ONLINE DATA APPENDIX
Deregulation, Consolidation, and Efficiency: Evidence from U.S. Nuclear Power

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This study is conducted using the most comprehensive dataset ever compiled on the operations of U.S. nuclear power reactors. Our primary dataset describes forty years of monthly operating performance for the universe of U.S. nuclear power reactors. This long panel is important because it allows us to use a variety of different approaches for addressing possible concerns about selection and pre-existing trends (see Section III D in the paper). We also put considerable effort into constructing detailed histories of the companies that own and operate nuclear reactors – information that we use to construct our measures of divestiture and consolidation. The 40-year monthly panel was constructed using data from the U.S. Department of Energy's *Power Plant Report* (EIA-923).[1] The *Power Plant Report* is a monthly survey of operators of nuclear reactors and other large electric generating facilities that includes total electricity generation and other information.[2] The compiled dataset provides a complete record of monthly generation for all reactors from 1970 to 2009. Of the 103 reactors used in our analysis,

[1] Previous versions of the EIA-923 were the EIA-906 and EIA-759.

[2] Reactor operators report monthly net electricity generation in megawatt hours (MWh). With electricity generation there is a distinction between gross generation and net generation, where net generation accounts for the electricity consumed by the plant itself and therefore can be negative during shutdowns. Power plants are supposed to report net generation rather than gross generation, but the presence of many exact zeros, particularly during the 1970s and 1980s suggests that at least some plants during some years were reporting gross generation instead. Fortunately in practice the difference is negligible for nuclear power plants because on-site electricity consumption averages less than 1% of total electric generation.

only two began commercial operation prior to 1970 so the dataset includes the entire operating history for all but two reactors.[3] Reactor outages are recorded as zeros. There are no missing observations.

During the relevant period there is very little entry or exit of nuclear reactors. This simplifies the analysis considerably because it mitigates concerns about selection bias that have been an important issue in analyses of deregulation in other markets (e.g. Olley and Pakes 1996). We include in the main analysis all U.S. nuclear power reactors that were operating as of January 1, 2000. This excludes a small number of reactors that were closed during the 1990s, including Millstone 1 and San Onofre 1. No nuclear reactors have been closed in the United States since 1998. As of 2011 there are 104 operating nuclear reactors in the United States. We have 103 in our panel because we have excluded Browns Ferry 1 which was closed for more than two decades between 1985 and 2007.

The most commonly reported measure of nuclear reactor operating performance is the capacity factor,

$$\frac{net\ generation\ (in\ MWh)}{maximum\ potential\ generation\ (in\ MW) * number\ of\ hours} * 100. \tag{1}$$

Capacity factor is calculated as the ratio of actually generated power and maximum potential generation. Usually reported in percent as it is here, the capacity factor is a convenient summary measure of performance that is easily interpretable and facilitates comparisons of performance across reactors of different sizes.

For our baseline estimates we use a closely related measure,

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[3] During 1970-1985 and 2001-2002, generation in the *Power Plant Report* is reported at the plant level but not reported separately for individual reactors within multi-reactor plants. Of the 65 plants in our sample, 29 have one reactor, 33 have two reactors and 2 plants have three reactors (Oconee and Palo Verde). During these years for multi-reactor plants we impute reactor-level measures of generation by assigning plant-level generation to each reactor proportionately to each reactor's capacity. This imputation is unlikely to bias our results because divestitures tend to occur at the same time for all reactors in multi-reactor plants. The one exception is Indian Point where prior to 2001 the plant's two active reactors had different owners. It turns out, however, that because of this ownership structure the *Power Plant Report* includes reactor-level generation for Indian Point for all years, making no imputation necessary.

$$\frac{net\ generation\ (in\ MWh)}{reactor\ design\ capacity\ (in\ MW) * number\ of\ hours} * 100. \qquad (2)$$

When reactor design capacity is equal to maximum potential generation these two measures are identical. The important difference between (1) and (2) is that reactor design capacity does not change over time whereas maximum potential generation may change over the lifetime of a reactor. Consequently, the latter measure reflects both the *intensity* with which the reactor is used and *changes* over time in maximum potential generation. Whereas capacity factor never exceeds 100, our measure can exceed 100 for a reactor that on average during a period operates at a level of generation above the reactor design capacity. Later in the paper we examine these two components separately, but for the baseline estimates it is valuable to have a single measure.[4] We use the reactor design capacities reported in U.S. Department of Energy, Energy Information Administration, *Nuclear Power Generation and Fuel Cycle Report 1997*, "Appendix C: Nuclear Units Ordered in the United States, 1953-1996."

