Market Restructuring, Competition and the Efficiency of Electricity Generation: Plant-level Evidence from the United States 1996 to 2006

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This paper examines the effects of market restructuring initiatives that introduced competition into the United States electricity industry on the thermal efficiency of electricity generation. An empirical model is estimated on annual data for over 950 plants from 1996 to 2006. Model estimates show that access to wholesale electricity markets and retail choice together increased the efficiency of investor-owned plants by about nine percent and that these gains stem from organizational and technological changes within the plant. Although not directly targeted by restructuring initiatives, similar efficiency gains are also found for municipality-owned plants. This result suggests that the potential benefits from competition have spilled over to public electricity generation.

Keywords: Competition, Efficiency, Electricity generation

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1. INTRODUCTION

Electricity is a fundamental input for almost all economic activity. By reducing the retail prices faced by consumers, and the emission of carbon dioxide during production, the efficient generation of electricity has substantial potential to increase societal welfare. This paper examines empirically the effects on the

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thermal efficiency of generation plants from state market restructuring initiatives that introduced wholesale and retail competition into the United States (U.S.) electricity industry. Thermal efficiency is measured by the heat rate, the number of British Thermal Units (BTUs) of fuel used to generate a kilowatt hour (kWh) of electricity.

The electricity industry is comprised of generation, transmission and distribution. Until recently, U.S. electricity was typically supplied by vertically-integrated utilities with a monopoly in their local geographical area. These utilities were either privately owned by shareholders ("investor-owned utilities", "IOUs") or publically owned by cooperatives, municipalities, state and federal governments. The Federal Energy Regulatory Commission (FERC) regulated wholesale sales and the transmission of electricity in interstate commerce while state Public Utility Commissions (PUCs) oversaw generation, retail sales and intrastate transmission and distribution. FERC and the PUCs typically employed cost-based regulation whereby wholesale and retail prices were set to cover the utilities' costs of production plus a "fair" return on investment. Some states have also experimented with incentive regulations that made the utility the residual claimant to their cost-reducing effort and innovation.[1]

Market restructuring commenced with the passing of the Federal Energy Policy Act of 1992 and FERC Order No. 888 in 1996 which permitted non-utilities to enter wholesale markets and placed greater emphasis on market-determined prices for IOUs.[2] Individual states responded by considering the unbundling of generation, transmission and distribution so that multiple generators could compete with one another over the supply of electricity to retailers. This wholesale competition would ultimately take place in various centralized state or regional markets operated by seven regional transmission organizations or independent system operators (hereafter "RTOs").[3] Several states also considered initiatives that would directly relate retail prices to wholesale markets. These included the abolishment of cost-based rate regulation and the introduction of retail competition that allowed end consumers to buy their electricity from two or more retailers ("retail choice"). By removing restrictions on revenue and exposing plants to competitive wholesale and retail forces, market restructuring was expected to increase the incentives for managers to increase plant efficiency in order to decrease costs.

Several papers study the efficiency of investor-owned plants in states transitioning towards competition. Using data from coal and natural gas fueled

1. For example, heat-rate programs set price conditional on the firm-level average heat rate. Individual utilities with a relatively low heat rate were able to retain the incremental profits from being more efficient. To see a specific example see http://www.resourceinsight.com/work/naruc_pbr_97.pdf which describes in detail performance-based regulations tied directly to the heat rate for San Diego Gas and Electric.

2. Non-utilities are firms that generate, buy and/or sell electricity but are not involved in transmission.

3. See Table 1 for a description of RTO member states.

plants from 1981 to 1996; Knittel (2002) finds that heat-rate programs increased efficiency by about two percent. Hiebert (2002) estimates a stochastic frontier cost model for 633 fossil-fueled plants from 1988 to 1997. He finds that the mean efficiency of coal plants increased by about 50 percent in states preparing for retail competition. Fabrizio et al. (2007) estimate input demand functions for 769 fossil fueled plants from 1981 to 1999. They show that the labor and non-fuel expenses of plants in states that passed market restructuring legislation were about three to five percent lower than similar plants in states that did not pass legislation. Moreover, the implementation of retail choice provided incremental reductions in labor and non-fuel expenses of about three to 17 percent. Using data from 73 nuclear plants from 1992 to 1998, Zhang (2007) shows that the passing of market restructuring legislation was associated with a reduction in fuel, operating, and maintenance costs by eleven to 23 percent.[4]

This paper uses variation in the timing of market restructuring initiatives across states from 1996 to 2006 to measure the effects of competition on the efficiency of investor- and municipality-owned generation plants.[5] We develop a unique and comprehensive annual data set of over 950 coal, natural gas, and petroleum fueled generation plants, representing six different types of generation technology. We use these data to make three contributions to the literature. First, because we study the entire population of states that implemented wholesale market reforms and retail choice, we are able to estimate the efficiency effects for states with access to wholesale electricity markets *only* ("partial competition") versus states with *both* access to wholesale electricity markets *and* with retail choice ("full competition").[6] Second, because our sample includes plants that are owned by municipalities and cooperatives, we also test if the efficiency gains from restructuring have spilled over to non-restructured, publically-owned generation. Third, by measuring efficiency with the heat rate we are able to directly convert any fuel reductions from market restructuring into environmental benefits, as measured by the associated decrease in carbon dioxide emissions.

