Submission for 2011 Dennis J. O'Brien USAEE Best Student Paper Award

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

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I. INTRODUCTION

Following the Energy Policy Act of 1992 and Federal Energy Regulatory Commission (FERC) Order 888, many U.S. states and the District of Columbia began to introduce competition to the wholesale electricity market and eventually transition to the consumer choice of “shopping” electricity in the retail electricity market. Before restructuring, electricity 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 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, or “gold-plating.” Since state regulator demand high reliability of electricity supply, it was easy for these regulated utilities to justify their excess investments in generation or transmission facilities, including over investments in nuclear power plants during 1970 and 1980, as needed to prevent electricity shortages or blackouts.

Electricity restructuring 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 produce competitively priced electricity in the deregulated market based on their prospects of future operation & maintenance cost, major equipment replacement and market competition. They also wondered if they were able to make their nuclear generation assets economical in the long-term.

Six power reactors were shutdown prematurely in 1997 and 1998 (EIA [1998]) before their operation license expired. 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[1], 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[2], which was equivalent to five or six new 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 generators to invest in nuclear power uprates. We hope this study also provides insights regarding the prospects of new nuclear power investment in restructured markets. This question is important because as mentioned in an interdisciplinary MIT study [2005], 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

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[1] U.S. Energy Information Administration, *Annual Energy Review*, Table 9.2 Nuclear Power Plant Operations, 1957-2009. (Release Date: August 19, 2010)

[2] U.S. Nuclear Regulatory Commission, *Approved Applications for Power Uprates*. Retrieved from http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html

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 confirms that construction cost is one of the dominant factors affecting new nuclear plant investments.

The remainder of the paper is organized as follow: Section II provides a brief discussion of U.S. electricity restructuring and its potential impacts on investment in nuclear generation. Section III presents status of power uprates activities in U.S. nuclear industry. Section IV develops the empirical model. The data is presented in Section V, and the estimation results Section VI. Section VII concludes the paper.

II. ELECTRICITY RESTRUCTURING AND ITS IMPACT TO NUCLEAR GENERATION INVESTMENTON

In United States, three parts of electricity industry, namely generation, transmission and distribution, were traditionally assumed as a monopoly and being vertically integrated. Electricity restructuring in many states first broke such vertical integration and introduced competition in generation sector. Since then, the discussion of generation investment under restructured market regime – how, when and by whom will new capacity be added – often encounters a popular response, "the market will provide." With a market-driven system, utilities or power generators will invest in new generation capacity if a profit is expected.

Except in Northwestern states, bulk base-load electricity in the U.S. is generally supplied by thermal power plants, mainly coal-fired and nuclear plants. Compared with base-load fossil power plants, nuclear power has significant advantage of low operation cost, particularly when the price of fossil fuel fluctuates upward. During 1998 and 2009, nuclear generation had steadily cost around 21 mills per Kilowatthour, but generation cost of coal-fired fossil steam plants had doubled from around 20 mills per kilowatthour to over 40 mills per kilowatthour[3]. Once being operated efficiently, nuclear plants had become extremely profitable in competitive wholesale markets.

Also in wake of concern of climate change and more stringent air regulation, the benefit of zero carbon emission had made nuclear power advantageous, since total system levelized cost estimation for new advanced coal plants has reached $129.3 per megawatthour with carbon control and sequestration (CCS), which is even higher than total system levelized cost estimation at $119 per megawatthour for new advanced nuclear plants[4]. But nuclear generation remains most capital

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[3] U.S. Energy Information Administration, *Electric Power Annual*, Table 8.2. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 1998 through 2009 (Mills per Kilowatthour).

[4] U.S. Energy Information Administration, *Annual Energy Outlook 2010*, December 2009, DOE/EIA-0383(2009)

intensive in terms of estimated levelized capital cost, when excluding O&M cost, fuel cost and necessary transmission investment.