The *Power Plant Report* also contains information about reactor operators including whether the reactor operator is a utility or a nonutility. We use this information to construct an indicator variable for reactors that have been divested. We identify divestitures in the *Power Plant Report* as the first month in which a reactor changes its status from utility to nonutility.[5] These same data were also used to describe industry consolidation. For each reactor and month observation we calculate the

[4] For our baseline estimates we might have alternatively used net generation itself (without this scaling) or net generation in logs. We prefer our measure because U.S. reactors vary widely in design capacity. Net generation in logs would help address this issue, but is not well suited to our application because we have a large number of zeros and negative numbers for net generation.

[5] See Appendix Table 2 for the complete list of divestitures. Because this variable is central for our analysis we put considerable effort into cross-checking divestiture dates against alternative sources. Our primary alternative source of divestiture dates is the U.S. Department of Energy, Energy Information Administration, *Electric Power Monthly*, which in March issues between 2000 and 2003 includes a table ``Electric Utility Plants That Have Been Sold and Reclassified" listing generating facilities that have been reclassified as non-utilities. For the years in which *Electric Power Monthly* is not available we cross-checked the divestiture dates against SEC filings from the companies involved in the transaction. In the vast majority of cases the different sources report the same divestiture date. For a small number of cases in which there were minor discrepancies in divestiture dates between the different sources we rely on SEC filings. Also in some cases the *Power Plant Report* identifies the year but not the month of divestiture and we have used the alternative sources to determine the exact month.

number of other reactors operated by that reactor's operator.[6] In cases where companies are subsidiaries of other companies we treat this as the same company. Where this is unclear we used SEC filings to determine the ownership structure.[7] Much, but not all, of the variation in consolidation is driven by divestitures so our careful treatment of the divestiture dates and operator changes helps ensure the accuracy of this measure.

We also use data from the U.S. NRC's *Power Reactor Status Reports*. These data are available for a shorter time period (1999-2009), but are available daily compared to monthly for the *Power Plant Report*. With higher frequency data, we can evaluate reactor outages with considerably more detail. Reactors are required to submit daily reports to the NRC describing capacity factor in percent. Reactors reporting less than 100% provide a brief explanation and reactors that are completely shutdown report whether the outages was due to a manual shutdown (e.g. refueling or maintenance) or an automatic shutdown, also known as a "scram." The daily data are a complete panel with no missing observations during this 11 year period; a total of 4,017 total days.

We augment the operating data from the *Power Plant Report* and *Power Reactor Status Reports* with time-invariant reactor characteristics including reactor type, reactor manufacturer, and the date that each reactor began commercial operation from the *NRC Information Digest 2010-2011* (NUREG-1350, Volume 22), published August 2010, Appendix A "U.S. Commercial Power Reactors."

Appendix Table 1 provides descriptive statistics. Panel A reports reactor characteristics. Reactor openings peaked during the 1970s and 1980s and most reactors had been operating for more than 10 years when divestitures began in 1999. The

[6] The *Power Plant Report* elicits information about reactor "operators" rather than "owners." For most reactors there is no distinction between the two. However, there are few reactors with multiple owners. In these cases typically the reactor is operated by the majority owner. There are also a small number of cases in which reactor owners signed operating contracts with outside companies.

[7] One complication is that AmerGen, at the time of some of the divestitures was 50% owned by Exelon and 50% owned by British Energy. In the baseline specification we treat these reactors as being wholly owned by Exelon. Results are essentially identical when we alternatively calculate consolidation for these reactor-month observations by multiplying by .50 the number of reactors owned by each of the co-owners. The simple correlation between the two consolidation measures exceeds .99.

descriptive statistics show that U.S. reactors consist of two different reactor types produced by four different reactor manufacturers.[8] In the paper we evaluate whether operating performance differs systematically across these different designs.

Panel B in Appendix Table 1 describes operating performance and outages. Mean net generation as a percent of design capacity increases substantially over our sample period from 61% during the 1970s to 92% during the 2000s. The daily reactor status data from the NRC reveals that reactors tend to operate either at full capacity or not at all. In our sample, 77% of all daily observations are 100% capacity factor and 9% are 0% capacity factor. It is relatively common for reactors to operate between 90% and 99% but capacity factors between 1% and 89% are less common and usually indicate a reactor that is ramping up or ramping down, rather than a reactor that is permanently operating at an intermediate power level. For 45% of all observations between 1% and 89% we find that there is a reactor shutdown within 7 days, compared to 23% for reactors operating 90-99%, and only 5% for reactors operating at 100%.

