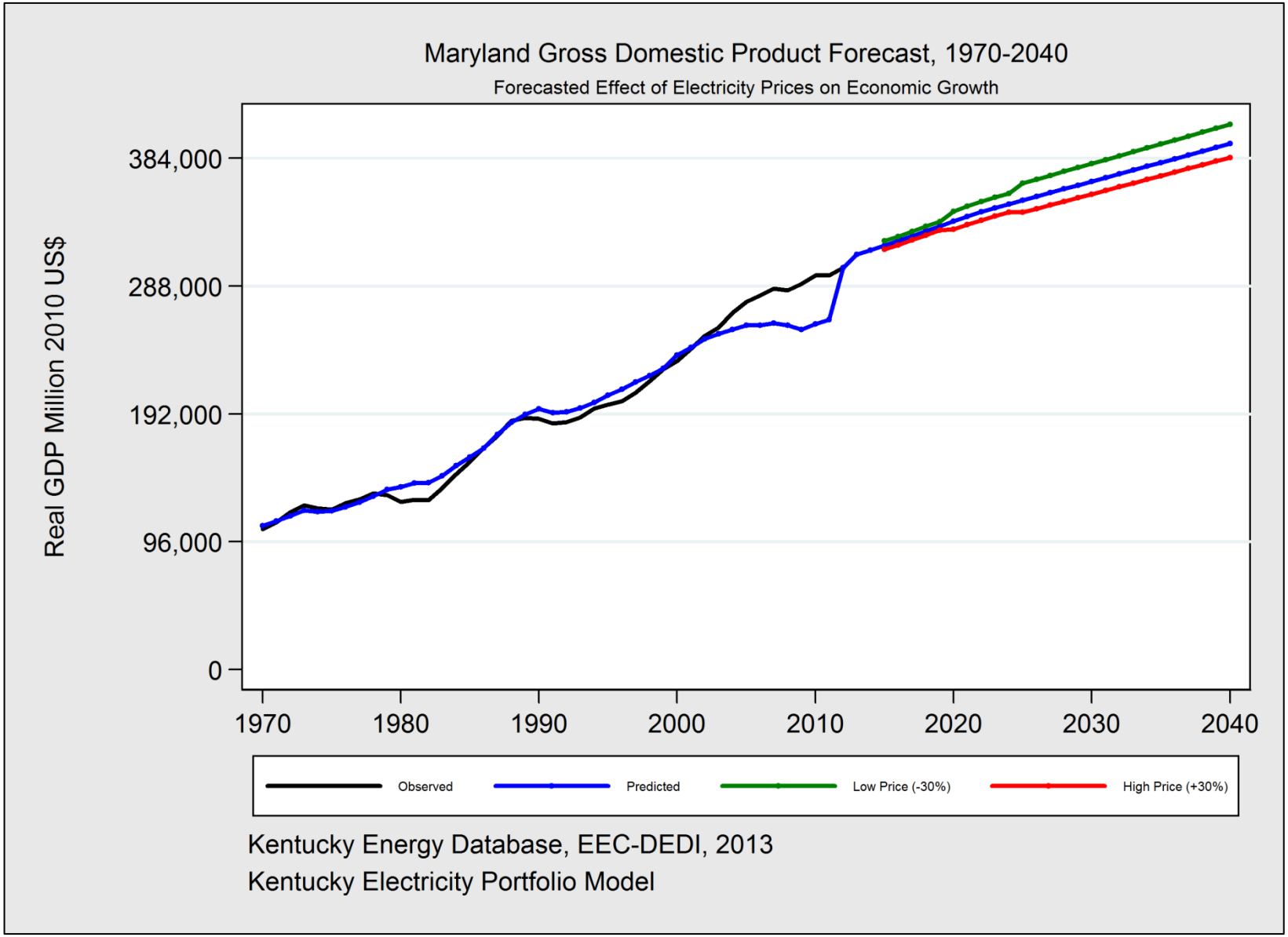

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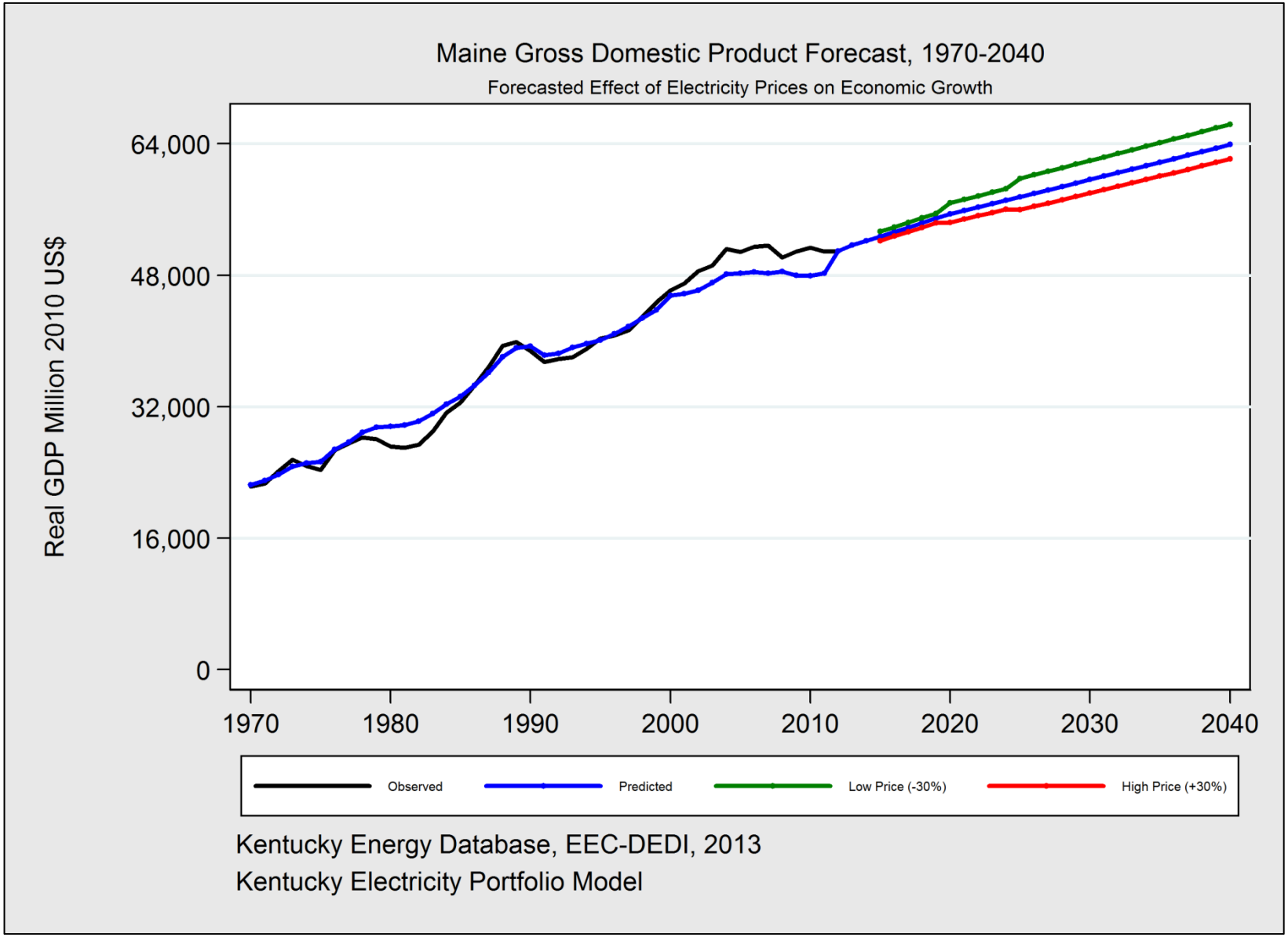

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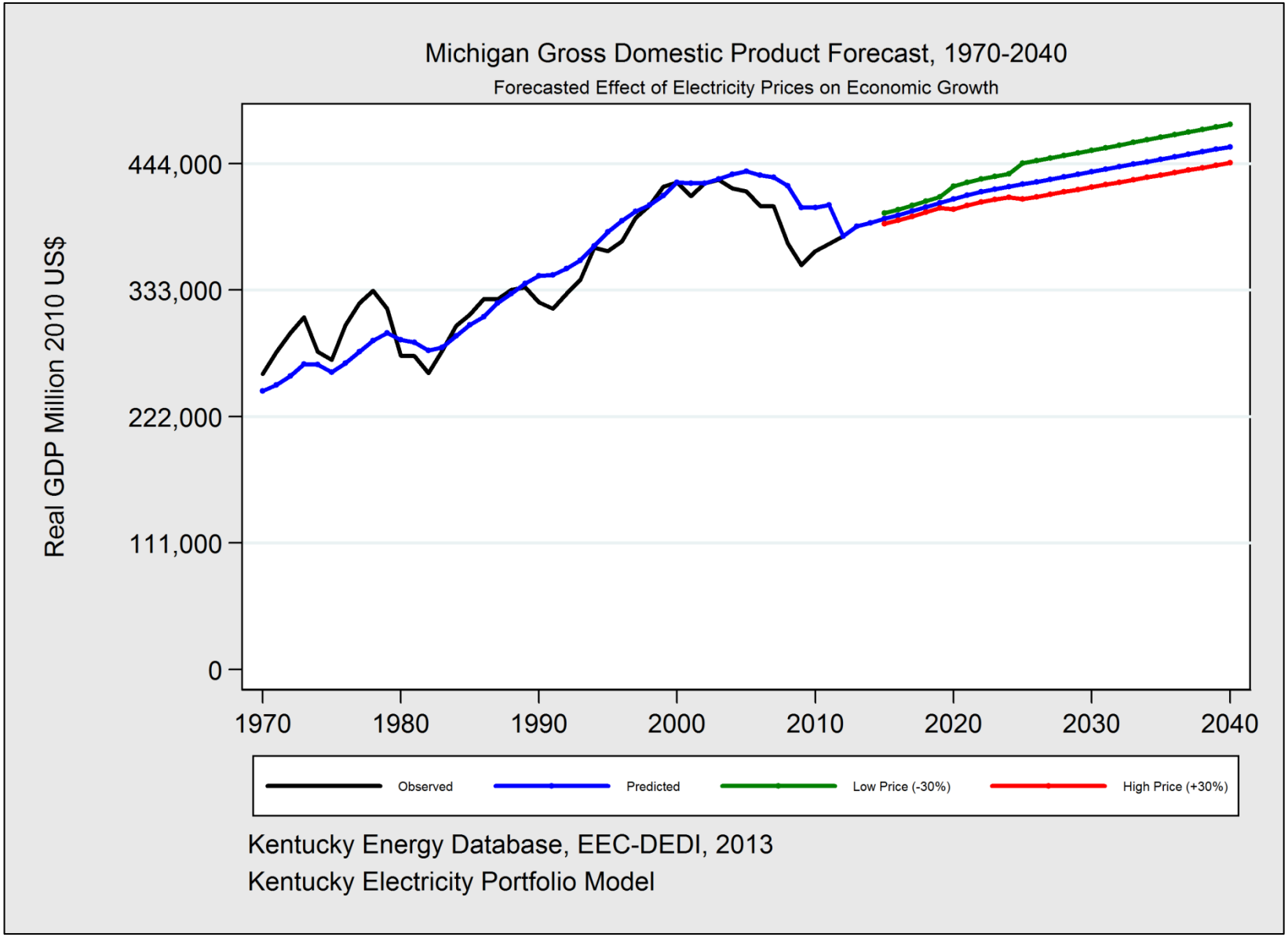

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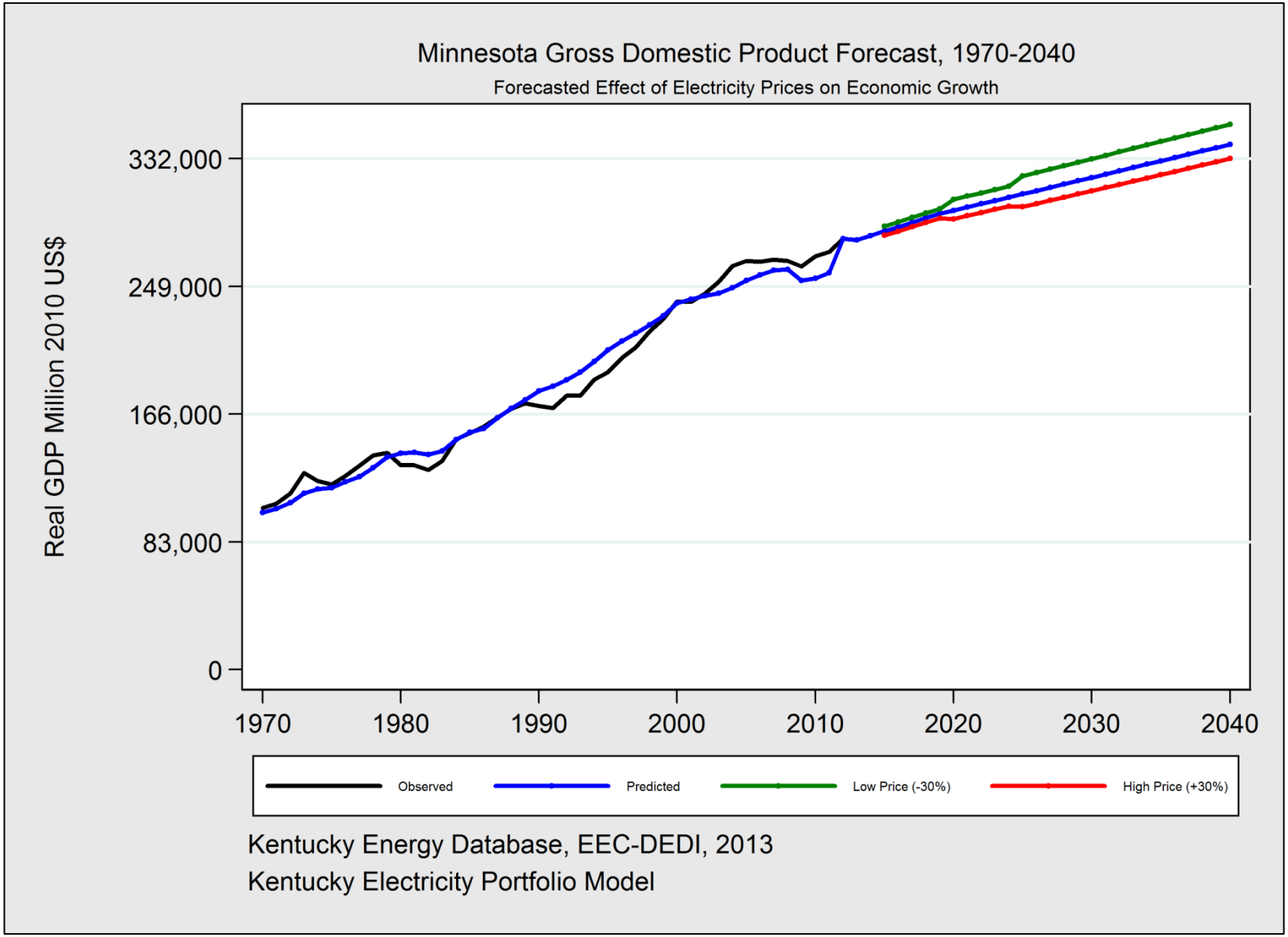