Our results show no significant correlation between partial competition and thermal efficiency. However, thermal efficiency is roughly nine percent higher

4. Several papers study the price effects from restructuring. Kleit and Tecrell (2001) use data from 78 gas plants in 1996 to estimate cost savings from restructuring of up to 13 percent. Joskow (2006) find that restructuring of wholesale and retail markets leads to lower retail prices. Taber et al. (2006) investigate residential, industrial, and commercial prices and find that restructuring did not lower electricity rates. Blumsack et al. (2008) find that states with restructuring have higher price-cost markups. Kwoka (2008) reviews the recent literature and summarizes the methodological problems associated with measuring the price effects from restructuring. In a related literature, Sanyal and Ghosh (2010) find that deregulation does not increase upstream innovation.

5. For the purpose of this study, we use "municipality-owned utilities" to describe plants that are publically owned by municipalities or cooperatives.

6. Table 1 shows there are 17 states in our sample where at least ten percent of consumers within the state can buy their electricity from two or more retailers. Only seven states actually implemented retail choice in Fabrizio et al.'s (2007) sample; four in 1998 and three in 1999. Four states implemented retail choice in Zhang's (2007) sample.

for both investor-and municipality-owned plants located in states with full competition than comparable plants in states without. These results are interesting because they imply that access to wholesale electricity markets and retail choice together are important for realizing the most efficiency gains from electricity generation. Moreover, competition became less popular following the price increases and blackouts in California in 2000 and 2001, and many states decided to delay or suspend restructuring. Such decisions may not have been economically rational. All other things held constant, our results imply that market restructuring initiatives that lead to a more fully competitive marketplace are associated with significant benefits corresponding to a 30 to 50 million ton decrease in carbon dioxide emissions during the sample period. The public power sector has also opposed restructuring (Kwoka, 2008). Our results suggest that the efficiency gains from restructuring may have spilled over to the non-restructured, public power sector. This implies that restructuring is good for consumers and society, but maybe not so good for public power executives who have to work more efficiently.

The paper is organized as follows. Section 2 describes the competition-efficiency hypothesis in the context of U.S. electricity generation and outlines the empirical model used to test the hypothesis. The data are described in Section 3. Section 4 presents the empirical results and Section 5 uses the results to calculate the potential reduction in carbon dioxide emissions due to market restructuring. Section 6 concludes.

2. EMPIRICAL MODEL

2.1 Market Restructuring and Competition

An important question facing state regulators considering market restructuring is the extent to which the production and distribution of electricity should be opened up to competition. California was the first state to pass independent market restructuring legislation in 1996 that introduced competition into wholesale and retail markets during 1998. Column one of Table 1 shows that another 36 states followed California's lead by also permitting their utilities to trade in market places for wholesale electricity, operated by several regional or state RTOs.[7] Column two shows the seven RTOs that operate the wholesale electricity market places. Of the 37 states that permitted wholesale electricity trading, column three shows that 17 states also implemented retail choice, with wholesale market reforms typically preceding retail reforms. The remaining 20 states preferred to restrict reforms to the wholesale level, at least until experience resolved some of the market uncertainties and justified the additional move to retail competition. Note that following California's electricity crises in 2000 and 2001,

7. The District of Columbia (D.C.) is included and will be counted as a state hereafter.

Table 1: States with Competition 1996–2006

	Access to wholesale markets ("partial competition")		Retail choice	Access to wholesale markets and retail choice ("full competition")
State	Year	RTO	Year	Year
Arkansas	2004	MISO, SPP		
California	1998	California ISO	1998	1998
Connecticut	1997	ISO-NE*	2000	2000
Delaware	1997	PJM*	2001	2001
Illinois	2002	PJM, MISO*	1999	2002
Indiana	2002	PJM,MISO*		
Iowa	2002	MISO		
Kansas	2004	SPP		
Kentucky	2002	PJM*		
Louisiana	2004	SPP		
Maine	1997	ISO-NE*	2000	2000
Maryland	1997	PJM*	2000	2000
Massachusetts	1997	ISO-NE*	1998	1998
Michigan	2002	PJM,MISO*	2001	2002
Minnesota	2002	MISO		
Mississippi	2004	SPP		
Missouri	2002	MISO, SPP		
Montana	2002	MISO		
Nebraska	2004	SPP		
New Hampshire	1997	ISO-NE*	1998	1998
New Jersey	1997	PJM*	1999	1999
New Mexico	2004	SPP		
New York	1999	NYISO*	1998	1999
North Carolina	2002	PJM*		
North Dakota	2002	MISO		
Ohio	2002	PJM, MISO*	2001	2002
Oklahoma	2004	SPP		
Pennsylvania	1997	PJM, MISO*	1999	1999
Rhode Island	1997	ISO-NE*	1998	1998
South Dakota	2002	MISO		