Although new nuclear plants may look promising, investors are still facing different uncertainties in restructured market. Holt, Sotkiewicz and Berg [2008] addressed uncertainties facing nuclear generation investment in restructured market paradigm during project development, construction and commercial operation phases, and how these uncertainties differ from uncertainties in the regulatory paradigm in which rate-of-return regulated utilities operate. Holt, Sotkiewicz and Berg (2010) also argued that these uncertainties are more pronounced in states with restructured retail electricity markets than in those with rate-regulated generation, given that restructured wholesale markets introduce uncertainty in commercial operation for nuclear plant operators with respect to prospective future revenue streams that depend on fossil fuel costs, fluctuations in demand, and outcomes in policies related to climate change and renewable energy technologies. In terms of future revenue streams, it has also been argued that competitive wholesale electricity markets for energy and operating reserves do not and perhaps cannot credibly provide sufficient net revenues to attract adequate investment in generation to meet conventional operating and investment economic efficiency and reliability criteria, referred to as the “missing money” problem (Joskow [2006]). Several market reform programs, such as forward capacity market, had been proposed to solve this problem. Although some of these programs look promising, there is no academic consensus on which electricity market design provides the least distorting investment incentives (Roques et el. [2005]).

Therefore, although eighteen combined license applications (COL) to build 28 new nuclear reactors had been received by United States Nuclear Regulatory Commission as of March 2011[5], we have not yet noticed significant progress other than those applications. The economic viability of some of these projects has been put in doubt due to flattened growth of demand and decrease in natural gas price. North American Electric Reliability Council [1996] raised their concern that the adequacy of existing and planned resources and transmission systems will become less certain because commitments to new resources were being delayed to the last possible moment, and recommended that state, provincial, and federal regulators need to encourage investment in long-term bulk power system projects [2007].

Contrary to new nuclear build, which associated with heavy regulatory scrutiny that any new nuclear reactor may receive, industry players use uprates to increase capacity instead of adding firm locations. Given that the cost of nuclear fuel and O&M are essentially fixed for any operational nuclear power plants (see EIA [1998]), uprating the power output of nuclear reactors is recognized as a highly economic source of additional generating capacity (see WNA [2005]) and is much easier than constructing a new plant. By refurbishing the turbine generators combined with utilizing safety margins in initial reactor designs and digitalizing instrumentation and control systems, nuclear plant generation

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[5] U.S. Nuclear Regulatory Commission, *COL Applications Received*. Retrieved from http://www.nrc.gov/reactors/new-reactors/col.html

capacity can be increased significantly by up to 15 to 20%.

III. POWER UPRATES IN U.S. NUCLEAR INDUSTRY

Based on U.S. NRC regulation, power uprates (PUs) are categorized as three types, which are measurement uncertainty recapture (MUR), stretch (S) and extended (E) power uprates. MUR PUs are less than 2 percent increase of power output and involves the use of latest flow measurement devices to more precisely measure feedwater flow, which is important to improve thermal power within reactor. Stretch PUs are typically up to 7 percent increase of power output, which involve changes to instrumentation set points but do not involve major plant modifications. Extended PUs are as high as 20 percent of power output increase, which require significant modifications to major balance-of-plant equipment.[6]

U.S. nuclear industry had actively undertook power uprates to tweak more megawatts out of an existing power plant without turning a spade of dirt in the past decades. Between 1977 and 2010, U.S. NRC had approved 135 power uprates applications, which added 17,429.2 MWt or 5,810 MWe of nuclear generation capacity, equivalent to five to six new power reactors. 3,600 MWe or 60% of the aforementioned power uprate applications were approved since year 2001. U.S. NRC also expects another 1,840 MWe capacity of power uprates applications through 2015 based on a December 2010

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[6] See *Types of Power Uprates*. U.S. NRC at http://www.nrc.gov/reactors/operating/licensing/power-uprates/type-power.html

survey of its licensees.[7] Major nuclear generators such as Exelon and Entergy all announced their

Since power uprates involves amending commercial nuclear power plant licenses, nuclear generators or licensees shall prepare application document along with technical specifications related to power uprates and submit for U.S. NRC review and approval in accordance with process governed by 10 CFR 50.90, 50.91 and 50.92. U.S. NRC may approve or deny the power uprate request. Besides U.S. NRC regulation, generators or utilities in states maintaining traditional rate-of-return regulation shall also first demonstrate to state regulator that the power uprate investment is needed; cost recovery will be subject to state regulator's prudence review.

IV. ECONOMETRIC MODEL

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:

$$Y_{it} = \beta_0 + \beta_1 Regulatory_{it} + \beta_2 Fleet_{it} + \beta_3 Capacity_{it} + \beta_4 Demand_{it} + \gamma Z_{it} + \sum_{t=1991}^{2010} \delta_t T_t + u_i + \varepsilon_{it}$$

where the dependent variable Y_{it} is any three types of power uprates applications submitted to U.S. NRC for power reactor *i* in year *t*, in either the number or the capacity of power uprates investments. Y_{it}^{MUR}, Y_{it}^{S} and Y_{it}^{E} on the other hand counts MUR, Stretch and Extended power uprates

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[7] U.S. Nuclear Regulatory Commission, *Expected Applications for Power Uprates*. Retrieved from http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/expected-applications.html

applications respectively submitted for power reactor *i* in year t.