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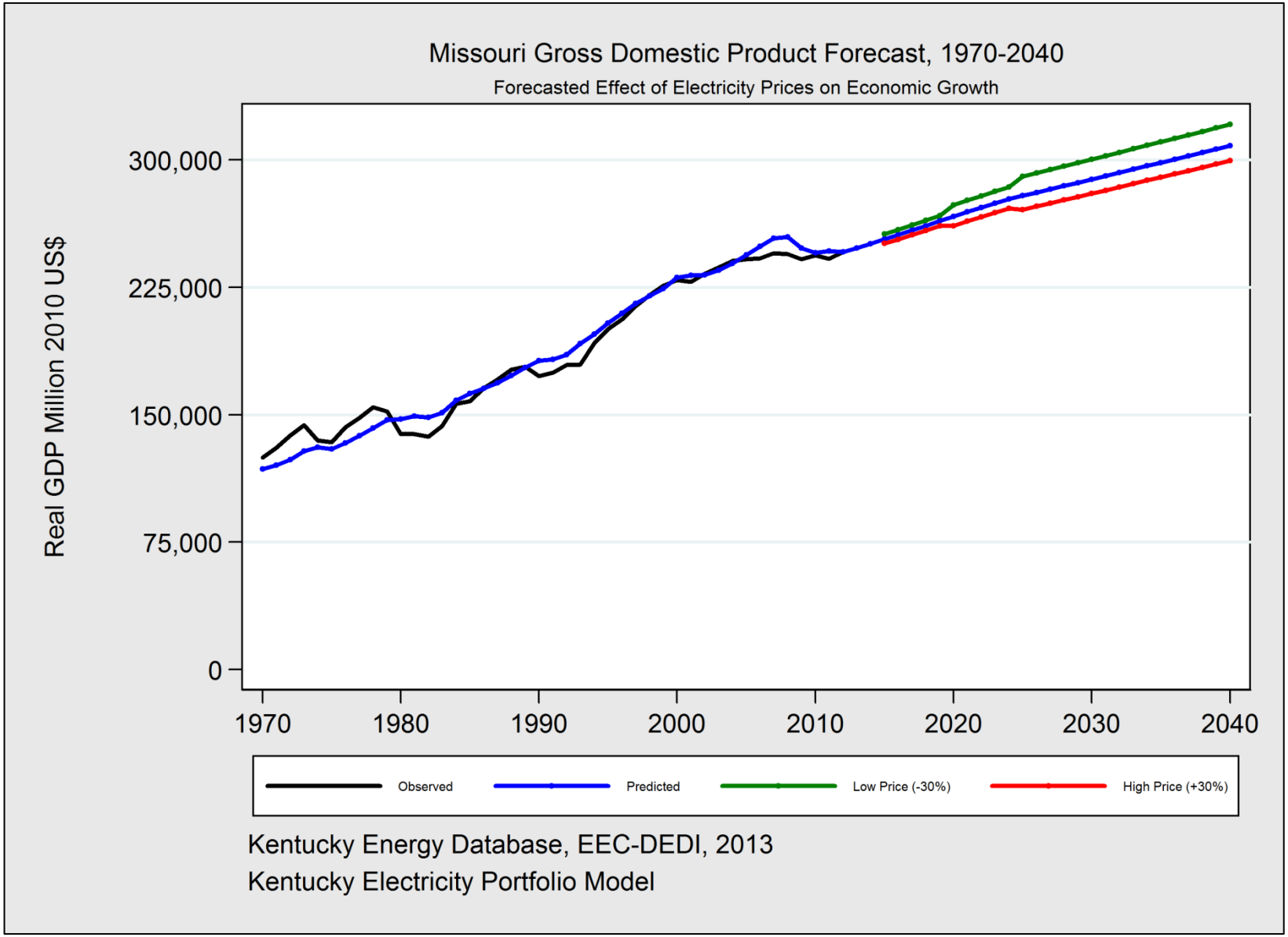
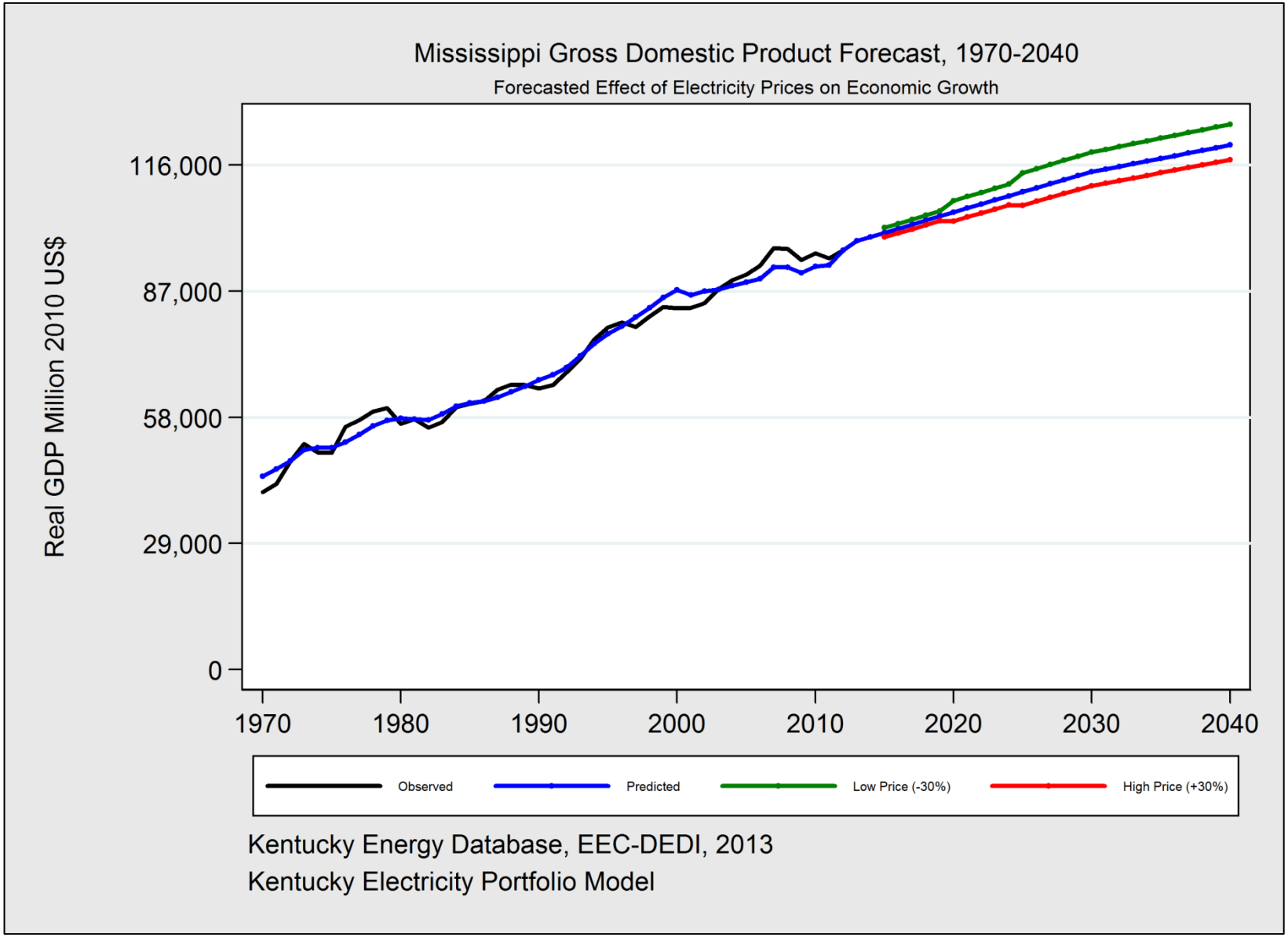


Model Validation



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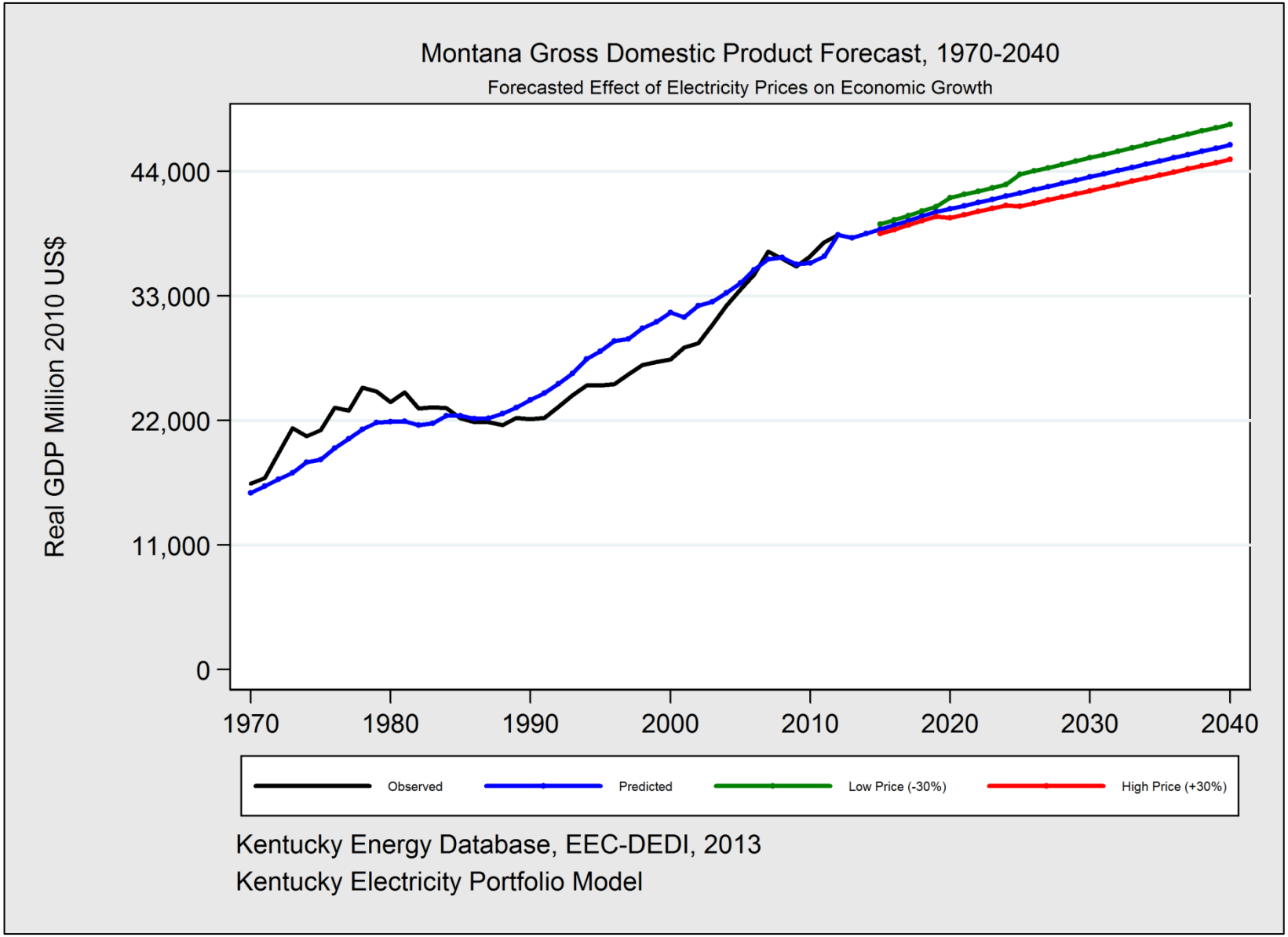

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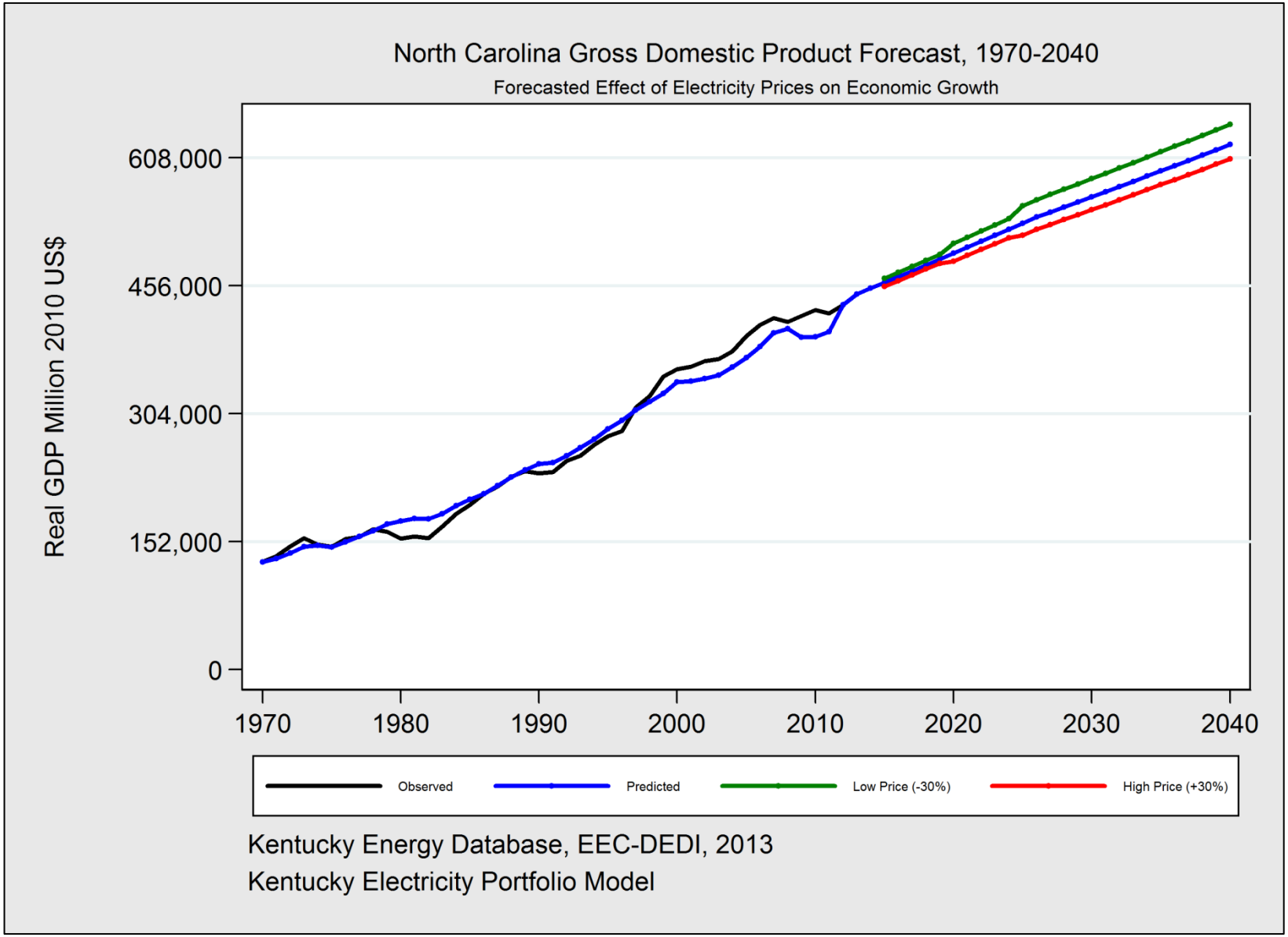