(continued)

Table 1: States with Competition 1996–2006 *(continued)*

	Access to wholesale markets ("partial competition")		Retail choice	Access to wholesale markets and retail choice ("full competition")
State	Year	RTO	Year	Year
Tennessee	1997	PJM*		
Texas	1997	ERCOT, SPP	2002	2002
Vermont	1997	ISO-NE*		
Virginia	2002	PJM*	2002	2002
West Virginia	2002	PJM*		
Wisconsin	2002	MISO		
D.C.	2002	PJM*	2001	2002

NOTES: California suspended retail restructuring in 2001. Virginia suspended retail market restructuring in 2007. The EIA currently list Oregon as having retail choice but this occurred after 2006. Retail choice is the year when at least ten percent of consumers within the state could buy their electricity from two or more retailers. * Indicates that the state is part of a wholesale market that allows for capacity trading. MISO stands for Midwest Independent Transmission System Operator. PJM stands for Pennsylvania-New Jersey-Maryland Interconnection. California ISO stands for California Independent System Operator. ISO-NE stands for Independent System Operator New England. SPP stands for Southwest Power Pool Electric Energy Network. NYISO stands for New York Independent System Operator. ERCOT stands for Electric Reliability Council of Texas.
SOURCES: EIA, FERC, NARUC (2009); NEAAP (2009); State PUC web sites.

Arizona, California, Nevada, and Oregon suspended part or all of their restructuring activities, as did Arkansas and Virginia in 2003 and 2007, respectively.[8] Note also that columns one and four highlight the state and time differences in the implementation of wholesale and retail market reforms that permit empirical testing of the separate efficiency effects from partial competition (i.e., access to wholesale electricity markets) versus full competition (i.e., access to wholesale electricity markets *and* retail choice).

2.2 Competition-efficiency Hypothesis

About 90 percent of U.S. electricity was generated by steam-cycle technology in 2006 (Energy Information Administration (EIA), 2009). Coal, natural gas, nuclear fission or petroleum was used to heat a water boiler with the steam from the boiler rotating a turbine that generates electricity. For coal-, natural gas-, and petroleum-fired plants, fuel comprises about 80 percent of total variable costs. All other things being equal, plants with a relatively lower heat rate, or higher

8. Oregon subsequently lifted its suspension of retail choice after 2006.

thermal efficiency, have a lower fuel cost for producing a single unit of output and, potentially, higher profits.

When operating in wholesale market bid systems, firms can submit bids to the spot market that indicate the prices and supply from their generation plants. The ranking of bids from lowest to highest price determines the electricity dispatch order and the market wholesale price, which is the price bid from the marginal plant (Fabrizio et al., 2007). Plants with low variable costs are placed higher in the dispatch ranking and can earn higher expected profits through relatively larger price-cost margins and by increasing their likelihood of supply. Plants with high variable costs face the prospect of short-run losses and ultimately potential exit from the market place. As such, managers of investor-owned plants in states with wholesale market restructuring are subject to entry, exit, and competitive pricing. This gives them a strong incentive to decrease operating costs by reducing their plant's heat rate. They can achieve this by implementing industry best practice maintenance and operational procedures, downsizing, upgrading to higher quality fuel, and/or by introducing new technologies that improve boiler efficiency.[9] The effects from market restructuring can also spill over to non-restructured, publically-owned utilities. For example, municipality-owned utilities may improve their efficiency through the exchange of knowledge with investor-owned utilities or in response to latent threats of restructuring and the associated competition.

Prima facie, one could expect trading in wholesale electricity market places to provide sufficient competitive pressures (as described above) to encourage more efficient electricity generation. However, without the corresponding implementation of retail market restructuring, the buyers of electricity in the newly formed wholesale markets are predominantly distribution companies that have been divested from the previously vertically-integrated incumbent utilities. Because historical practices in procurement, distribution and marketing are likely ingrained in these distribution companies, their behavior may be unresponsive to the changes in electricity trading conditions. Under this scenario, relatively inefficient generation plants would still be able to sell their electricity in wholesale markets for a profitable price and, as such, face weaker incentives to reduce their plant's heat rate. If such behavior occurs, there could be no observable impact on measures of plant efficiency from wholesale market reforms only.

With both wholesale and retail competition, customers may purchase their electricity either directly from the wholesale market or from one of several new competing retail or marketing companies. Innovative new retail entrants that are successful in building end-user (retail) market share, and in procuring their electricity at lower costs, will grow and comprise an increasing share of the low-cost plant's revenue base (Bohi and Palmer, 1996). Under these market conditions,

9. For example, improved sensor technology within the boiler maintains the ideal mixture of oxygen and carbon monoxide so that the optimal heat is obtained from the given fuel source. This means less fuel is needed to spin a turbine (Vesel et al., 2007).

relatively higher-cost plants will have incentive to become more efficient in order to be placed higher in the dispatch ranking in wholesale markets and to sell more electricity. As such, actual or potential retail competition from market restructuring may be sufficient to encourage generating plants to become more efficient. Ultimately, the efficiency effects from partial competition versus full competition remain an empirical question and are the focus of the remainder of this paper.