$Regulatory_{it}$ is binary variable of regulatory status of 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 and cost recovery regulation by state public utility commission, and zero denotes otherwise.[8]

$Fleet_{it}$ is the number of nuclear reactors in a generation fleet owned by the same power generator or regulated utility in year *t*, where power reactor *i* is in such generation fleet. The reason to include this variable is because merger and transfer of power reactor ownerships had actively took placed since market deregulation. It is assumed that the larger the nuclear generation fleet owned by the same entity becomes through merger or acquisition, the higher the possibility or ability would the generator or utility to undertake power uprate investment[9]. $Capacity_{it}$ is the operation thermal limit (MWt) approved by U.S. NRC of reactor i in year t. This variable is time-variant since U.S. NRC amend operation thermal limit after approving each power uprate application. These two variables are to capture possible economies of scale.

The variable $Demand_{it}$ is to capture the impact of electricity demand to power uprates investment decision. I used two different demand variables respectively in my analysis, which are

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[8] U.S. EIA. *Status of Electricity Restructuring by State*. Retrieved from http://www.eia.doe.gov/cneaf/electricity/page/restructuring/restructure_elect.html

[9] Number of nuclear reactors owned by the same generator in any year *t* throughout the analysis period was summarized based on data retrieved from Form EIA-860 Annual Electric Generator Report.

(1)$state\_sales_{it}$: indicating annual electricity sales (MWh) within the state where power reactor *i* located in year *t*.[10] (2)$avg3yr_{it}$: indicating average electricity sales growth rate (%) in the previous three years from year *t*.

The vector Z_{it} determines reactor characteristics, includes:AGE_{it}, which is how many years the reactor *i* being put into commercial operation; and $Expiration_{it}$, which is how many years left before expiration of operation license of reactor *i*. Since some reactors have obtained operation extension approval from U.S. NRC and some have not, thus there should be no collinearity between AGE_{it} and $Expiration_{it}$.

Year-specific dummy variable T_t $(t = 1991, 1992, 1993, \ldots 2010)$ 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.

V. DATA AND DESCRIPTIVE ANALYSIS

This study uses a highly balanced panel of 91 investor-owned nuclear power reactors[11] and its

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[10] US EIA. *Detailed Sales and Revenue Data by State, Monthly Back to 1990 (Form EIA-826)*. Retrieved from http://www.eia.doe.gov/cneaf/electricity/page/sales_revenue.xls

[11] Nuclear plants owned by federal, state or municipal agencies were excluded from my analysis, including Browns Ferry, Sequoyah and Watts Bar owned by Tennessee Valley Authority, Cooper owned by Nebraska Public Power District, and Fort Calhoun owned Omaha Public Power District. Nuclear plants owned by a diverse mix of an investor-owned utility, electric cooperatives, and municipality groups were also excluded from analysis, whenever an investor-owned utility only have less than 50% of ownership, including Palo Verde in Arizona and Catawba in South Carolina.

associated power uprates applications submitted to U.S. NRC between 1991 and 2010. Power uprates data before 1990 was excluded in this study since accumulative power uprates applications were only 511 MWe in 1990 and were far before electricity restructuring took place.

To identify when power uprates investment decisions were being made and timeline them with electricity restructuring enactments in state-level , I use "year of power uprate application submission" instead of "year of U.S. NRC approval" of each power uprates, since it generally takes U.S. NRC about 12 months to review and approve power uprates applications. Thus "year of power uprate application submission" by U.S. NRC licensees provides better signal of the timing that power uprate investments were actually kicked-off.[12] There were also cases that in states maintaining tradition rate-of-retuen regulation, even though state public utility had granted approval of power uprates investment, such regulated investor-owned utility somehow delayed or canceled their investment plan and never submitted uprate application to U.S. NRC. Thus utilizing only U.S. NRC uprate application and approval data could provide us a more solid analysis basis. Table I list the summary statistics of power uprates data in reactor level.

Table I – Summary Statistics of Reactor-Level Power Uprates Application Data

Type of PUs	Total Number of PUs Applications	Total MWt of PUs Applications	Approx. MWe
MUR	49	2,161	720
Stretch	41	5,879.2	1,959.7

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[12] I retrieve power uprate application documents from NRC website and identify year of application submission of each uprate in the analysis.