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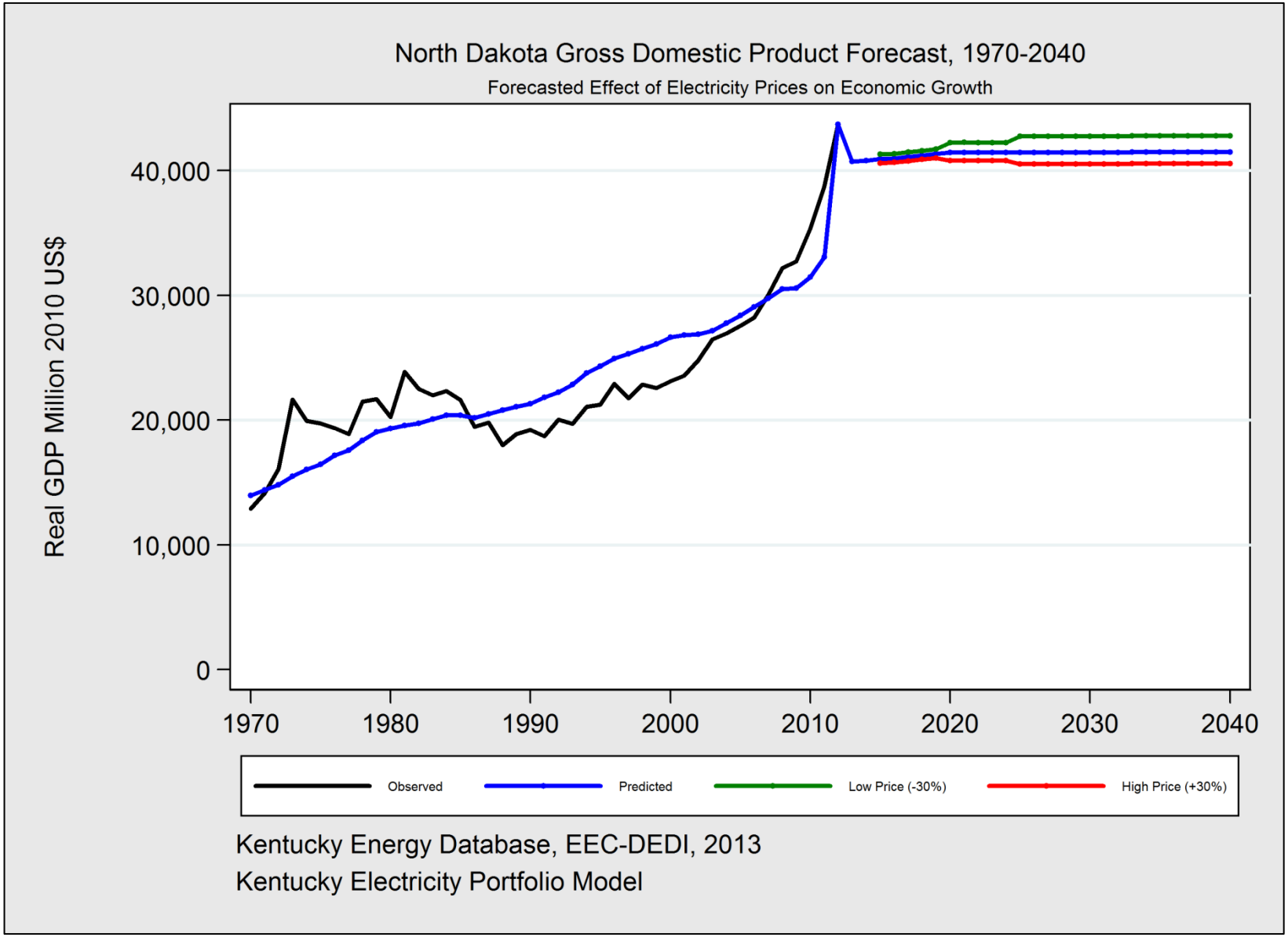

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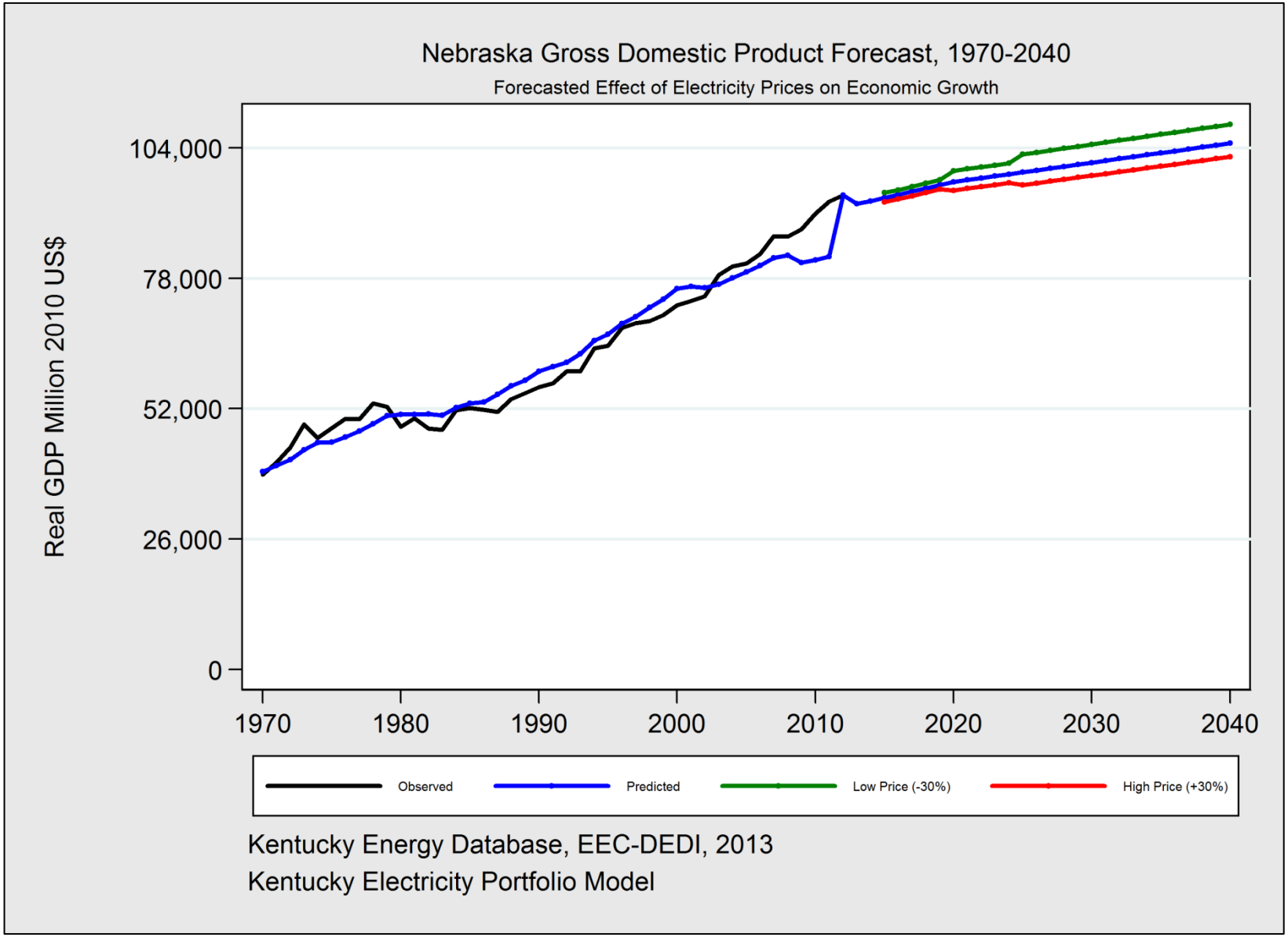

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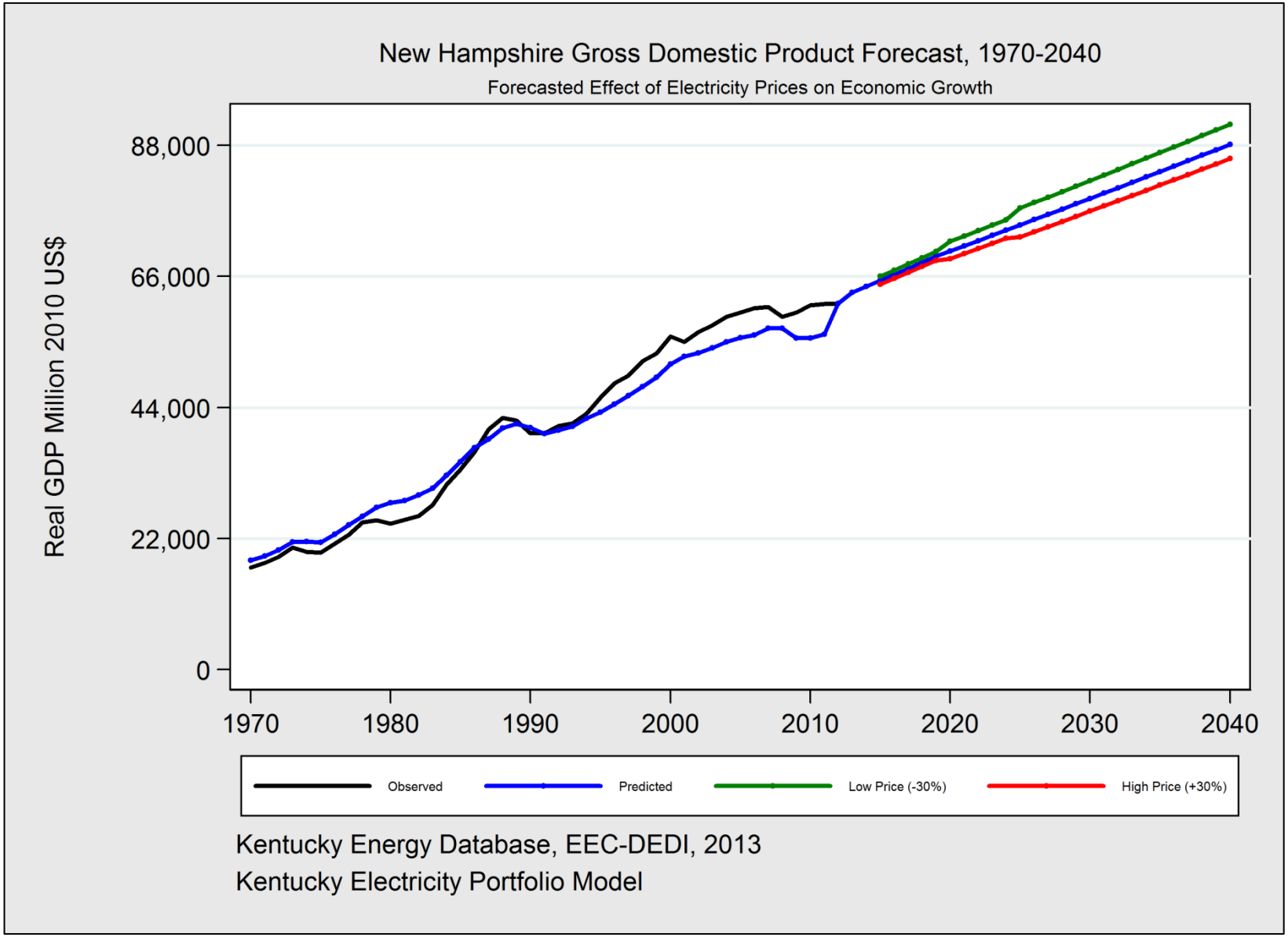

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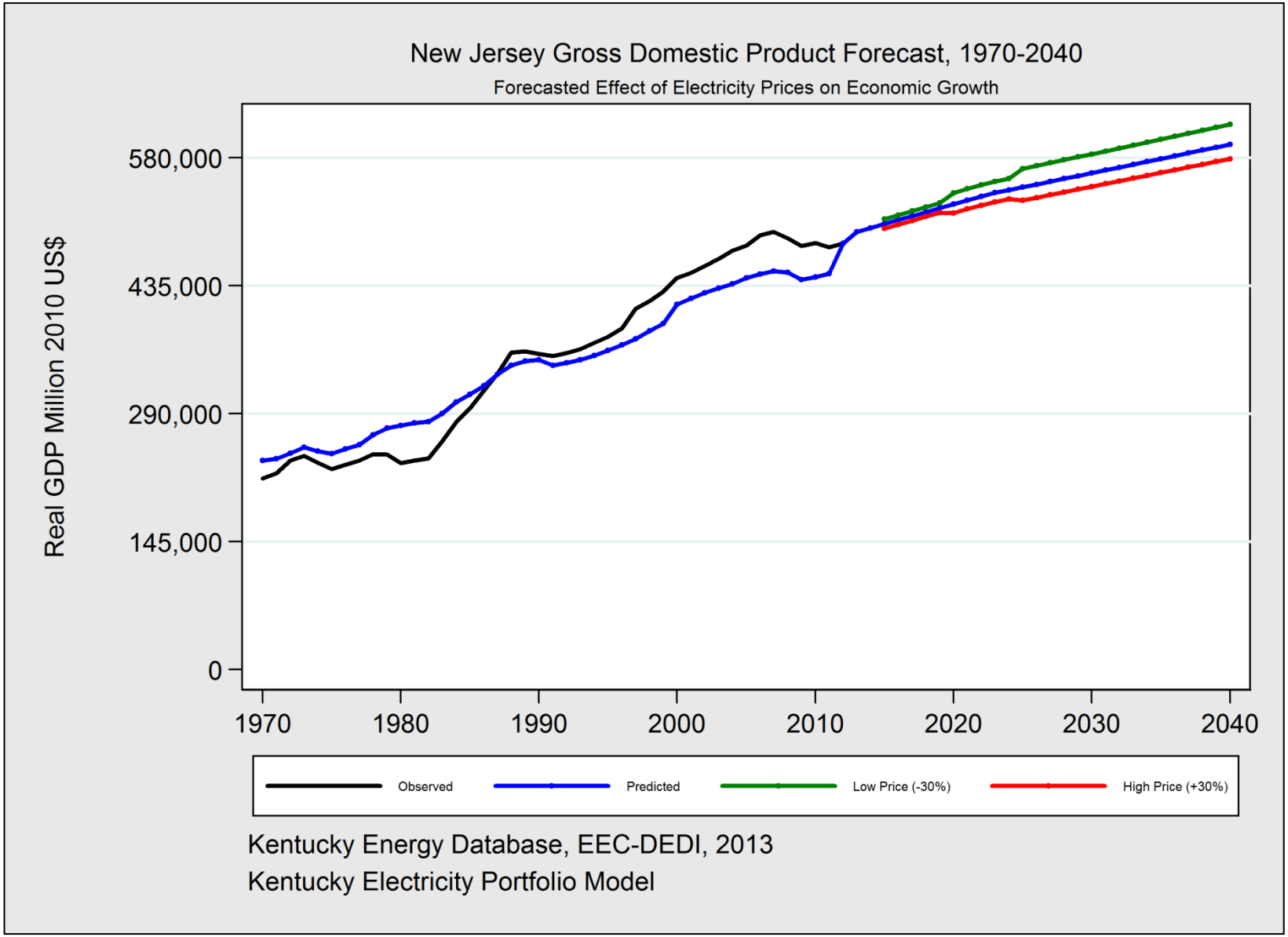