2.3 Model Specification

Market restructuring can be measured in several different ways: (a) plant access to wholesale electricity market places through an RTO; (b) the date at which formal hearings on restructuring began; (c) the date at which restructuring legislation was enacted; (d) the implementation date for retail choice under that legislation; and (e) complementary aspects of restructuring, such as access to wholesale markets that permit capacity trading, the mandatory divestiture of generating assets and the type of rate regulation (Fabrizio et al., 2007; Zhang, 2007; Kwoka, 2008; Craig, 2009; and Davis and Wolfram, 2011). In this paper, we construct our primary independent variables of interest with information on plant access to wholesale electricity market places, and with a new measure of retail choice that replaces the date of implementation with the date when at least ten percent of customers within the state have a choice between two or more retailers of electricity.

These measures allow us to make two contributions to the literature. First, because most states implemented wholesale reforms first, we construct two variables that capture the phasing in of restructuring initiatives through time and the associated increase in the intensity of competition. Specifically, *PCOMP* is partial competition, which equals one when the plant is located in a state where utilities have access to wholesale electricity market places through an RTO, and zero otherwise.[10] *FCOMP* is full competition, which equals one when the plant is located in a state where utilities have access to wholesale electricity market places and at least ten percent of customers have a choice between two or more retailers of electricity, and zero otherwise. Because *FCOMP* measures the incremental gains in efficiency gains from retail choice beyond access to wholesale electricity markets, the estimated coefficients on *PCOMP* and *FCOMP* provide the basis for testing whether wholesale market reforms are a sufficient condition for restructuring.

Previous studies use the date of implementation of retail choice to measure the start of retail competition. However, because it reflects the removal of a significant barrier to entry and not actual entry, the date of implementation mea-

10. To be clear, we are not confusing electricity market restructuring with the presence of an RTO. Instead, we are using the timing of wholesale and retail reforms by the states to test whether the presence of an RTO, as measured by *PCOMP*, is sufficient for maximizing the efficiency gains from restructuring.

sures actual and potential competition.[11] Ideally, firm specific market share data are needed to measure actual competition in retail markets, but these data are not publically available. Nevertheless, our second contribution to the literature improves upon the date of implementation by employing information on the number of customers within each state that have a choice between two or more retailers of electricity. In order to provide a better measure of actual competition, we then measure retail competition with the date at which ten percent of customers within the state had retail choice. Moreover, for a robustness check, we consider an alternative measure for retail competition where retail choice is permitted to vary from zero to 100 percent of residential customers.[12]

We test the competition-efficiency hypothesis with an empirical model that compares the efficiency of generation plants located in states with competition to the efficiency of similar plants in states without.[13] Estimates of these effects are consistent when restructuring is randomly assigned between states. However, as noted by Grogger (2003) and Zhang (2007), policy endogeneity can arise when unobserved time varying state factors affect the timing of electricity market restructuring. For example, when changes in unobserved management practices, resulting in lower (higher) production costs, are positively associated with changes in competition, the coefficient estimates for competition will be biased downwards (upwards). One way to minimize this bias is to use state-specific time trends to decompose from the error term the unobserved state-time components that may be correlated with both efficiency and the market restructuring variables.

The baseline model specification for plant $i = 1, \ldots, n$ in state $s = 1, \ldots, S$ at year $t = 1, \ldots, T$ is:

$$\log EFF_{ist} = \alpha PCOMP_{st} + \beta FCOMP_{st} + W_{is}\delta + X_{ist}\gamma + TREND_{st}\tau + \nu_s + \eta_t + \varepsilon_{ist} \quad (1)$$

11. Actual competition refers to firm responses to actual entry by new competitors and is typically measured by new entrant's market share or by market concentration. Potential competition refers to plant responses to expected entry and is typically measured by the removal of barriers to entry. By comparing plants in states that implemented restructuring reforms to plants in states that did not, this paper is important to economists and policymakers considering the implementation of restructuring or the lifting of any current suspensions. As such, at this initial stage of the restructuring process, it is not as important where the efficiency gains come from but that they exist and have economic and statistical significance.

12. In Section 4.1 below we also perform a sensitivity analysis that considers three complementary measures of restructuring: access to wholesale markets that permit capacity trading; the mandatory divestiture of generating assets; and the presence of performance based rate regulation.