Extended	28	9,501	3,167

VI. EMPIRICAL RESULTS

VI (i). Estimating Number of Power Uprates Applications

Table II through V report results from estimating number of power uprate applications identified in equation (i) via panel data regression with fixed effect. From the results in Table II, the coefficient estimates of the “Regulatory” variable consistently remain significance regardless different specifications of the model, which strongly suggests that electricity restructuring did provide incentives for generators to more likely carrying 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 nuclear generation investment, since Extended power uprates cost up to over $1,400 per KWe, but Stretch power uprates only cost around $600 per KWe (Kang [2008]).

Two variables to capture possible economies of scale end up with opposite statistical significance. Coefficient estimates of the Fleet variable are not significant in any of regression, which implies that utility or power generator owning larger fleet does not necessary to make more power uprates investments, and the investment decisions may be more likely made based upon business model in where the power reactor operates. The significance of the Capacity variable on the other hand is expected, since for power reactors with higher initial nameplate capacity, there are many other ways to increase thermal output within original design limit, and is less necessary to do power uprates.

For two variables to capture the impact of plant vintage to power uprates investments, there are no consistent statistical significance across different model specifications. But in general, the results of the Age variable implies that the odder the power reactor, the more likely to do Stretch and Extended power uprates, since it is necessary to replace equipment which wear down during normal plant operation for the safety concern.

Finally, none of any two of Demand variables are consistently and statistically significant associated to power uprates investments, which implies that the growth of electricity demand may not be a decisive factor for power uprates investments.

Table II – Determinants of Number of Any Three Types of Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	.0340555* (.017481)	.0501297*** (.0185225)	.0462535** (.0190292)	.0514068** (.0223383)	.054143** (.0227823)
Fleet		.0018755 (.0029432)	.0025742 (.0031846)	.0026911 (.0031965)	.004948 (.0034507)
Capacity		-.0088015*** (.0019331)	-.0111946*** (.0009934)	-.0111498*** (.0009983)	-.0126841*** (.0011636)
Age			.0085773*** (.0020375)	.0074419*** (.002692)	.0080497*** (.0022818)
Expiration			-.0016353* (.0009105)	-.0017371* (.0009071)	-.0019795** (.0009176)
State_sales				.0846304 (.135453)	
Avg3yr					.0712324 (.5692881)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis.

*** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table III – Determinants of Number of MUR Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	-.0044453 (.0097295)	-.003928 (.0098894)	-.0058875 (.0098911)	-.0006154 (.0103893)	-.0111844 (.0118985)
Fleet		.0013388 (.0014662)	.001501 (.0015284)	.0016206 (.0015157)	.002048 (.0016196)
Capacity		-.0014128** (.0006522)	-.0020534*** (.0006145)	-.0020076*** (.0006296)	-.0025916*** (.000747)
Age			.0040973*** (.0014028)	.0029358* (.0016744)	.0048755** (.0020695)
Expiration			-.000804 (.0007461)	-.000908 (.0007448)	-.000789 (.0008038)
State_sales				.0865791 (.0835533)	-.2557125 (.4114567)
Avg3yr					
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table IV – Determinants of Number of Stretch Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	.0268912* (.0138893)	.0380025*** (.0139726)	.0375803*** (.0139745)	.0362955** (.0149699)	.048807*** (.0166235)
Fleet		-.0012062 (.0016675)	-.00088 (.0016434)	-.0009092 (.0016543)	.0002241 (.0015731)
Capacity		-.003873*** (.0011035)	-.0048785*** (.0010189)	-.0048897*** (.0010171)	-.0043376*** (.0010466)
Age			.0009382 (.0008662)	.0012212 (.0014531)	-.0014995 (.0013253)
Expiration			-.0002078 (.0004881)	-.0001825 (.0005075)	-.0003228 (.0004856)
State_sales				-.0210994 (.0850008)	
Avg3yr					.3228186 (.2758927)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table V – Determinants of Number of Extended Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)

Regulatory	.0116095 (.0096122)	.0160552 (.0108646)	.0145606 (.0114665)	.0157267 (.0121333)	.0165204 (.013437)
Fleet		.0017428 (.0017879)	.0019532 (.0019094)	.0019797 (.001923)	.0026759 (.002212)
Capacity		-.0035157*** (.0008243)	-.0042626*** (.0006527)	-.0042525*** (.0006494)	-.0057549*** (.0007775)
Age			.0035418*** (.0012842)	.0032849*** (.0011611)	.0046737*** (.0015898)
Expiration			-.0006235 (.000528)	-.0006466 (.0005352)	-.0008676 (.0005428)
State_sales				.0191506 (.0652157)	
Avg3yr					.0041263 (.2519799)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor’s licensed thermal list in MWt. (2) State_sales is the log of a state’s annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