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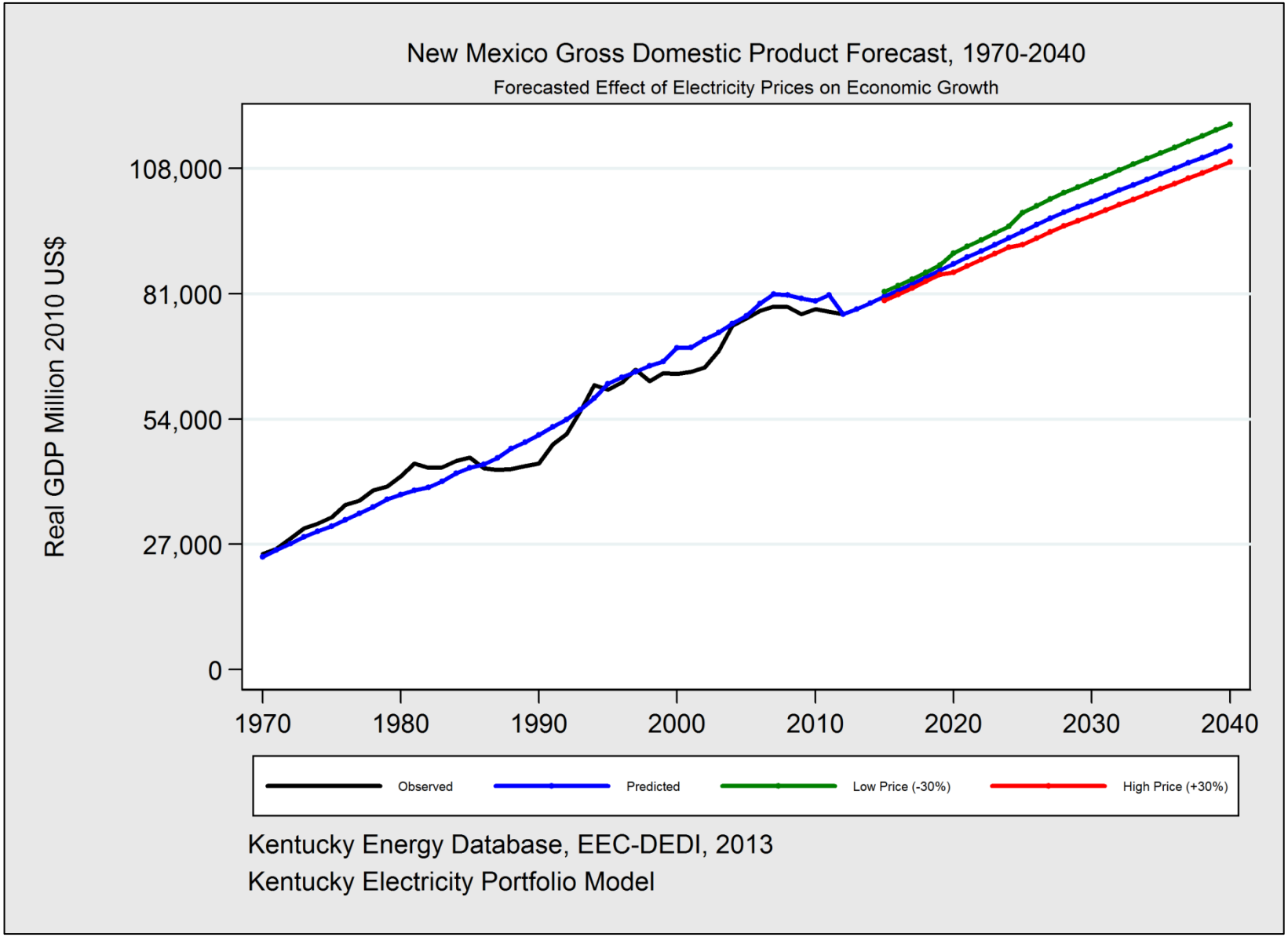

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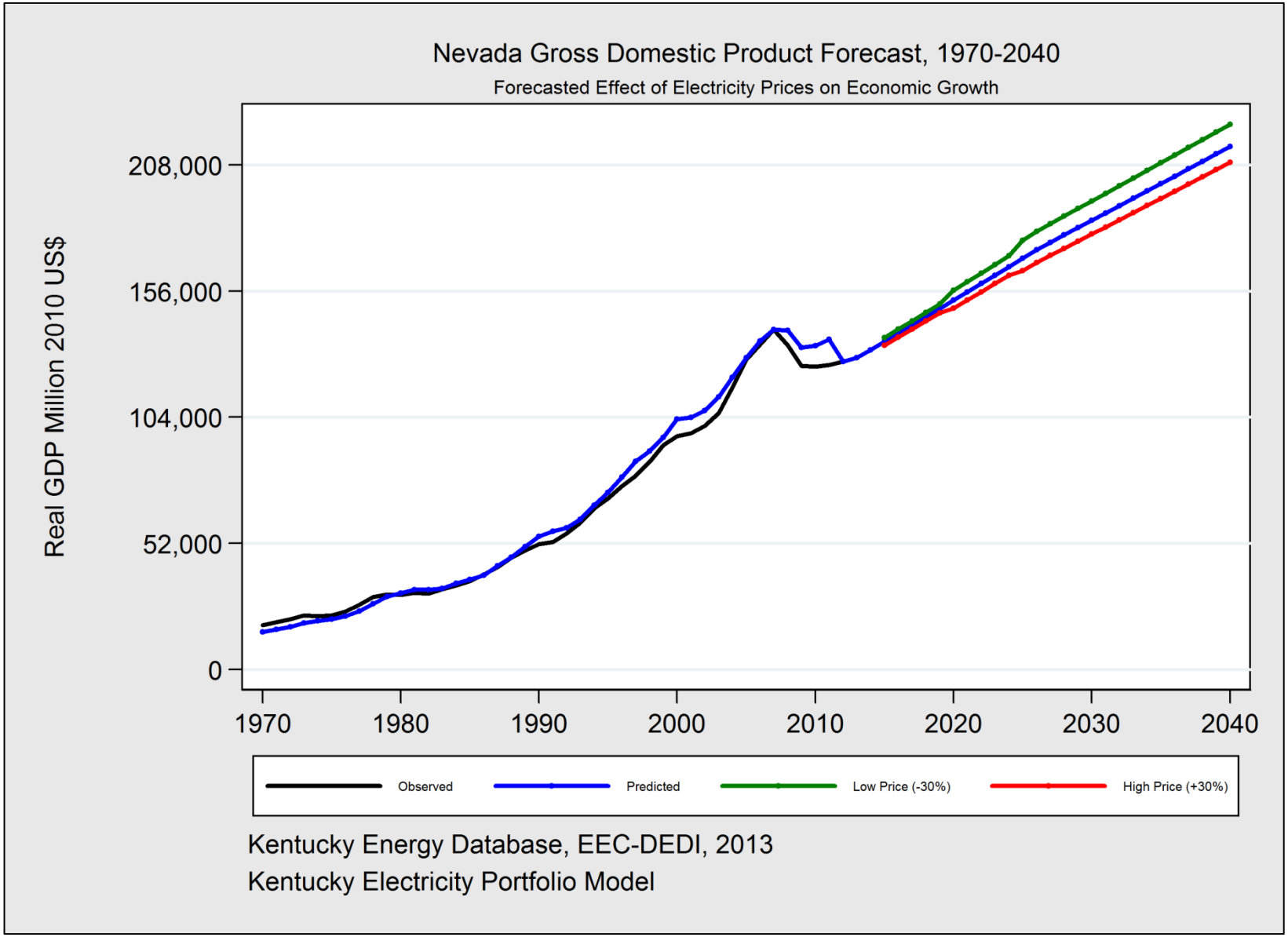

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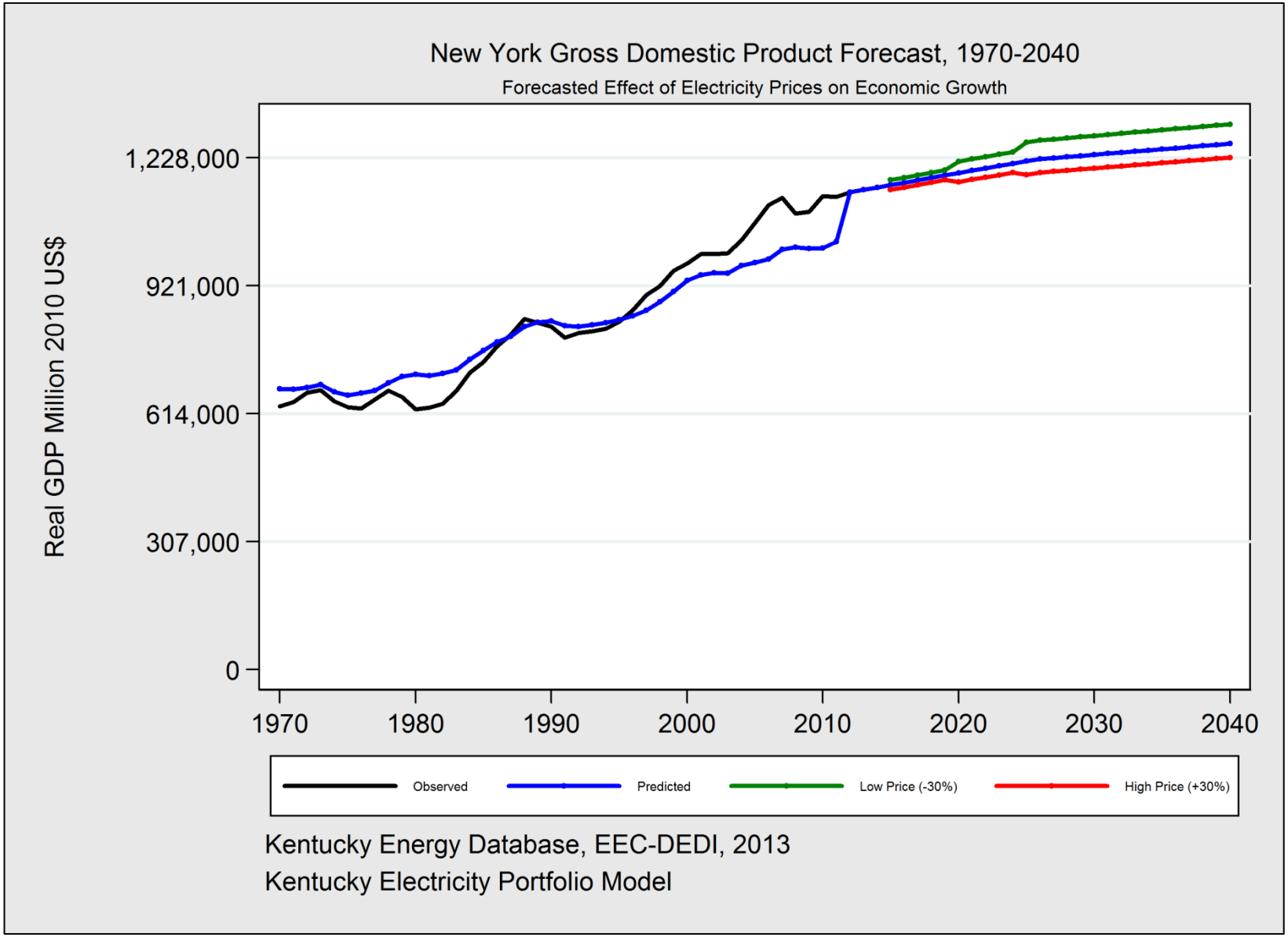

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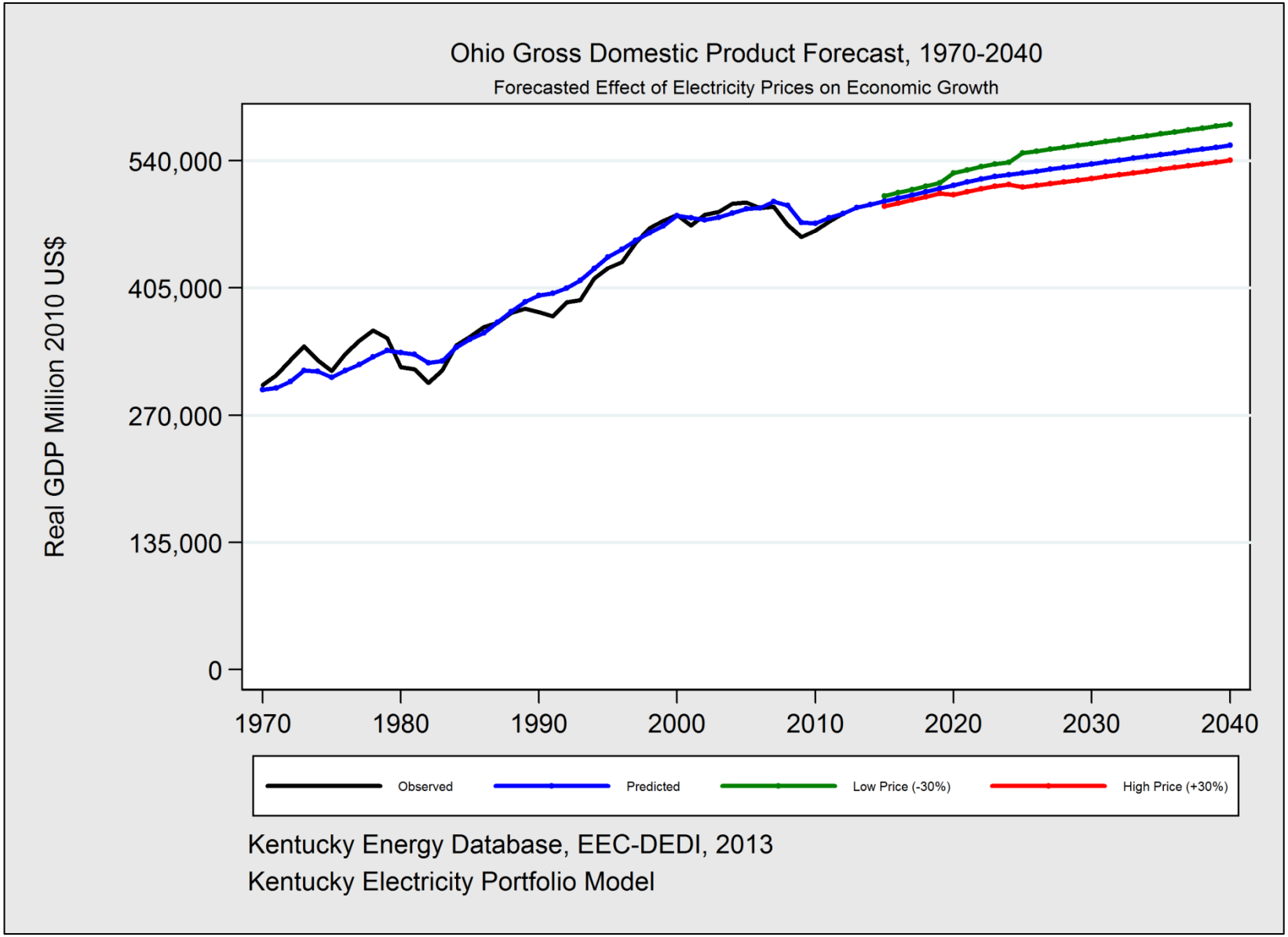