13. It would be ideal to also work with cost data. While we have some information on firm costs, these are not complete across the sample, and are often interpolated from the characteristics of similar plants. This makes estimation of a stochastic cost frontier problematic. However, we were able to perform frontier estimation with heat rate data from IOUs and a parsimonious model specification with fewer controls. The estimated coefficient on *PCOMP*, $\alpha = -0.009$, is not significantly different from zero, while the estimated coefficient on *FCOMP*, $\beta = -0.120$, is significant at the one percent level. These results, not reported in the paper, are qualitatively similar to those from our baseline specification reported in Table 4.

where *EFF* is thermal efficiency, *W* is a vector of time-invariant plant characteristics, *X* is a vector of time-varying plant characteristics, *TREND* is a vector of state-specific time trends that control for unobserved state effects that vary through time, the υs are unobserved state fixed effects, the ηs are unobserved time fixed effects and ε is an error.[14]

The parameters of interest $\partial \log EFF/\partial PCOMP = \alpha$ and $\partial \log EFF/\partial FCOMP = \beta$ indicate the percentage differences in efficiency due to partial and full competition, respectively. If the null hypothesis that $\alpha = \beta = 0$ cannot be rejected, this implies that we cannot reject the null hypothesis that market structuring does not affect efficiency. A finding of $\alpha < \beta = 0$ supports the hypothesis that the competitive forces from wholesale markets are sufficient to lower the heat rate and increase thermal efficiency. A finding of $\beta < \alpha = 0$ supports the hypothesis that the competitive forces from both wholesale and retail markets together are required to lower the heat rate and increase thermal efficiency.

An issue we must address when estimating equation (1) concerns attrition bias. Because efficiency is observed for a non-random sample of plants that survive the sample period, it is possible that the estimates of α and β measure the effects from exit by less efficient firms. That is, output moves from "high cost" to "low cost" plants during the sample period and the total inputs required to produce a given level of electricity output decreases (Olley and Pakes, 1996; Disney et al., 2003; Syverson, 2004). We address this potential bias with Heckman and Lee's two-step estimation procedure that estimates the effects on efficiency from market restructuring given the observed, surviving plant was a relatively more efficient generator of electricity to begin with.

For the first-step selection equation, we define the new dependent variable *SURVIVE*, which equals one when the plant survived throughout the sample period and zero when the plant exited the sample and/or reported no observations for continuous years during the sample period. The plant's decision to remain in the market is based on their expected profits:

$$\pi^{*}_{ist} = Z_{ist}\phi + \varphi FC_{ist} + u_{ist} \tag{2}$$

where $Z = [PCOMP, FCOMP, W, X, TREND]$, *FC* is a vector of variables that approximate the fixed costs of electricity generation and *u* is an error. Although expected profits are not observable to the researcher, it is possible to observe

14. It is also possible to account for the potential bias from non-random assignment of retail market restructuring with instrumental variable (IV) estimation. For instruments, we follow Craig (2009) and use a vector of state-time level variables that approximate interest group pressures and the preferences of policy makers to explain the state legislatures' decision to restructure electricity markets. IV estimates of the efficiency equation, not reported, are similar to those presented in Section 4. Specifically, the IV estimate of the effect of full competition on thermal efficiency is slightly more negative, with a larger standard error, and marginally insignificant for the IOU sample. For municipality-owned plants the coefficient estimate on full competition is more negative, with a larger standard error, and also marginally insignificant.

when the plant provides electricity, with $SURVIVE_{ist}=1$ if $\pi^*_{ist}>0$ and $SURVIVE_{ist}=0$ if $\pi^*_{ist}\leq 0$. The probability that the plant is a survivor is:

$$Prob(\pi^*_{ist}>0)=Prob(u_{ist}<Z_{ist}\phi+\varphi FC_{ist})=F(Z_{ist}\phi+\varphi FC_{ist}) \qquad (3)$$

where $F(\cdot)$ is the standard normal distribution function. In the second step, the efficiency for the surviving plants is:

$$\log EFF_{ist}=\alpha PCOMP_{st}+\beta FCOMP_{st}+W_{is}\delta + X_{ist}\gamma+TREND_{st}\tau+\sigma_u\lambda_{ist}+v_s+\eta_t+\varepsilon_{ist} \qquad (4)$$

where $\lambda_{ist}=-f(Z_{ist}\hat{\phi}+\hat{\varphi}FC_{ist})/F(Z_{ist}\hat{\phi}+\hat{\varphi}FC_{ist})$ is the inverse mills ratio (*MILLS*), $f(\cdot)$ is the standard normal density function and σ_μ is the covariance between the errors u and ε. By conditioning on λ, equation (4) controls for unobserved selection effects that might otherwise bias the relationship between efficiency and market restructuring. This allows us to assess the extent to which the efficiency gains from market restructuring are driven by changes to production within the plant, or by market selection effects where the inefficient plants exited the market during the sample period.

3. DATA

3.1 Sample

We follow the industry standard and define a plant as a facility that contains prime movers, electric generators, and auxiliary equipment for converting mechanical, and chemical energy into electricity. A prime mover is the engine, turbine, water wheel or similar machine that drives an electric generator or a device that converts energy to electricity directly. Ideally, we would prefer to measure production from the individual generating units within each plant but these data are not publicly available.