Finally, the table describes reactor outages over the period 1999-2009. By far the most common explanation for reactor outages is refueling. Here we have defined refueling as any outage in which refueling was occurring, regardless of whether or not other forms of maintenance were occurring at the same time. A smaller fraction of shutdowns are for maintenance not related to refueling. Finally, about 2% of shutdown-days were due to an automatic shutdown triggered by one of the reactor's safety systems. Also known as "scrams," this is when an operating nuclear reactor is shut down suddenly by rapid insertion of control rods, typically as a result of equipment or operator error. Whereas planned outages begin with a gradual decrease in power levels over several days, scrams shut down a reactor rapidly, putting great stress on plant equipment. There are a total of 831 scrams in our data, or 0.73 scrams per reactor year.

[8] In a nuclear reactor enriched uranium creates a chain reaction that creates heat that is used to produce electricity. Heat is produced either in the form of super-heated water in a pressurized water reactor or as steam in the case of a boiling water reactor. In our sample General Electric produced only boiling water reactors and the other three manufacturers produced only pressurized water reactors.

ONLINE APPENDIX TABLE 1

Descriptive Statistics: U.S. Nuclear Power Reactors

A. Reactor Characteristics (103 total reactors)

Number of Reactors By Vintage	
1960s	2
1970s	50
1980s	46
1990s	5
Number of Reactors By Type	
Pressurized Water Reactors	69
Boiling Water Reactors	34
Number of Reactors By Manufacturer	
Westinghouse	48
General Electric	34
Combustion Engineering	14
Babcock and Wilcox	7

Notes: Our sample includes all reactors that were operating as of January 1, 2000. Vintage, reactor type, and reactor manufacturer come from the *NRC Information Digest 2010-2011* (NUREG-1350, Volume 22), published August 2010. Vintage is defined as the decade the reactor began commercial operation.

ONLINE APPENDIX TABLE 1 (continued)

Descriptive Statistics: U.S. Nuclear Power Reactors

B. Operating Performance and Reactor Outages

Net Generation as a Percent of Design Capacity (Department of Energy)	
1970s	61%
1980s	61%
1990s	75%
2000s	92%
Daily Reactor Status 1999-2009 (Nuclear Regulatory Commission)	
Percentage of Daily Observations at 100% Capacity Factor	77%
Percentage of Daily Observations at 90% - 99%	9%
Percentage of Daily Observations at 1% - 89%	4%
Percentage of Daily Observations at 0%	9%
Outages 1999-2009 (Nuclear Regulatory Commission)	
Percentage of Outage Days Manual Shutdown for Refueling	73%
Percentage of Outage Days Manual Shutdown for Other Reasons	24%
Percentage of Outage Days Automatic Shutdown ("scram")	2%

Notes: This table describes operating performance and reactor outages for the 103 U.S. nuclear power reactors that were operating in the United States as of January 1, 2000. Capacity factor in the first four rows was calculated by the authors by dividing generation levels from U.S. Department of Energy, Energy Information Administration, *Power Plant Report* (EIA-906), 1970-2009 by design capacity (in MWe) from U.S. Department of Energy, Energy Information Administration, *Nuclear Power Generation and Fuel Cycle Report 1997*, "Appendix C: Nuclear Units Ordered in the United States, 1953-1996." Daily reactor status and explanations for outages come from U.S. NRC, *Power Status Reports*.

ONLINE APPENDIX TABLE 2

U.S. Nuclear Reactors Divestitures (1999-2007)