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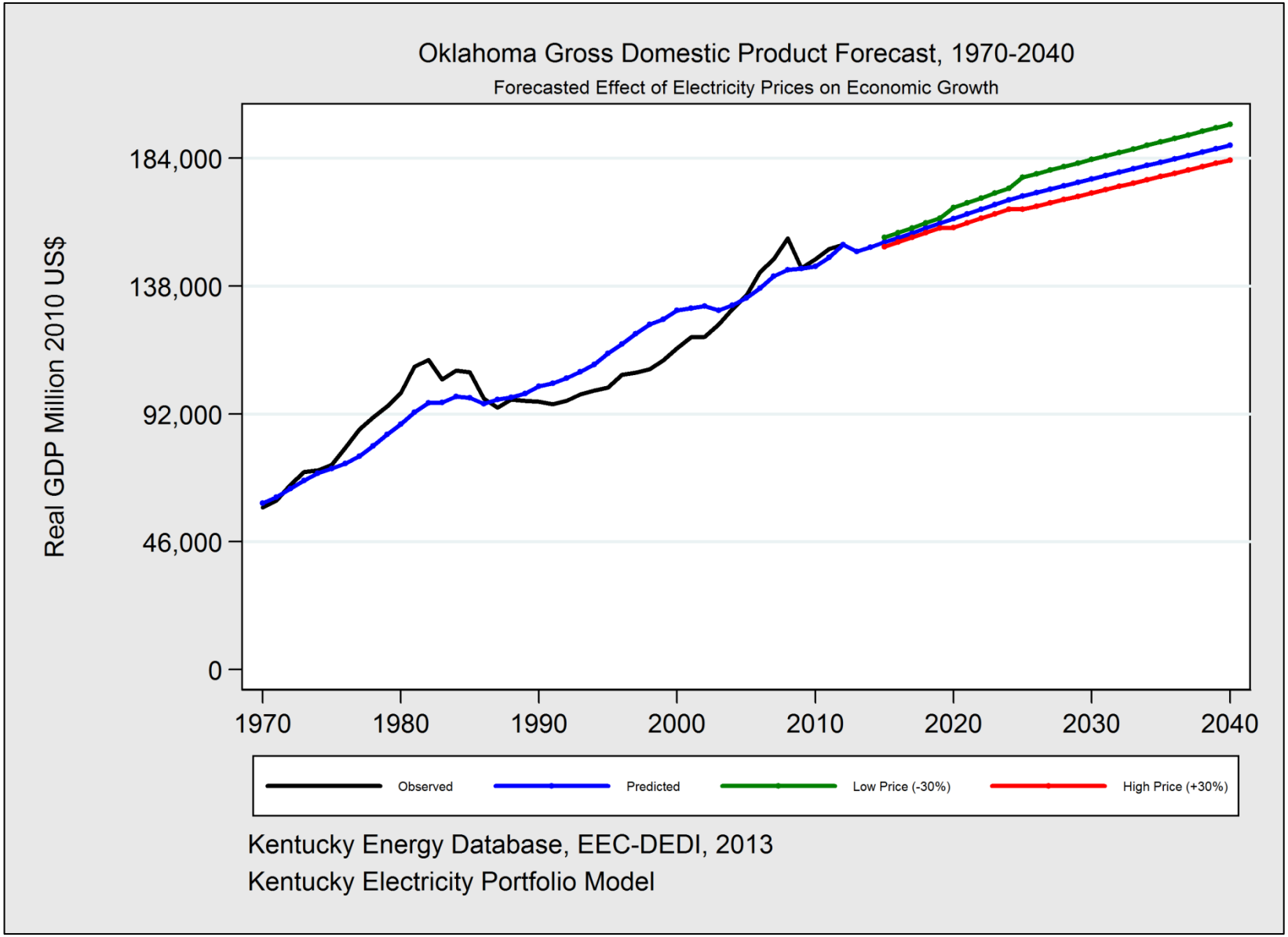

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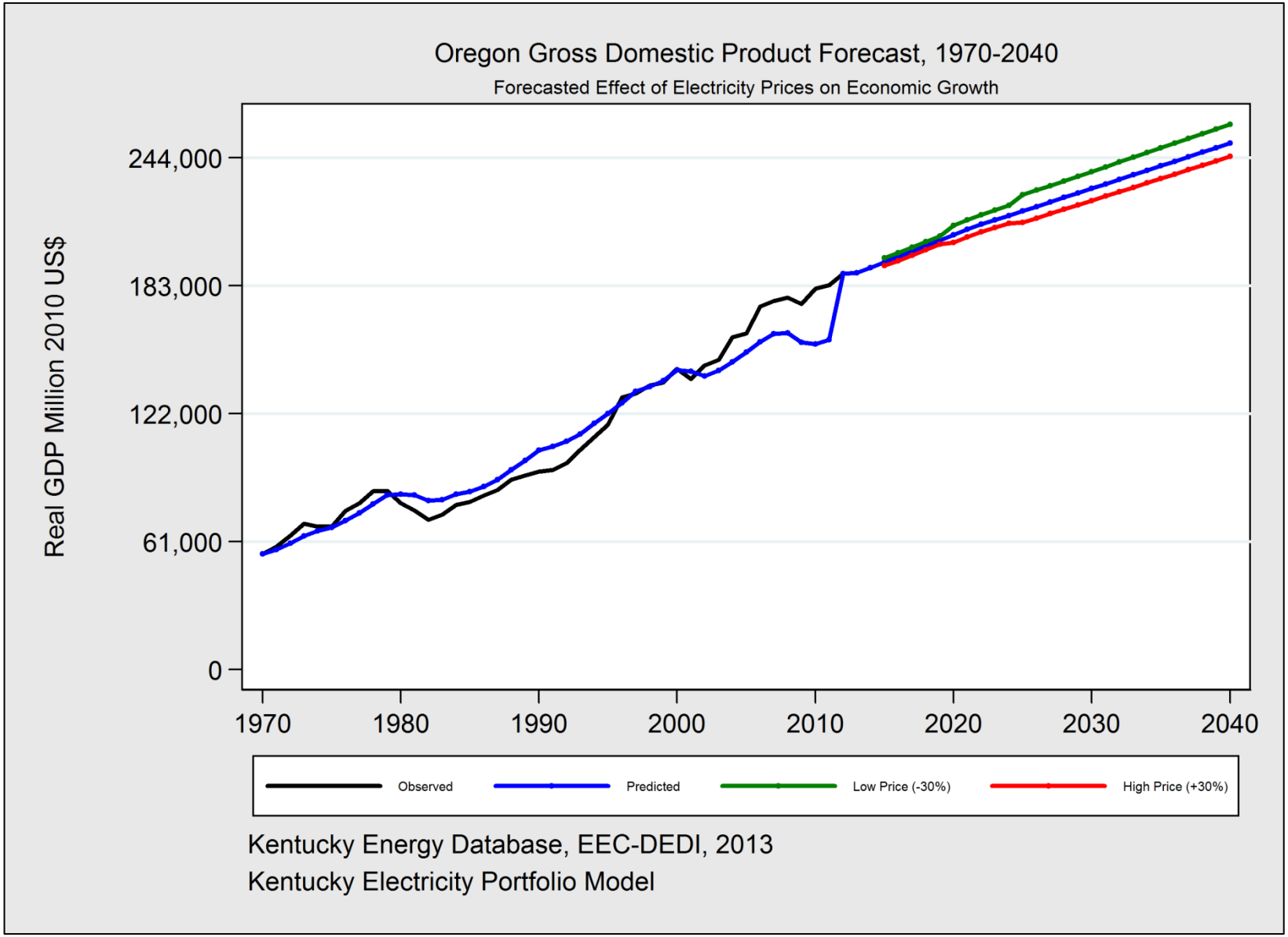

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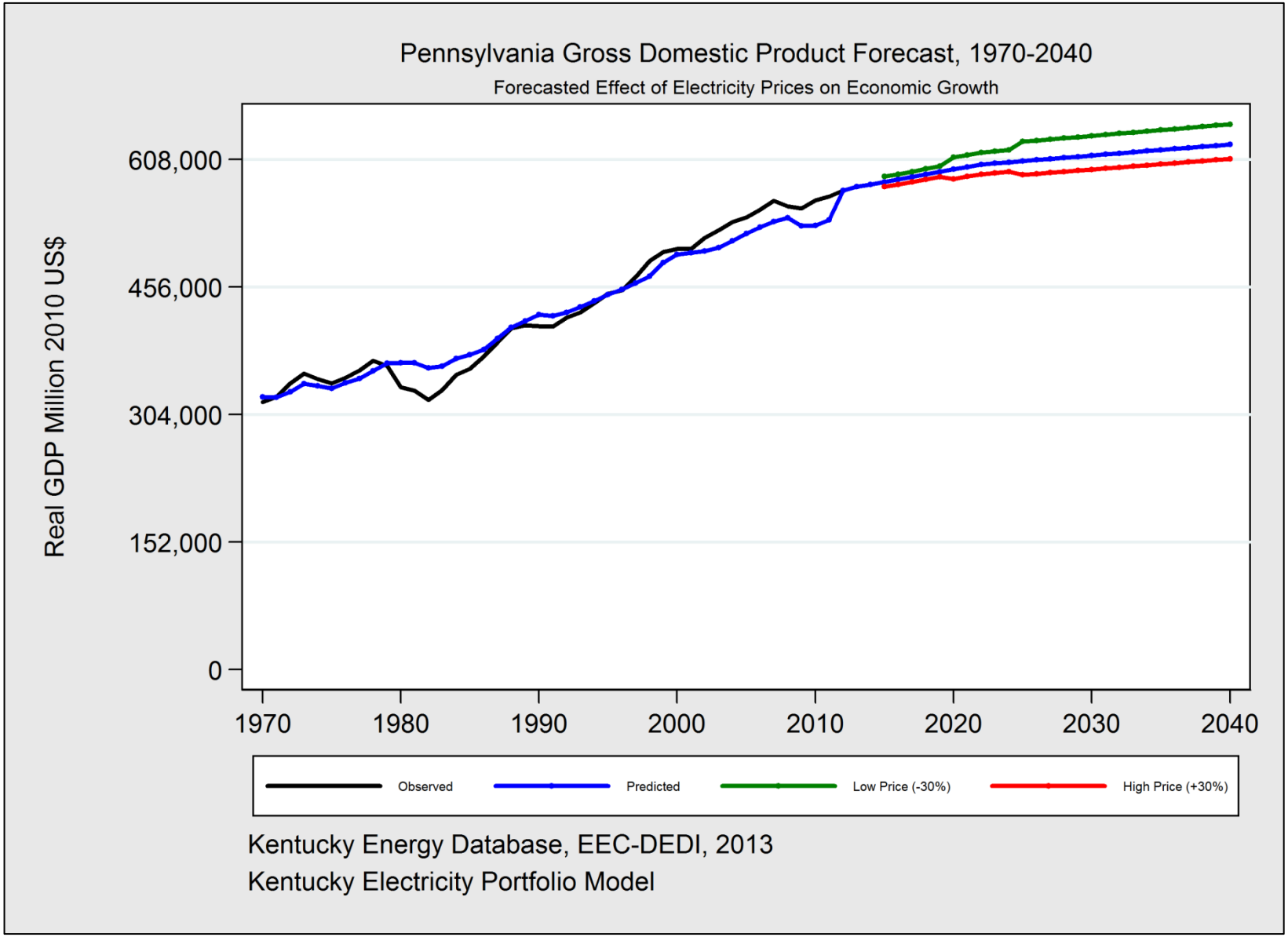