Annual data on location, ownership structure and production for 977 steam-cycle plants were sourced from Ventyx Energy.[15] The data are from 1996 to 2006 and represent plants in all 50 states and D.C.; 717 plants are investor owned and 260 are municipality owned. The sample plants are fired by coal, natural gas and/or petroleum and accounted for about 48 percent of total U.S. net generation by all energy sources in 2006, and about 67 percent of total U.S. net generation by coal, natural gas and petroleum (Ventyx Energy, 2007; EIA, 2009).[16]

15. Ventyx Energy (formerly Global Energy Decisions) gathers data from FERC and other reporting services, and packages these data to private and government entities.

16. Total U.S. net generation includes electricity generated by all energy sources; coal, petroleum, natural gas, other gases, nuclear, hydroelectric, other renewables, and by type of producer; electric utilities, independent power producers, electric power, commercial and industrial (EIA, 2009).

Table 2: State Characteristics 1996–2006

	All states	States with partial competition	States with full competition	States with no competition
Variable	Mean	Mean	Mean	Mean
Net generation (1000 MWh)	1,360.8	1,392.9	1,234.8	1,612.6
Area (miles^2)	92,760	62,294	98,519	127,983
Population (millions)	11.1	4.3	17.0	7.7
Population per mile^2	215.1	78.6	342.5	128.5
Median household income ($)	43,269	40,170	45,476	42,948
Republican PUC	0.58	0.41	0.66	0.68
Number of states	51	20	17	14

NOTES: Republican PUC equals one when the majority of state's PUC commissioners are Republican. Partial competition is when a majority of states power producers has access to some form of wholesale market, full competition is when a majority of the states power producers have access to some form of wholesale market, and at least 10 percent of customers have access to their choice of retail provider. *SOURCES*: EIA, NARUC (1995, 2001), U.S. Census Bureau, Ventyx Energy (2007).

We merged our plant data with information on the timing of the implementation of market restructuring initiatives across states obtained from the EIA, FERC, the National Energy Affordability and Accessibility Project (NEAAP, 2009), individual RTO websites, and state PUC web sites. Table 2 presents selected characteristics for states with partial competition, full competition, and no competition during the sample period. States with full competition produce less total electricity, have larger populations, greater population densities and higher median income than states with either partial or no competition. States with partial competition have Democrat dominated PUCs, while states with no competition or full competition have Republican dominated PUCs.

3.2 Variables and Summary Statistics

The unit of observation is plant $i = 1, \ldots, n$ in state $s = 1, \ldots, S$ at year $t = 1, \ldots, T$. The outcome variable of interest is thermal efficiency, or, the net heat rate (*EFF*). This is the number of BTUs of fuel used to generate a kWh of electricity that is sent from the generation plant to the grid.[17] The important in-

17. Plant production can be measured in terms of gross generation and net generation. Gross generation comprises all the electricity supplied to the grid, the electricity used by the plant to run equipment, provide lighting, etc. and in some cases, the electricity supplied to a complementary production process, such as steel manufacturing. See Joskow and Schmalensee (1987) for a study of the determinants of thermal efficiency based on gross generation. Net generation is the electricity

dependent variables of interest are partial competition (*PCOMP*) and full competition (*FCOMP*).[18] Table 3 provides a detailed description of *EFF*, *PCOMP*, *FCOMP* and all the other variables used in the empirical analysis and their sources.

In order to measure *PCOMP* and *FCOMP* we first identified which states permitted wholesale and retail competition, respectively, and in what years. To determine wholesale competition we visited the FERC website to find out the year that the RTO was founded and the corresponding member states. We then verified this information by checking the individual RTO websites or other online sources, such as press releases and State PUC websites, to see if all states were included on the date indicated by FERC or if states were added at a later date. For example, the website http://www.ferc.gov/market-oversight/mkt-electric/pjm.asp indicated that Pennsylvania is a member of the Pennsylvania-New Jersey-Maryland Interconnection (PJM), an RTO ". . . that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia." Complementary information from PJM's website at http://www.pjm.com/about-pjm/who-we-are/pjm-history.aspx indicated that Pennsylvania companies first became part of the PJM in 1927 but that the PJM officially became an RTO in 1997. As such, we measure the year that Pennsylvania implemented wholesale restructuring as 1997 (See column two, row 28 of Table 1). Maine provides another example. The FERC website indicates that Maine has Independent System Operator New England (ISO-NE) membership and that ISO-NE became an RTO in 1997. Corresponding information from the ISO-NE website at http://www.iso-ne.com/aboutiso/co_profile/history/index.html shows that six states have been part of ISO-NE dating back to when it was the New England Power Pool (NEPOOL).[19] Because Maine is one of these six states and the ISO-NE was founded in 1997, we measure the year that Maine permitted wholesale competition as 1997 (See column two, row eleven of Table 1).[20] http://www.eia.gov/cneaf/elec-

supplied to the grid. "Down time" can result in plants having zero or negative generation. For example, the plant may have to source electricity from the grid when management temporarily closes the plant for maintenance, because of poor market conditions and/or to supply a complementary production process.

