***Electricity Market Restructuring and Investment in Nuclear Power Generation – Evidence from Power Uprates in U.S. Nuclear Industry***

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Ph.D. Option in Energy Management and Policy

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## Overview

Following the Energy Policy Act of 1992 and Federal Energy Regulatory Commission (FERC) Order 888, many U.S. states and the District of Columbia introduced competition to the wholesale electricity market and eventually transition to the consumer choice of “shopping” electricity in the retail electricity market. Before electricity market restructuring, utilities were vertically integrated monopolies being granted franchise to serve customers in specific geographic areas but subject to rate-of-return regulation by state public utility commissions. Averch and Johnson (1962) argued that the guaranteed rate-of-return provided incentives for these regulated monopolies to engage in excessive amounts of capital investment, in order to expand the volume of their profits, including enthusiasm of investments in nuclear power plants in late 1960 and early1970.

Electricity market restructuring nevertheless stirred the stable and mature nuclear industry and brought significant impact to these base-load nuclear power plants. Before electricity restructuring enactments in relevant states became effective, some utilities were concerned that their nuclear generation units were unable to compete in the deregulated market. Six power reactors were shutdown prematurely in 1997 and 1998. However, it turned out that the remaining nuclear plants were able to operate competitively and efficiently in wholesale electricity markets and the entire U.S. nuclear fleet in turn managed to increase nuclear electricity generation from 612.6 billion Kilowatt-hours in 1991 to 798.7 billion Kilowatt-hours in 2009, which accounted over 20% of overall power generation in U.S. One of the primary reasons is that U.S. nuclear industry aggressively added a cumulative 5,810 MWe of generation capacity to the existing nuclear plants through power uprates (PUs) as end of 2010, which was equivalent to five to six new 1,000 MWe reactors. And 3,600 MWe of the aforementioned capacity addition took place after 2001.

The objective of this paper is to study whether state-level electricity restructuring provided incentives for utilities or independent power producers to invest in nuclear power uprates. We hope this study could also provide insights regarding the prospects of new nuclear power investment in restructured markets. This question is important because as mentioned in an interdisciplinary MIT study (MIT 2003 and 2009), it is essential to retain nuclear power as a significant option for reducing greenhouse gas emissions and meeting growing needs for electricity supply. Given that construction of new nuclear plants had been in stagnation in U.S. over the past twenty years, it is therefore important to have a better understanding about impacts of electricity restructuring on investment in new nuclear plants.

This study is based on power uprates applications submitted to U.S. Nuclear Regulatory Commission (U.S. NRC) between 1991 and 2010 for all investor-owned nuclear power reactors that were active during the study period. Using panel data with fixed effect regression, I find strong and consistent evidence that electricity restructuring did provide incentives for power uprates investments. However, investors prefer Stretch power uprates over Extended power uprates, even though the latter could add up to 20% of generation capacity but requires a higher upfront cost per unit of capacity added. This further suggests that construction cost is one of the dominant factors affecting new nuclear plant investments.

## Methods

I use panel data regression with fixed effect at reactor level to test if electricity restructuring did provide incentives for investor-owned utilities or power generators to make power uprates investments in deregulated regime. I refer to one-stage regression model of Zhang (2007) and lay out the econometric specification as the following:

$$Y\_{it}=β\_{0}+β\_{1}Regulatory\_{it}+β\_{2}Fleet\_{it}+β\_{3}Capacity\_{it}+β\_{4}Demand\_{it}+γZ\_{it}+\sum\_{t=1991}^{2010}δ\_{t}T\_{t}+u\_{i}+ε\_{it}$$

where the dependent variable $Y\_{it}$ is any three types of power uprates applications of power reactor *i* submitted to U.S. NRC in year *t*, in either the number or the capacity addition (MWt) of power uprates applications.

Ultimate interest of this research lies on the $Regulatory\_{it}$ variable, which is binary variable indicating regulatory status of each power uprate investment, when one denotes power reactor *i* located in state having electricity restructuring enactment effective in year *t* and thus any capital investment in power uprates is not subject to traditional rate-of-return regulation and cost recovery by state public utility commission, and zero denotes otherwise.

Regarding other independent variables in the econometrics specification, $Fleet\_{it}$ is the number of nuclear reactors in a generation fleet owned by the same indenpendt power producer or regulated utility in year *t,* and $Capacity\_{it}$ is the operation thermal limit (MWt) approved by U.S. NRC of reactor *i* in year *t*. These two variables are to capture possible economies of scale. The variable $Demand\_{it}$ on the other hand is to capture the impact of electricity demand in stae level on power uprates investment decision. I used $ state\\_sales\_{it}$ variable, which is annual electricity sales (MWh) within the state where power reactor i located in year t.

The vector $Z\_{it}$ determines various reactor characteristics, specificly plant vintage and expiration of operation license. Year-specific dummy variable $T\_{t}$ ( t=1991,1992,1993,…2010 ) is also included to pick up exogenous effects common to different reactors, such as technical progress of conducting power uprates in the industry. An unobservable reactor-level time-invariant fixed effect is represented by $u\_{i}$ to capture fixed characteristics that affect power uprates investment.

## Results

The coefficient estimates of the “Regulatory” variable consistently remain significance regardless putting different dependent variables in the model, which strongly suggests that electricity restructuring did provide incentives for generators to carry out any three types of power uprate investments. And among three types of power uprates, investors prefer Stretch power uprates over Extended power uprates, even though the later could increase capacity up to 20 percent. This result may suggest that upfront construction cost may still be impediment for new nuclear power plant investment, since Extended power uprates may cost up to over $1,800 per KWe, but Stretch power uprates only cost within $600 to $800 per KWe range (Kang 2008).

## Conclusions

This paper examines whether electricity restructuring provides incentives to invest in nuclear power uprates. By investigating power uprates applications data of 91 investors-owned power reactors in U.S. during the period of 1991 to 2010, this research provides evidence for the connection between electricity restructuring and investments in nuclear generation capacity through power uprates, and the insights on new nuclear power plant investment in U.S. The differences among investments in three types of power uprates on the other hand suggests that upfront construction cost may still be impediment for investors who consider investing in new nuclear power plants. This observation is consistent with current federal polies and industrial activities, which both aim to reduce the risk and difficulty associated with financing nuclear generation facility. For example, the Department of Energy provides loan guarantee to new nuclear projects in accordance with the Energy Policy Act of 2005 . Major nuclear equipment vendors are also promoting smaller module reactors , allowing utilities or power generators to increase nuclear capacity in their generation portfolio by increments. However, Fukushima nuclear accident has once again put national nuclear policy in muddle, and its impact on the future of new nuclear plants investment in U.S. will be an interesting topic for further research.

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