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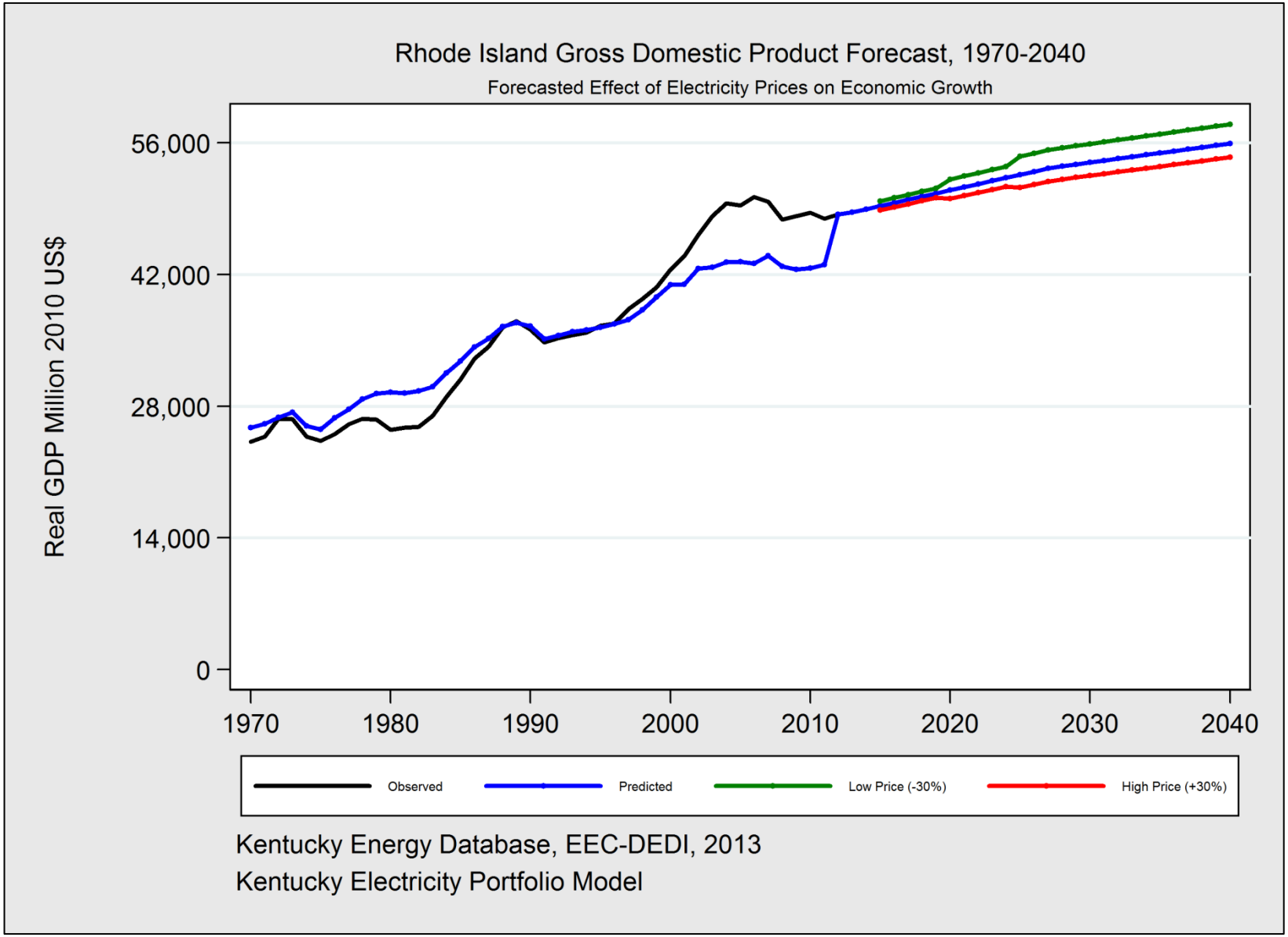

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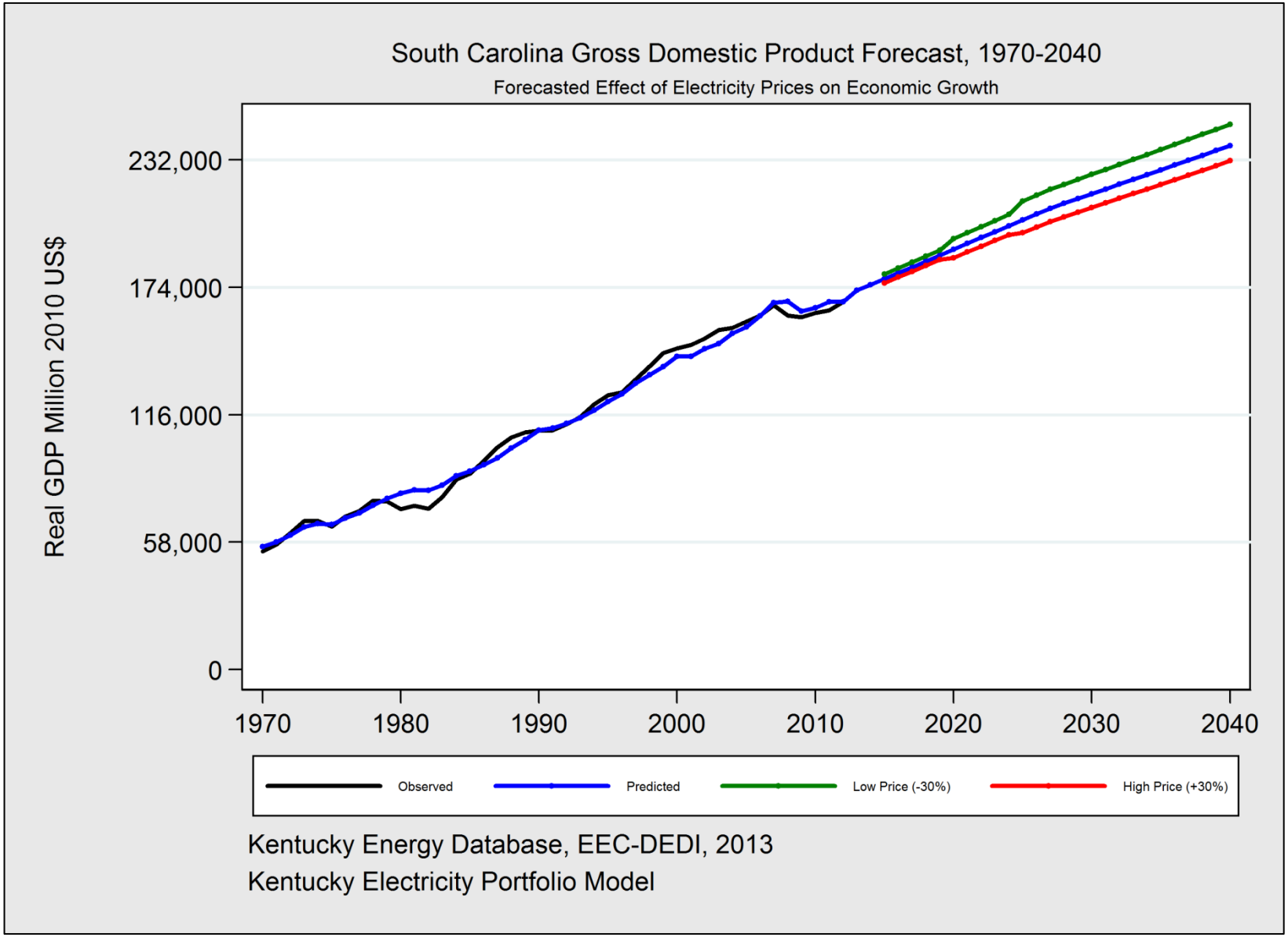

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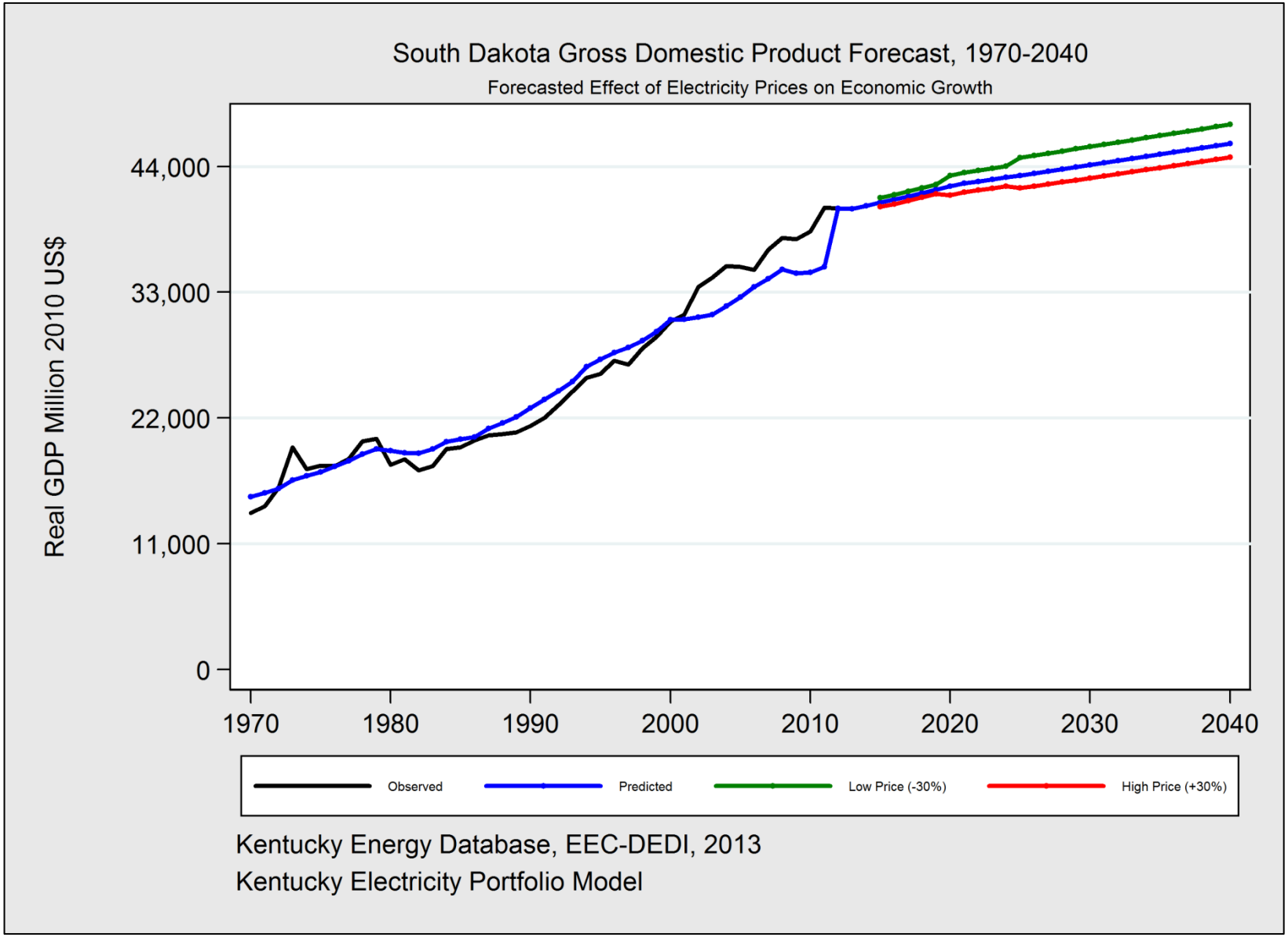

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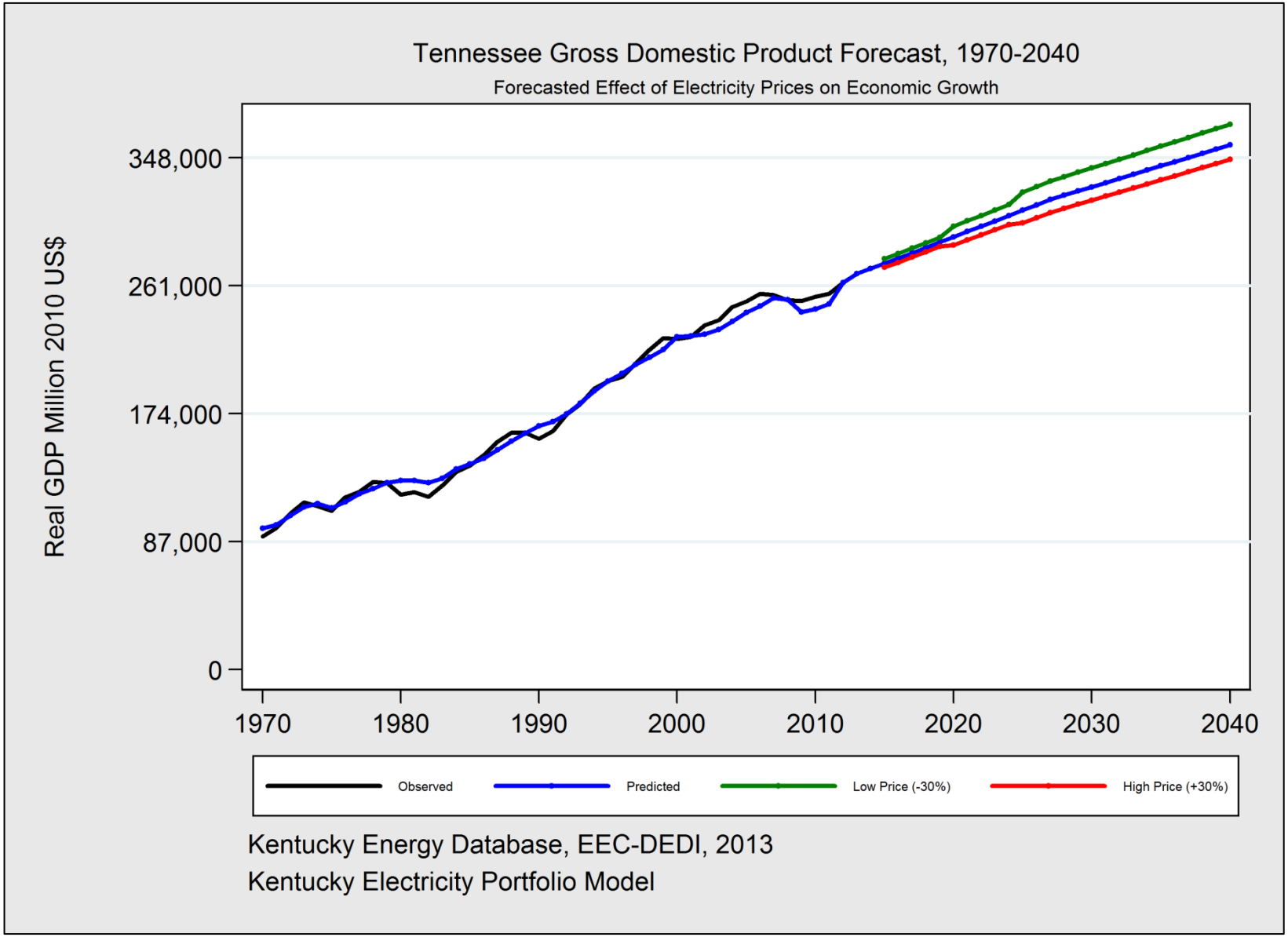

