***Electricity generating Capacity expansion and factor utilization In The dynamic energy Landscape***

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## Overview

Electricity generation, in addition to capacity, is a relevant economic good in balancing supply and demand in the power sector. The mix of generation from different technologies has important implications for long-run sustainability issues such as greenhouse gas emissions and energy consumption. Changes in electricity generation result from two distinct mechanisms: i) constructing new capital, termed capacity expansion, or ii) increasing or decreasing operations of existing capital, termed factor utilization. Long-term return on capital investment in electric power technologies drives capacity expansion, while factor utilization is the substitution of technologies in response to prevailing economic conditions, namely fuel prices. The two mechanisms are interrelated in that the amount of generation produced per unit of capacity (i.e. capacity factor) drives capital rents, and short-term factor utilization may be counterbalanced by long-term capacity expansion. These relationships are critical in determining long-run projections of electricity generation considering the current dynamic energy landscape with large economic shocks (e.g. shale oil and gas boom). However, these joint mechanisms are overlooked in long-term projections of the evolution of electricity generation in both technologically-rich, partial equilibrium optimization ("bottom-up") and globally consistent general equilibrium ("top-down") models.

Bottom-up models are technologically-rich and use exogenous projections of capital, fuel, operating, maintenance, and other costs to drive changes in total capacity of electricity generating technologies. Capacity factors for each technology are also exogenous which implies that existing capacity is unable to adjust to the prevailing economic conditions, and new capacity must operate at a preordained level. Another major criticism is that price projections are exogenous despite the possibility that both demands for fuel and their corresponding prices are endogenously determined by changes in the electricity sector. Endogenously determined capacity factor utilization requires endogenously determined prices. This point will only increase in importance considering the dynamic energy landscape and possibilities for international trade. Top-down, namely computable general equilibrium (CGE), models have endogenously determined prices and trade, but typically characterize the substitution of technologies in generation (GWh) terms directly, which treats factor utilization and capacity expansion implicitly. This ignores a key distinction in how different economic and policy shocks impact the electric power sector. For instance, fuel price shocks (e.g. decline in gas prices as a result of the shale boom) can be adjusted for in the short-term with existing infrastructure prior construction of new capital and decommissioning of old. However, subsidies to capital (e.g. investment tax credits in the US) impact only new capital investments.

This work formulates a partial equilibrium model which explicitly and *endogenously* captures factor utilization, capacity expansion, and their independency. The model also introduces a novel variant of the constant elasticity of substitution function which is homothetic in inputs (i.e. GWh). Model estimates for factor utilization, capacity expansion, and total generation are each validated against observations between 2002 and 2012. Next, the partial equilibrium model is translated into a CGE model with endogenously determined prices. An endowment shock is applied to gas resources which simulates the decline in gas prices resulting from the shale gas boom in the US. Factor utilization in the short-term, capacity expansion in the long-term, and their joint impact on the evolution of the electricity sector are explored to 2020 against the backdrop of other relevant policies in the US electricity sector (i.e. investment tax credits for renewables and emission quotas).

## Methods

The model focuses on the following accounting relationship between generation and capacity:

$Q\_{t}^{g}=c\_{t}∙α∙Q\_{t}^{c}$ (1)

where $Q\_{t}^{g}$ is the quantity of GWh generated by technology *t*. $c\_{t}$ is the capacity factor (i.e. share of actual production out of total possible use) for technology *t*. $Q\_{t}^{c}$ is the quantity of capacity (in GW), and α is the number of hours (one calendar year ~ 8,760 hours). The quantity of generation can be increased (decreased) by increasing (decreasing) the capacity factor and/or the total capacity. Here, the representation explicitly represents factor utilization and capacity expansion in the generation of electricity.

There are two components of factor utilization: flexibility and substitutability. Flexible technologies can adjust production levels using existing capacity (i.e. coal, oil, and gas power). Inflexible technologies (i.e. nuclear, hydro, wind, solar, and other) show little utilization in response to the changing economic conditions. Their variability is a result of normal annual operational fluctuations rather than in response to prevailing economic conditions. Elastic and inelastic supply curves are estimated for each flexible and inflexible technology, respectively.

To capture the change in capacity factor, $c\_{t}$, we estimate a modified constant elasticity of substitution function which is homothetic in inputs (i.e. GWh from each technology sum to the total GWh). There are separate nests for base and peak load technologies which are then Leontief inputs to total generation and transmission and distribution.

Capital expansion is represented with capacity supply elasticities which respond to the change in value of capital rents. Plants are decommissioned at a uniform annual rate estimated from EIA data. These representations of factor utilization and capacity expansion are consistent with standard economic theory and can be easily integrated with non-linear CGE models which include endogenous prices to study their interactions.

## Results

To validate capacity factor utilization, the partial equilibrium model is subjected to shocks to the main determinants of factor utilization (i.e. fuel prices) and some important longer-term determinants of demand and supply - population and technical efficiency of the electricity sector. In the validation scenario there is no long-term capacity growth (factor utilization only). The model has a base year of 2007 which is shocked retrospectively to previous years back to 2002 and prospectively to 2012. The results for the change in capacity factor for each flexible technology are then compared to the observed capacity factors over that same time period (Figure 1).

Figure 1. Factor utilization validation of model results (Model) against observed values (Obs). (EIA data)

Capacity expansion and total generation (with both factor utilization and capacity expansion mechanisms) are also validated against EIA data. Next, we investigate how the shale oil and gas boom might impact the future mix of technologies and total electricity generation in the United States up to 2020. We find that large negative shocks to gas prices increases the capacity factor for gas plants (in both base and peak load markets) which drives an increase in capital rents and investment in gas capacity expansion. The endogenously determined increase in capacity factor drives an additional increase in returns to capital and thus more investment than from the reduction in generation cost alone (as is the case with many existing models).

## Conclusions

Factor utilization and capacity expansion are two distinct mechanisms in the evolution of electricity generation. This work presents a model which explicitly and *endogenously* captures factor utilization, capacity expansion, and their interactions in long-term projections of electricity generation. The model also implements a novel CES function which is homothetic in quantities. The validation exercises (e.g. Figure 1) provide convincing evidence in the model’s predictive ability. Experiments show that endogenous capacity factor utilization has an important impact on returns to capital and, in turn, investment in capacity expansion, which is demonstrated in the context of the highly relevant shale oil and gas boom in the United States. Thus, the joint mechanisms described here are of importance in highly dynamic energy landscapes such as the current experience in the United States. This work advances the state-of-the-art in both bottom-up and top-down electricity modeling.

## References

U.S. Energy Information Administration (2015). Electricity database. <<http://www.eia.gov/electricity/data.cfm>>