Reactor Name	Design Capacity	State	Sales Date	Seller	Buyer
Pilgrim	655	MA	7/1999	Boston Edison Co	Entergy
Clinton	950	IL	12/1999	Illinois Power Co	Amergen (Exelon)
Three Mile Island 1	819	PA	12/1999	GPU Nuclear Corp	Amergen (Exelon)
Calvert Cliffs 1	845	MD	7/2000	Baltimore Gas & Electric	Constellation
Calvert Cliffs 2	845	MD	7/2000	Baltimore Gas & Electric	Constellation
Susquehanna 1	1065	PA	7/2000	Penn Power and Light	PPL Corp
Susquehanna 2	1052	PA	7/2000	Penn Power and Light	PPL Corp
Hope Creek 1	1067	NJ	8/2000	Public Service E&G	PSEG Power
Oyster Creek	650	NJ	8/2000	GPU Nuclear Corp	Amergen (Exelon)
Salem 1	1090	NJ	8/2000	Public Service E&G	PSEG Power
Salem 2	1115	NJ	8/2000	Public Service E&G	PSEG Power
Fitzpatrick	821	NY	11/2000	Power Authority of New York	Entergy
Indian Point 3	965	NY	11/2000	Power Authority of New York	Entergy
Braidwood 1	1120	IL	1/2001	Commonwealth Edison	Exelon
Braidwood 2	1120	IL	1/2001	Commonwealth Edison	Exelon
Byron 1	1120	IL	1/2001	Commonwealth Edison	Exelon
Byron 2	1120	IL	1/2001	Commonwealth Edison	Exelon
Dresden 2	794	IL	1/2001	Commonwealth Edison	Exelon
Dresden 3	794	IL	1/2001	Commonwealth Edison	Exelon
La Salle 1	1078	IL	1/2001	Commonwealth Edison	Exelon
La Salle 2	1078	IL	1/2001	Commonwealth Edison	Exelon
Limerick 1	1065	PA	1/2001	Philadelphia Electric Co	Exelon
Limerick 2	1065	PA	1/2001	Philadelphia Electric Co	Exelon
Peach Bottom 2	1065	PA	1/2001	Philadelphia Electric Co	Exelon
Peach Bottom 3	1065	PA	1/2001	Philadelphia Electric Co	Exelon
Quad Cities 1	789	IL	1/2001	Commonwealth Edison	Exelon
Quad Cities 2	789	IL	1/2001	Commonwealth Edison	Exelon
Millstone 2	870	CT	3/2001	Northeast Nuclear	Dominion
Millstone 3	1156	CT	3/2001	Northeast Nuclear	Dominion
Indian Point 2	873	NY	9/2001	Consolidated Edison Co of NY	Entergy
Nine Mile Point 1	620	NY	11/2001	Niagara Mohawk Power	Constellation
Nine Mile Point 2	1080	NY	11/2001	Niagara Mohawk Power	Constellation

ONLINE APPENDIX TABLE 2 (continued)

U.S. Nuclear Reactors Divestitures 1999-2007

Reactor Name	Design Capacity	State	Sales Date	Seller	Buyer
Comanche Peak 1	1150	TX	1/2002	Texas Utilities Electric Co	TXU Generation
Comanche Peak 2	1150	TX	1/2002	Texas Utilities Electric Co	TXU Generation
Vermont Yankee	514	VT	7/2002	Vermont Yankee Nuclear Power Corporation	Entergy
Seabrook 1	1198	NH	11/2002	North Atlantic Energy Services Corporation	FPL Group
South Texas 1	1250	TX	1/2003	Reliant	CenterPoint
South Texas 2	1250	TX	1/2003	Reliant	CenterPoint
Ginna	470	NY	6/2004	Rochester Gas & Electric	Constellation
Kewaunee	535	WI	7/2005	Wisconsin Public Service	Dominion
Beaver Valley 1	835	PA	12/2005	Pennsylvania Power Company	FirstEnergy
Beaver Valley 2	852	PA	12/2005	Pennsylvania Power Company	FirstEnergy
Davis-Besse	906	OH	12/2005	Toledo Edison Co	FirstEnergy
Perry 1	1205	OH	12/2005	Cleveland Electric	FirstEnergy
Duane Arnold	538	IA	1/2006	Interstate Power And Light	FPL Group
Palisades	805	MI	4/2007	Consumers Energy Co	Entergy
Point Beach 1	497	WI	10/2007	Wisconsin Electric Power	FPL Group
Point Beach 2	497	WI	10/2007	Wisconsin Electric Power	FPL Group

Notes: Divestiture dates come from U.S. Department of Energy, Energy Information Administration, *Power Plant Report*. We identify divestitures using the first month in which a reactor operator changes its status from utility to non-utility. These dates were cross-checked against U.S. Department of Energy, Energy Information Administration, *Electric Power Monthly*, ``Electric Utility Plants That Have Been Sold and Reclassified,” March Issues 2000-2003 and against SEC filings from the companies involved.