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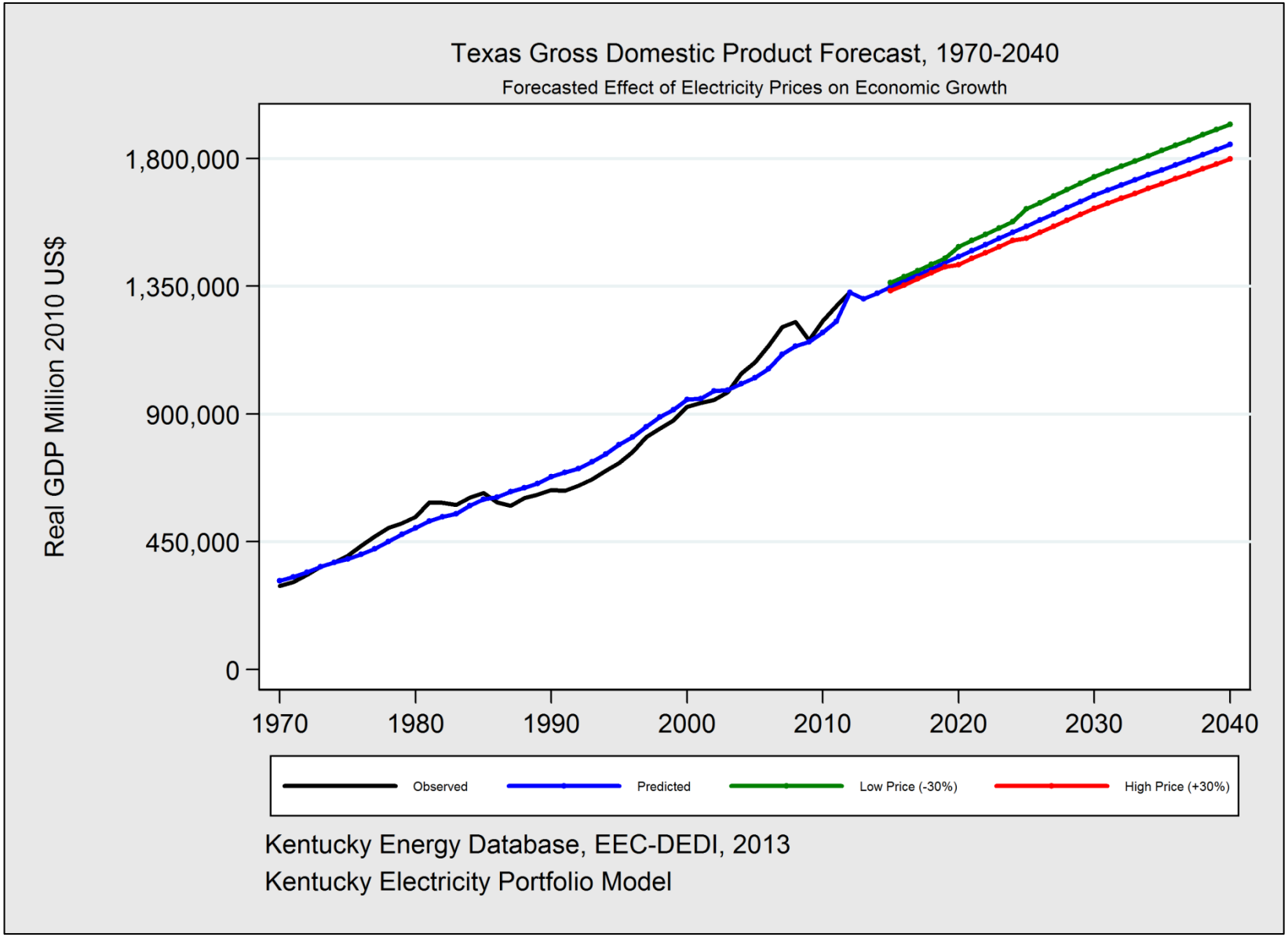

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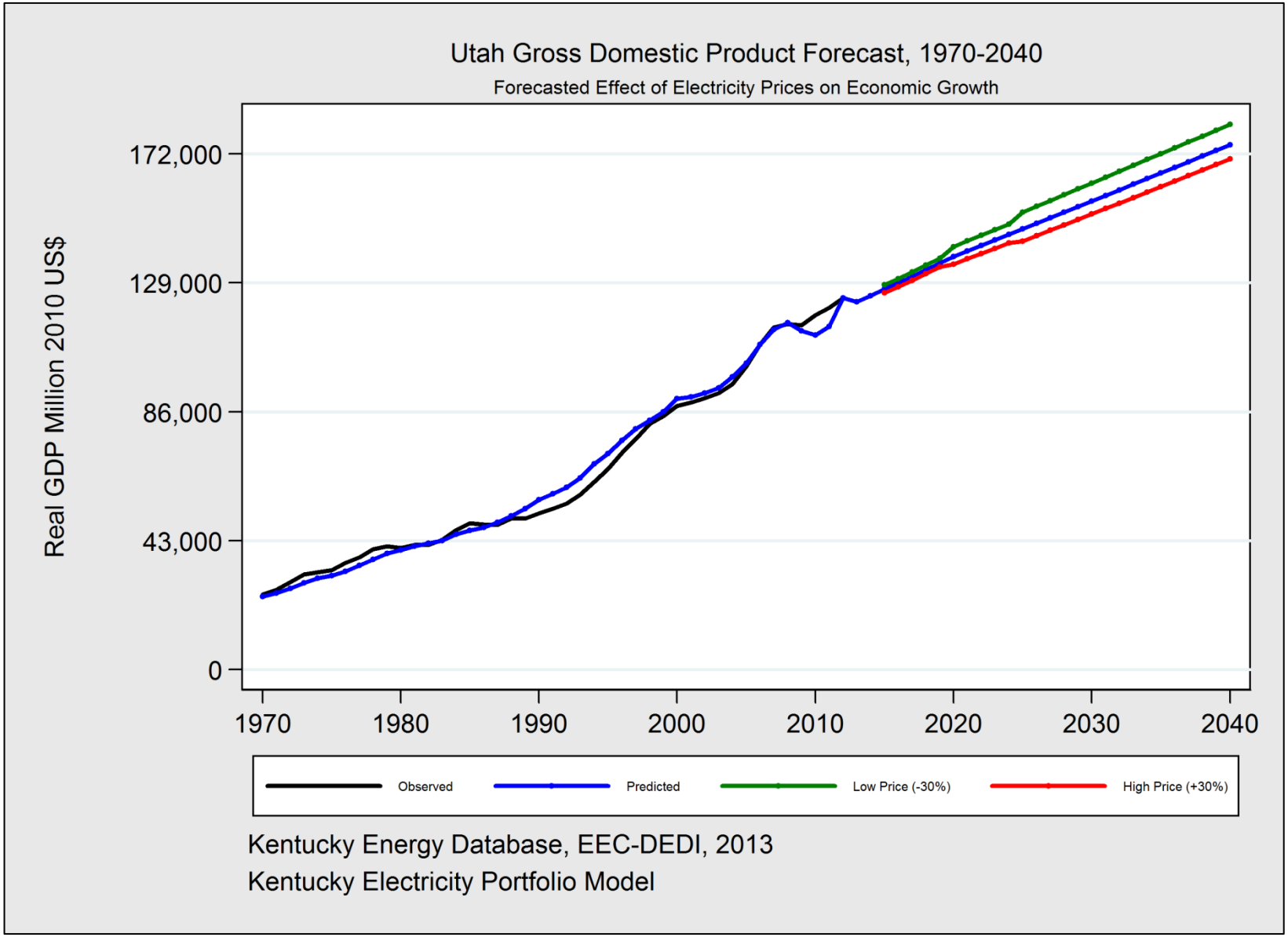

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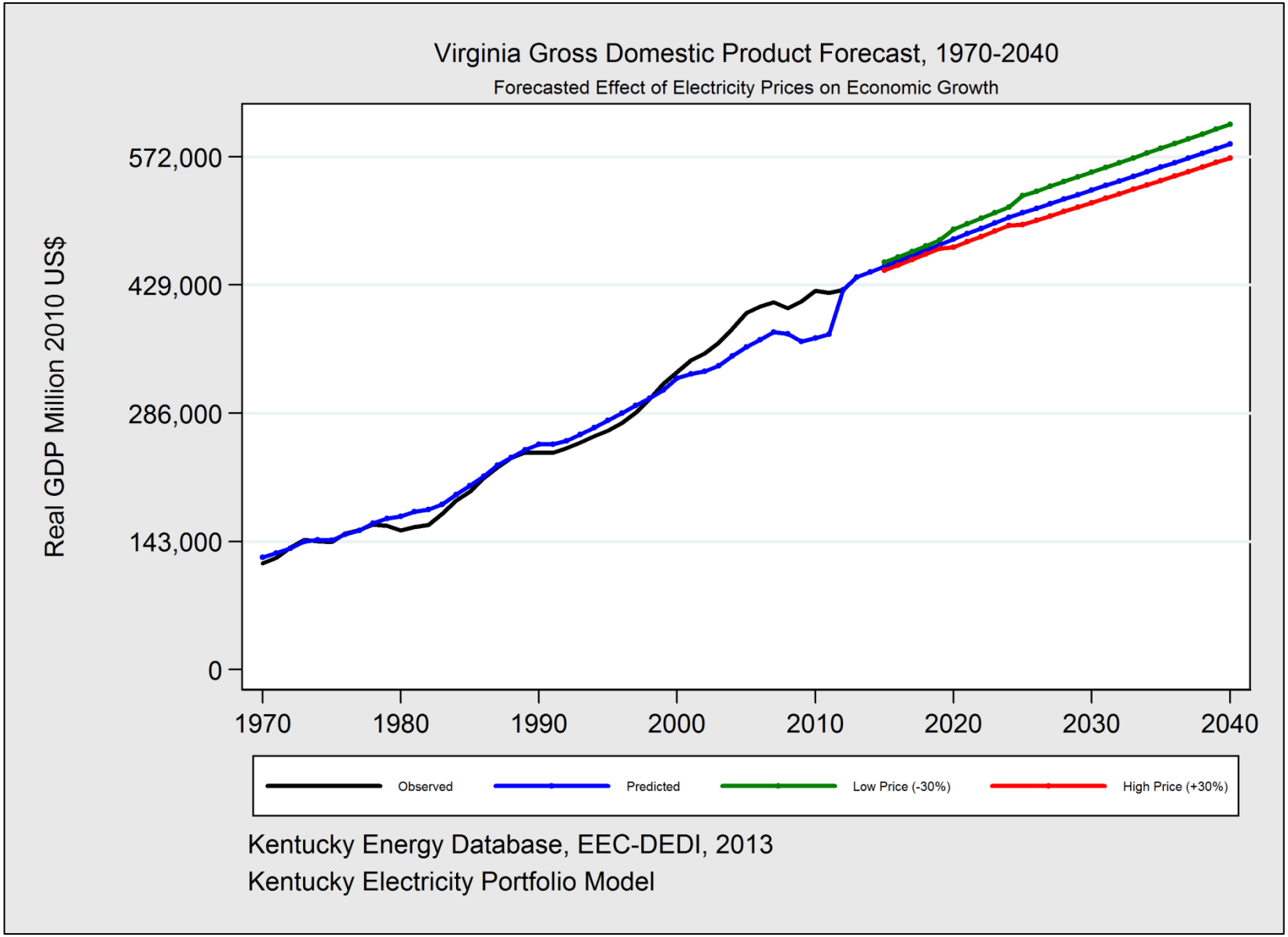

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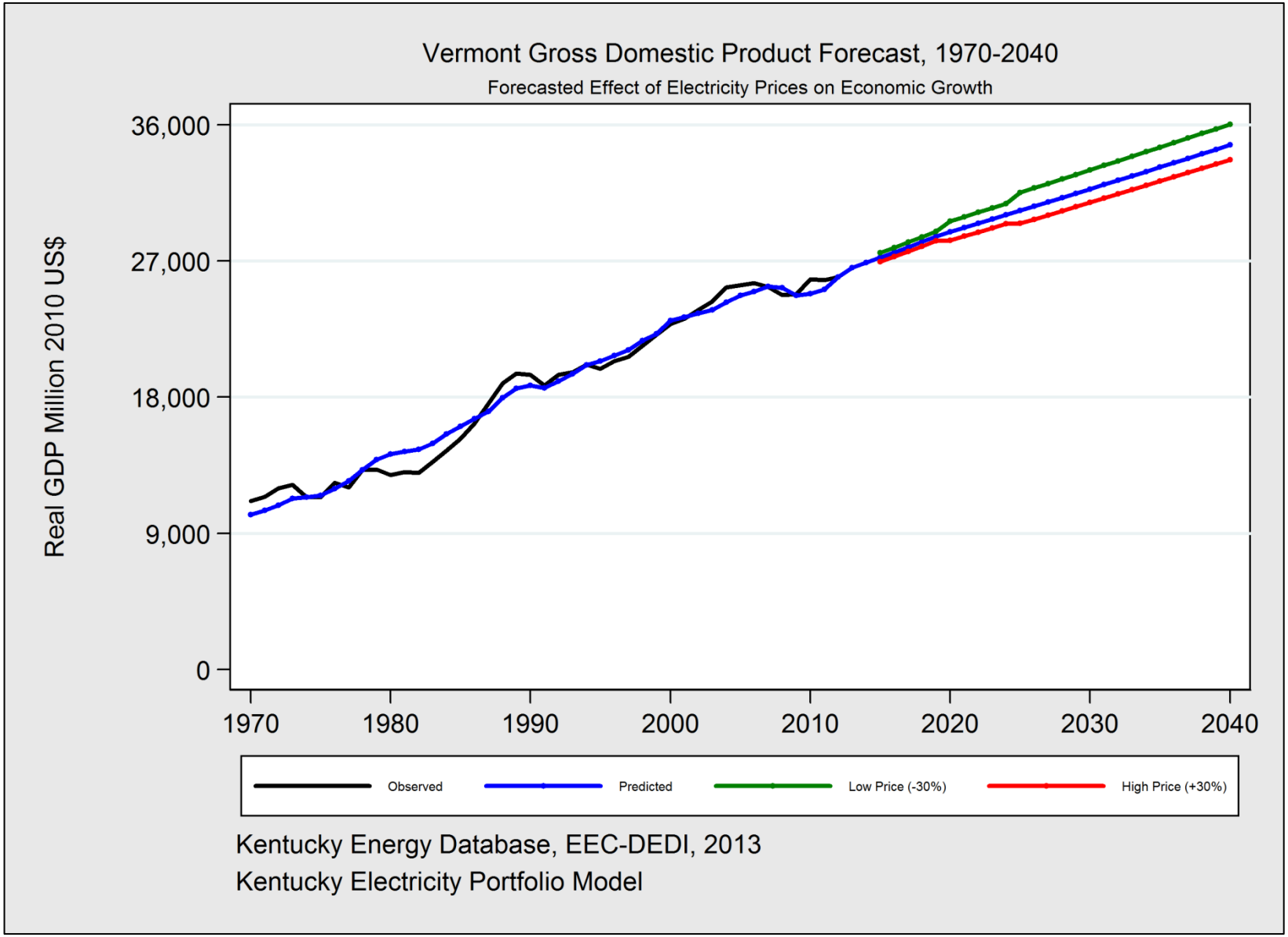