VI (ii). Estimating Capacity Addition of Power Uprates Applications

By replacing dependent variable with capacity addition (in MWt) of each power uprates application in panel data, Table VI through IX report results from estimating capacity addition of each power uprate applications. The results of statistical significance of each independent variables are mainly as same as to what we have through Table II to V.

Table VI – Determinants of Capacity Addition of Any Three Types of Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	7.601799** (3.38314)	11.47205*** (4.149998)	10.68375** (4.384719)	11.60237*** (4.602471)	11.36901** (4.686177)
Fleet		.2939528 (.9428425)	.4274262 (1.0038)	.448267 (1.010301)	.8814717 (1.088453)
Capacity		-1.979905*** (.4118009)	-2.440921*** (.2270566)	-2.432947*** (.2252278)	-2.971075*** (.2891966)
Age			1.742029*** (.4965952)	1.539647*** (.505864)	1.920286*** (.5944115)
Expiration			-.3315497 (.2100728)	-.3496825 (.2184988)	-.4360663** (.2071776)
State_sales				15.08594 (27.49211)	
Avg3yr					3.881923 (102.0736)

Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table VII – Determinants of Capacity Addition of MUR Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	.0938715 (.4028894)	.0187588 (.4246576)	-.0909553 (.423678)	.2072741 (.4424873)	-.2587281 (.4897025)
Fleet		.1092718 (.0733811)	.1133727 (.0763388)	.1201387 (.075722)	.1438441* (.0794768)
Capacity		-.0631549** (.0285061)	-.0841927*** (.030746)	-.0816039*** (.0312785)	-.1115515*** (.0376445)
Age			.1879888*** (.0705834)	.1222859 (.0848346)	.2150885** (.099922)
Expiration			-.044423 (.0350289)	-.0503098 (.0354109)	-.0449475 (.0378556)
State_sales				4.897623 (3.858198)	
Avg3yr					-15.09492 (17.02264)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table VIII – Determinants of Capacity Addition of Stretch Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	3.634271* (1.999918)	5.570507*** (2.049609)	5.614305*** (2.097159)	5.661013** (2.276281)	6.804287*** (2.220084)
Fleet		-.2908344 (.2596942)	-.2377197 (.2562501)	-.2366601 (.2579947)	-.0411531 (.2357792)
Capacity		-.603646*** (.1734322)	-.7583634*** (.1598588)	-.757958*** (.1599145)	-.6713482*** (.1585664)
Age			.1979554 (.1292464)	.1876653 (.2275401)	-.1275597 (.1750075)
Expiration			.0112231 (.080675)	.0103011 (.0834322)	-.0007002 (.0768051)
State_sales				7670405 (13.49386)	
Avg3yr					33.17296 (38.23508)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

Table IX – Determinants of Capacity Addition of Extended Power Uprates Applications

Independent Variables	(1)	(2)	(3)	(4)	(5)
Regulatory	3.873657 (3.021047)	5.882788 (3.834111)	5.160398 (3.990829)	5.734086 (4.001424)	4.823456 (4.296464)
Fleet		.4755155 (.8200715)	.5517732 (.8671597)	.5647884 (.873403)	.7787807 (.9856181)
Capacity		-1.313104*** (.3407499)	-1.598365*** (.2929293)	-1.593385*** (.2913444)	-2.188175*** (.3500356)
Age			1.356085*** (.4860423)	1.229696*** (.4258917)	1.832758*** (.604691)
Expiration			-.2983498 (.1985011)	-.3096739 (.2077702)	-.3904187* (.1990359)
State_sales				9.421279 (23.86146)	
Avg3yr					-14.19612 (90.97722)
Obs	1820	1820	1818	1818	1547

Note: (1) Capacity is the log of a reactor's licensed thermal list in MWt. (2) State_sales is the log of a state's annual electricity sales in trillion watt-hours. (3) Robust standard errors clustered by reactor are reported in the parenthesis. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level.

VII. POLICY IMPLICATIONS AND 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[13]. Major nuclear equipment vendors are also promoting smaller module reactors[14], 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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