18. 17 states permitted retail competition in our sample. Eleven states permitted retail competition following the implementation of wholesale competition, and three just prior to implementing wholesale competition. One state, Illinois, permitted retail competition two years before wholesale competition. For a robustness check, we estimated an alternative specification of the efficiency equation in Table 8 of Section 4 with the additional variable *RCOMP* (equals one when ten percent or more of customers have a choice of two or more electricity providers and no wholesale competition, and zero otherwise) to account for the four states with retail competition only for a short period of time. The results are qualitatively similar to those from our baseline specification reported in Table 6.

19. NEPOOL was formed in 1991 by investor- and municipality-owned plants to help organize and coordinate the power grid for the six states that are now members of ISO-NE.

20. For our baseline efficiency equation, we coded $PCOMP = 1$ for Kentucky, Louisiana, Mississippi, New Mexico and Tennessee even though these states have only a small part of their territory served by an RTO. For robustness, we also estimated the efficiency equation with $PCOMP = 0$ for these five states. For investor-owned plants, the estimated coefficient on *PCOMP*, $\alpha = -0.041$, is not

Table 3: Variable Descriptions

Variable	Description
EFF	Number of BTUs of fuel used to generate a kWh of electricity that is sent from the generation plant to the grid. Source: Ventyx Energy (2007).
PCOMP	One when the plant is located in a state where utilities have access to wholesale electricity market places through an RTO, and zero otherwise. Source: EIA, FERC, NARUC (2009); NEAAP (2009); State PUC web sites.
FCOMP	One when the plant is located in a state where utilities have access to wholesale electricity market places through an RTO and at least ten percent of customers have a choice between two or more retailers of electricity, and zero otherwise. Source: EIA, FERC, NARUC (2009); NEAAP (2009); State PUC web sites.
CAPACITY	Maximum sustainable amount of thousands of MWh of electricity generated per hour. Source: Ventyx Energy (2007).
UNITS	Number of turbines within the plant. Source: Ventyx Energy (2007).
MULTI PLANT	One when the plant is owned by a firm that has acquired more than one plant and brought them under the umbrella of a single corporate entity and zero otherwise. Source: Ventyx Energy (2007).
ZERO OUTPUT	One when the plant had zero net generation of electricity for any month during the year. Source: Ventyx Energy (2007).
NEG OUTPUT	One when the plant had negative net generation of electricity for any month during the year. Source: Ventyx Energy (2007).
AGE	*t* minus the year of initial operation divided by 100. Source: Ventyx Energy (2007).
MULTI PRIME	One when the plant has more than one type of prime mover for generating electricity. Source: Ventyx Energy (2007).
COMB GAS	One when the prime mover is a combined gas plus waste turbine and zero otherwise. Source: Ventyx Energy (2007).
GAS	One when the prime mover is a combustion gas turbine, including jet engine design, and zero otherwise. Source: Ventyx Energy (2007).
PETROL	One when the prime mover is an internal combustion turbine, including diesel and piston design, and zero otherwise. Source: Ventyx Energy (2007).
COAL	One when the prime mover is an integrated coal gasification combined cycle turbine or a condensing steam turbine and zero otherwise. Source: Ventyx Energy (2007).
SURVIVE	One when the plant survived throughout the sample period and zero when the plant exited the sample and/or reported no observations for continuous years during the sample period. Source: Ventyx Energy (2007).

(continued)

Table 3: Variable Descriptions *(continued)*

Variable	Description
FIXED COSTS	Total fixed costs (million $). Source: Ventyx Energy (2007).
PBR	One when the plant was located in a state with current performance based regulation and zero otherwise. Source: Sappington et al. (2001), state PUC web sites (2009) and through personal correspondence with state PUCs (2009)
CAPACITY MARKET	One when the plant is located in a state that is a member of ISO-NE, NYISO or PJM, and zero otherwise. Source: NARUC (2009); NEAAP (2009); State PUC web sites.
YEARS PCOMP	Zero for the year in which utilities in the state first had access to wholesale electricity market places through an RTO, and increasing by one for each additional year that this reform was active. Source: NARUC (2009); NEAAP (2009); State PUC web sites.
YEARS FCOMP	Zero for the year in which utilities in the state first had access to wholesale electricity market places through an RTO and at least ten percent of customers had a choice between two or more retailers of electricity, and increasing by one for each additional year that these reforms were active. Source: NARUC (2009); NEAAP (2009); State PUC web sites.
DIVESTITURE	Percentage of a state's generating assets that had been divested. Source: NARUC (2009); NEAAP (2009); State PUC web sites.
RCOMP	One when ten percent or more of customers have a choice of two or more electricity retailers but utilities in the state had no access to wholesale electricity market places through an RTO, and zero otherwise. Source: EIA, FERC, NARUC (2009); NEAAP (2009); State PUC web sites.
FCOMP_PERCENT	Percentage of residential customers with a choice of two or more electricity retailers in states where utilities have access to wholesale electricity market places through an RTO and customers have a choice between two or more retailers of electricity. Source: EIA, FERC, NARUC (2009); NEAAP (2009); State PUC web sites.