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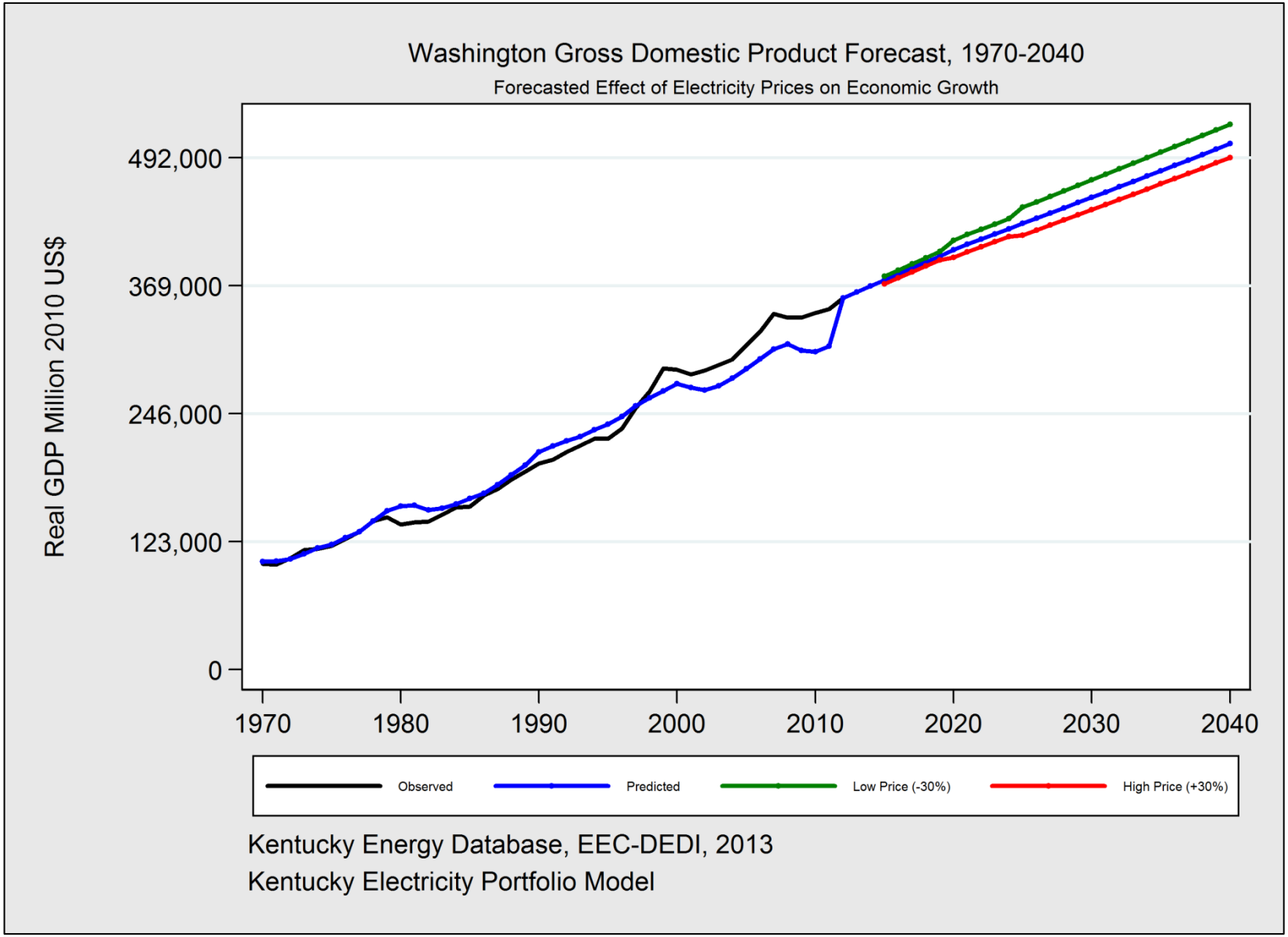

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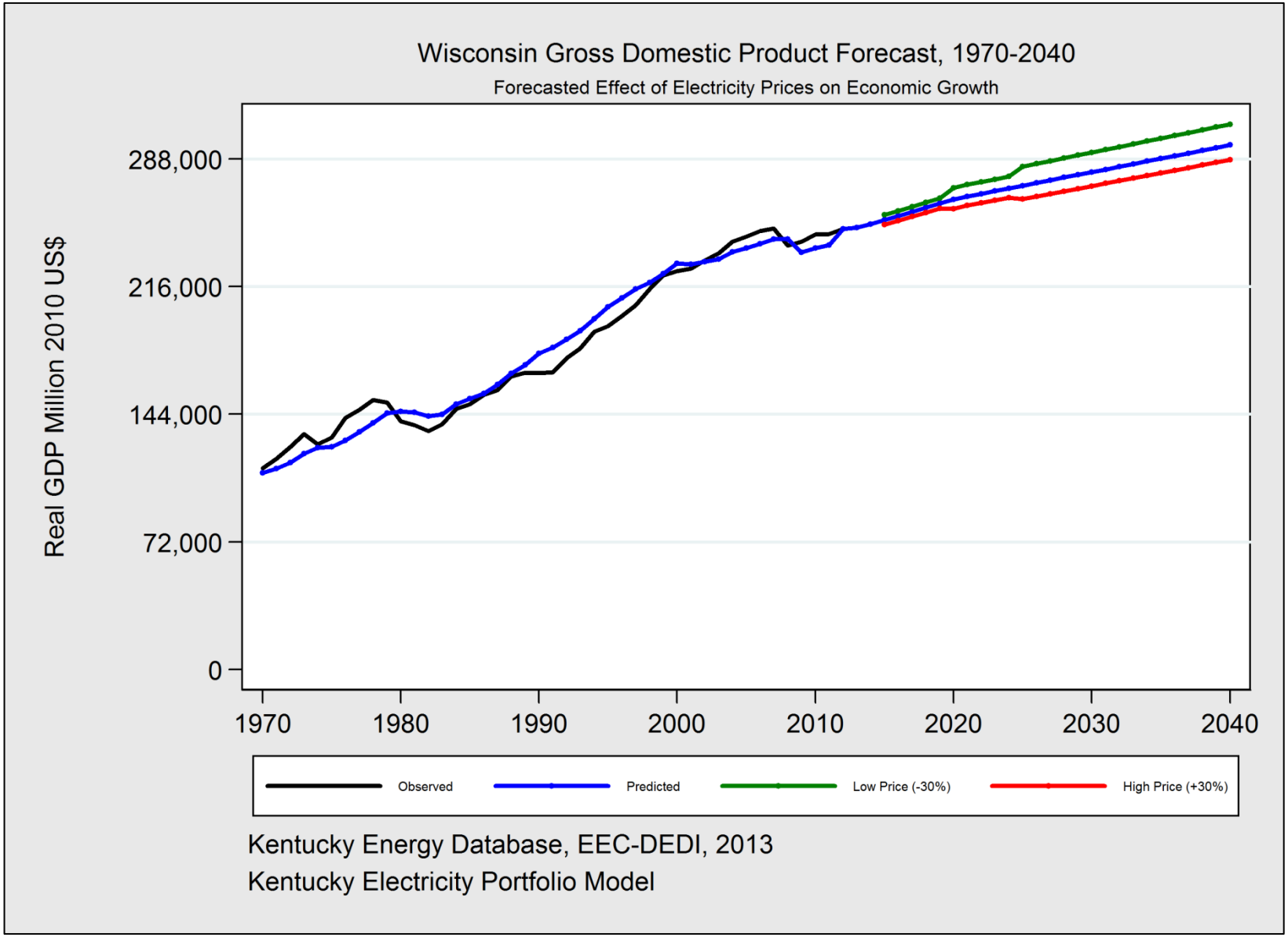

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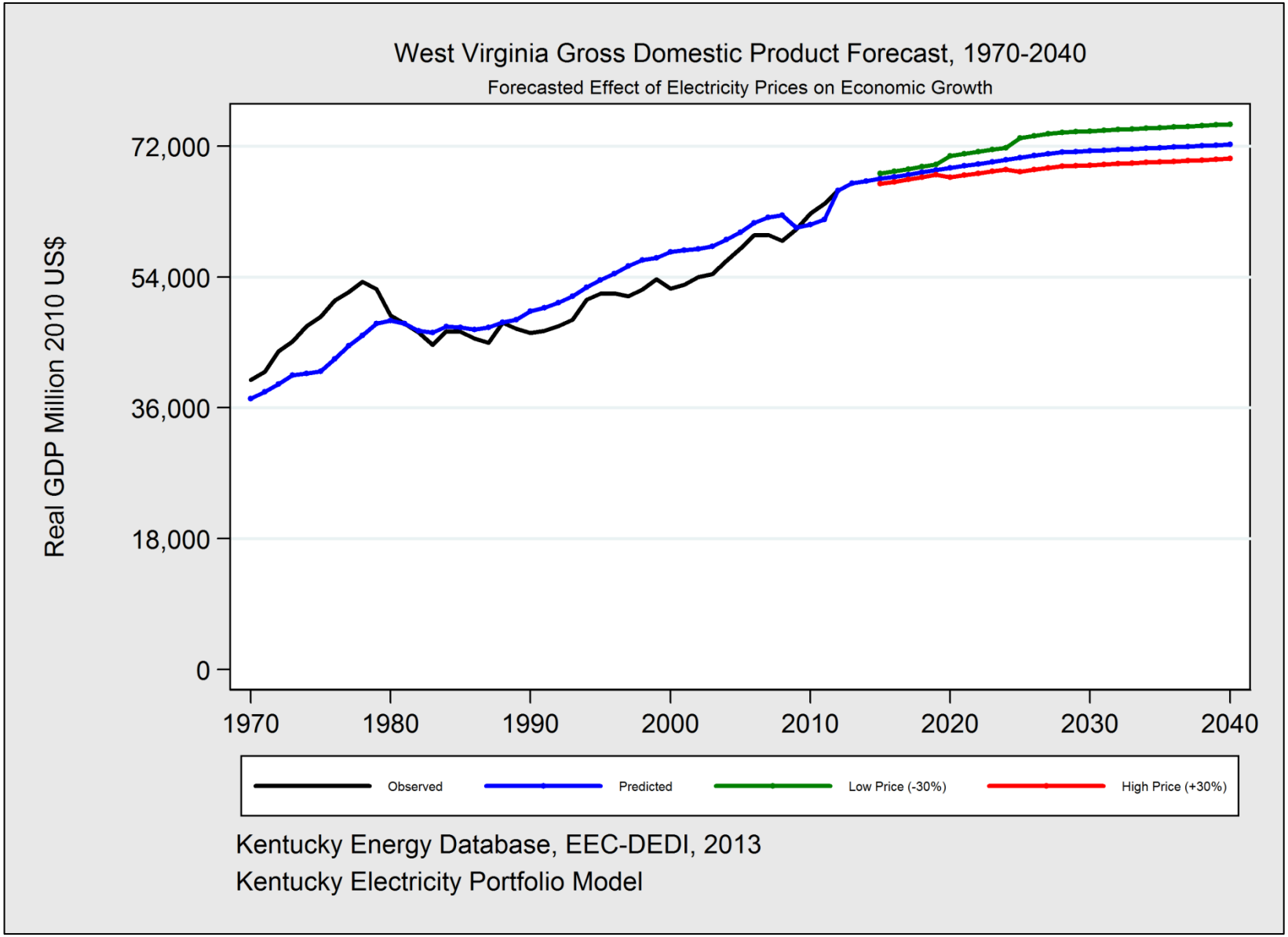

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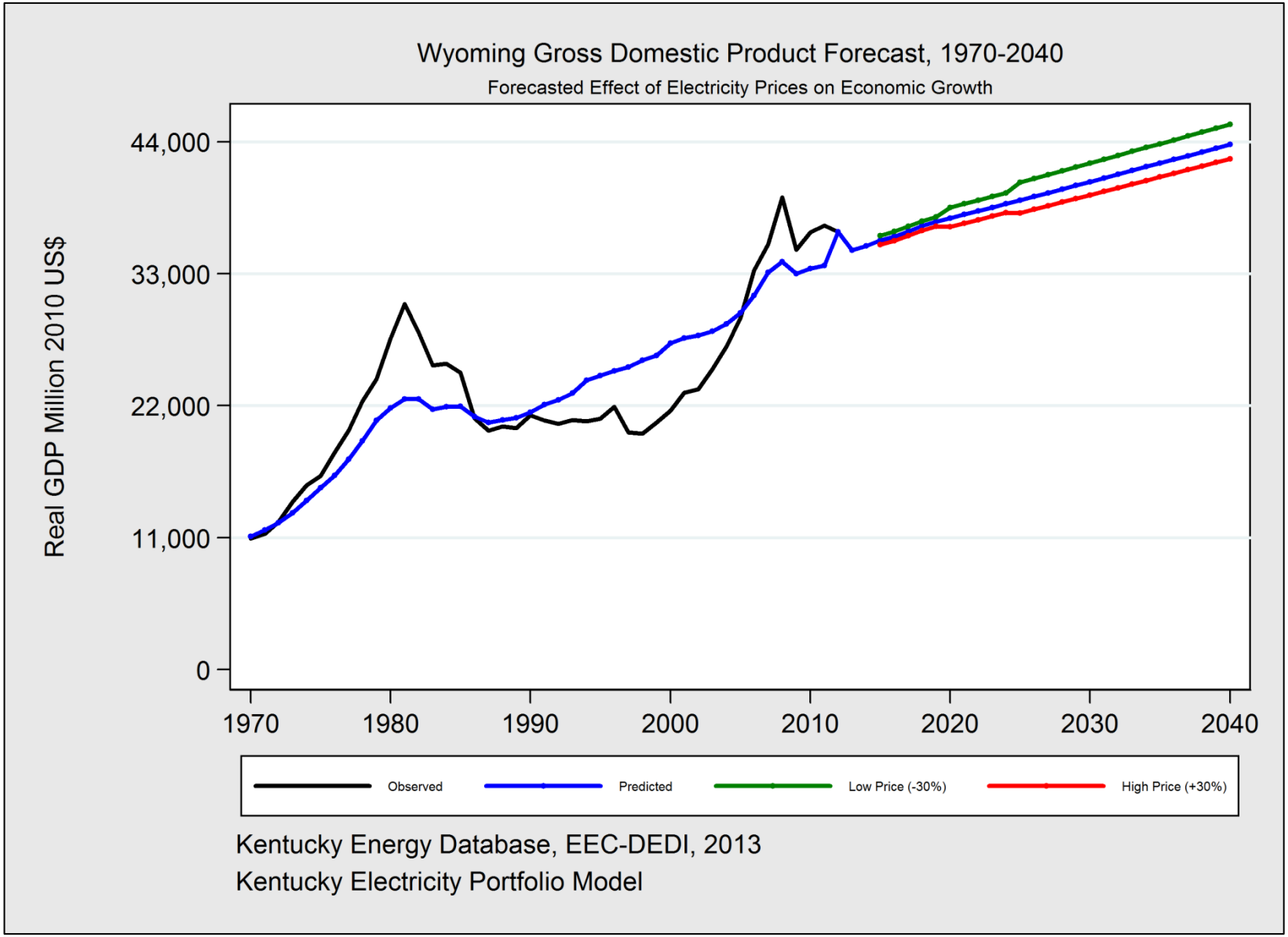

Questions?

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