Energy Policy Modeling Under Uncertainty: the Case of the Inflation Reduction Act

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In the U.S., the modelling of energy systems and the greenhouse gas (GHG) emissions they produce has been dominated by "bottom-up," optimization modeling, or sector level, input-output model frameworks. Examples of multi-sector models include the NEMS model used by EIA, and the PATHWAYS model used by E3. Other models (e.g. Purdue's GTAP for trade, agriculture and land use) deploy varying levels of sector-level detail and attempt to capture general equilibrium relationships between sectors through relationships specified through input-output tables. These models attempt to simulate, often at a sector or local level, relationships between stimuli such as energy prices and policy interventions and outcomes such as CO2 emissions.

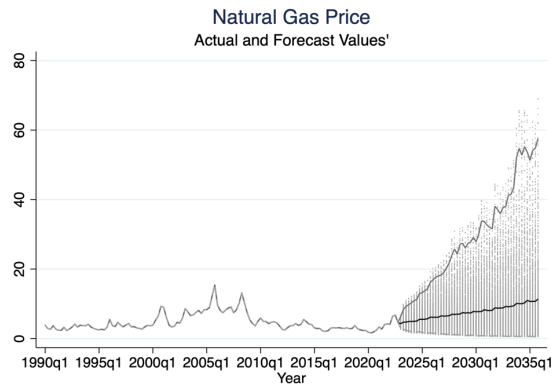
When implemented well, traditional models are typically calibrated to a "benchmark" year to provide normalized starting conditions, but are not otherwise restricted to fit actual trends in the data over time or between sectors. Traditional models are also limited to producing "point" estimates of single values for each output, rather than probabilistic ranges for those output values. Uncertainty can be tested via scenario analysis, but frequently the selection of scenarios is not based upon any statistical analysis of the likelihood or relevance of those scenarios.

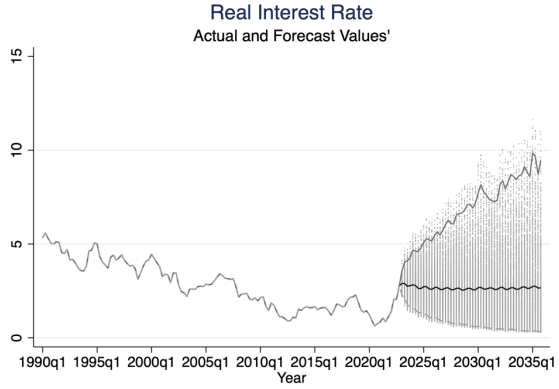
In this paper we introduce a more rigorous treatment of uncertainty into the optimization modeling environment. Our setting is the energy policy elements of the Inflation Reduction Act (IRA). Several reports have cited specific point estimates of the emissions benefits of elements of the IRA, but do not convey the potential impacts of uncertainty on their estimates or the prospects for the legislation. In this work, we deploy time-series forecasting methods to generate joint probability distributions of key inputs that impact investment and operations in the power sector. We combine these forecasts with an electricity system expansion model of the western United States to generate statistically valid distributions of outputs from this model. Preliminary results indicate that the impacts of the IRA depend heavily on the realization of several key exogenous variables.

Forecasting Model

In our analysis, we utilize a cointegrated vector error correction (VEC) model to understand the relationships between factors influencing investment and operations in the power sector. The four variables we use to fit the model and make forecasts are total electricity consumption in the U.S., gross domestic product (GDP), natural gas price, and 10-year real interest rate. Our model draws on quarterly data spanning from 1990 to 2022. It incorporates 4 lags and seasonal indicators to account for seasonality. Based on the Johansen test for cointegration, we specify that electricity consumption is associated with the remaining three variables in the long run. Utilizing the coefficient estimates from the VEC model, we project the distribution of each

variable from 2023 to 2035. Specifically, we simulate 1000 potential values for each variable in each quarter during this period.





Electricity Market Investment Model

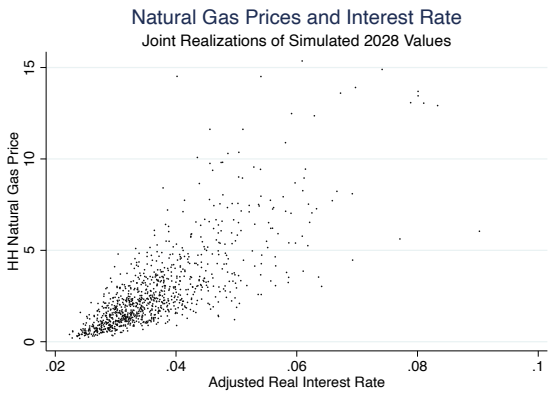
The economic elements forecast in the VAR are utilized in a more conventional optimization model that simultaneously solves electricity generation unit dispatch and equilibrium investment. The model is based upon that used in (Bushnell, et. al 2014) and has been updated to be calibrated to 2019 market conditions in the Western U.S. grid. One important feature of these market conditions is the shift in peak energy prices to early morning and particularly early evening hours, and the model incorporates dynamic operational constraints to better reflect these conditions.

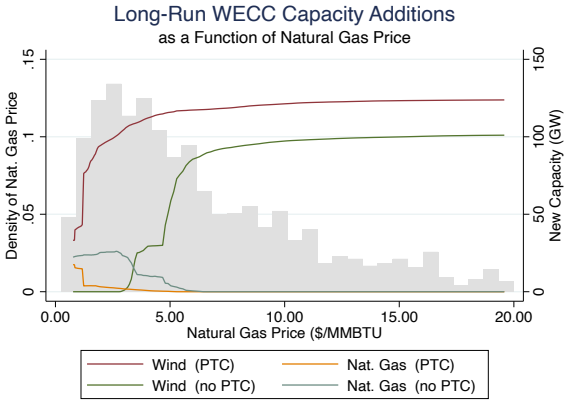
Investment is based upon common long-run equilibrium conditions whereby entry of each technology continues until the annual net operating profits of new generation is driven down to equal its annualized fixed cost, including capital carrying cost. The costs and production characteristics of each technology are taken from EIA documentation and vary by region within the Western grid.

Results

With these models we simulate equilibrium investment for each joint realization of future interest rates, fuel prices, and electricity demand to compare scenarios in which IRA production tax credits (PTC) are available to those in which they are not.

Results indicate that the extent and nature of future investment can depend dramatically upon one of several threshold conditions. Renewable energy, for example is highly attractive even in the absence of PTC payments under conditions of low interest rates and/or high natural gas prices. Once gas prices drop below a certain threshold, renewable investment decreases dramatically in the absence of a PTC. Similar conditions maintain for distributions of interest rates, although the interaction of demand growth with technology choice is more complex.





These conditions can produce heavily skewed distributions of key outcomes such as the amount of PTC payments, the emissions reductions induced by those PTC payments, and the implied marginal costs of abatement. Under some future realizations, the PTC provides little additional CO2 abatement at extremely high cost, due to the high degree of non-additionality of the capacity receiving payments. Under other realizations the PTC can "make the difference" between a more gas-intensive portfolio and one with more capital-intensive renewable energy.

Summary

This work is currently making more of a qualitative point about the highly non-linear sensitivity of policy forecasts to certain future inputs. There would be benefits to developing a convention where projections of instruments like a PTC are articulated as probability distributions rather than point estimates. A related point is that some policy instruments are more sensitive than others to future uncertainty. The PTC is effectively a "price" mechanism in the Weitzman sense, and this work illustrates how small shifts in production costs can lead to large shifts in the impact of these mechanisms.