tricity/page/restructuring/restructure_elect.html to find out which states have implemented retail choice. From this website, we then click through to individual states to find out if retail choice is active or suspended, and for additional information to determine when at least ten percent of customers within the state could choose among alternative retailers of electricity. For example, the EIA website

significantly different from zero, while the estimated coefficient on *FCOMP*, $\beta = -0.097$, is significant at the five percent level. For municipality-owned plants, the estimated coefficient on *PCOMP*, $\alpha = -0.065$, is not significantly different from zero, while the estimated coefficient on *FCOMP*, $\beta = -0.098$, is significant at the five percent level. These results, not reported in the paper, are qualitatively similar to those from our baseline specification reported in Table 6.

shows that customers in Pennsylvania have retail choice. We then click through to the individual profile for Pennsylvania and observe that in January 1999, retail choice was available to two thirds of their customers. As such, we measure the year that Pennsylvania permitted retail competition as 1999 (See column four, row 28 of Table 1). By following similar steps, we observe that at least ten percent of customers in Maine had retail choice by March, 2000 (See column four, row eleven of Table 1). Given these measurements of wholesale and retail competition, for Pennsylvania we code *PCOMP* = 1 for 1997 through 2006, and zero otherwise, and code *FCOMP* = 1 for 1999 through 2006, and zero otherwise. For Maine, we code *PCOMP* = 1 for 1997 through 2006 and zero otherwise, and code *FCOMP* = 1 for 2000 through 2006, and zero otherwise.

Some states delayed retail competition and eventually suspended it. For example, the EIA lists Arkansas' retail restructuring as suspended and when we click through to the individual state information we observe that Arkansas eventually discontinued competition initiatives in February, 2003. As such, for Arkansas, we code *PCOMP* = 1 for 2004 through 2006, and zero otherwise, and code *FCOMP* = 0 for 1996 through 2006. Similarly, the EIA website also lists Virginia's retail restructuring as suspended. When we click through to the individual state information, we see that over ten percent of customers had retail choice by the end of 2002, but that retail restructuring was suspended in February, 2007. As such we code *PCOMP* = 1 for 2002 through 2006, and zero otherwise, and code *FCOMP* = 1 for 2002 through 2006, and zero otherwise.

The vector of time-invariant plant characteristics, *W*, describes the prime movers used to generate electricity. The vector includes: *COMB GAS* (equals one when the prime mover is a combined gas plus waste turbine and zero otherwise); *GAS* (equals one when the prime mover is a combustion gas turbine, including jet engine design, and zero otherwise); *PETROL* (equals one when the prime mover is an internal combustion turbine, including diesel and piston design, and zero otherwise); and *COAL* (equals one when the prime mover is an integrated coal gasification combined cycle turbine or a condensing steam turbine and zero otherwise). For brevity we collapsed the original six generation technologies described in the data into the aforementioned four indicator variables.[21]

The vector *X* contains time-varying plant characteristics that may affect efficiency. *CAPACITY* (maximum sustainable amount of thousands of MWh of electricity generated per hour by the plant)[22] and *UNITS* (number of turbines within the plant) measure the potential for economies of scale. *MULTI PLANT* (equals one when the plant is owned by a firm that has acquired more than one plant and brought them under the umbrella of a single corporate entity and zero otherwise) measures potential economies of scope. *ZERO OUTPUT* (equals one

21. Estimates of equation (1) with the original six technology indicator variables, not reported, are similar to those presented in Section 4.

22. This is calculated during summer months when electricity generation is at a maximum and, as such, is a reasonably good proxy for capital input.

when the plant had zero net generation of electricity for any month during the year) and *NEG OUTPUT* (equals one when the plant had negative net generation of electricity for any month during the year) control for down time.[23] *AGE* (equals *t* minus the year of initial operation divided by 100) and AGE^2 control for changes in operating efficiency through time due to plant vintage. Because of coordination problems, efficiency may be lower in plants with several different types of prime mover. As such, *MULTI PRIME* (equals one when the plant has more than one type of prime mover for generating electricity) is included to control for plant heterogeneity.

TREND is a vector of state-specific time trends. For the linear specification of *TREND*, $TREND_{1st}$ is one for state one at 1996, two for state one at 1997,. . ., eleven for state one at 2006, and zero otherwise. Similarly, $TREND_{2st}$ is one for state two at 1996, two for state two at 1997,. . ., eleven for state two at 2006, and zero otherwise.

In summary, the gross sample comprises of 8,923 plant-year observations for investor-owned utilities and 3,119 plant-year observations for municipality-owned utilities from 1996 to 2006. Because of missing data due to plant exit or because some firms did not report operating information for certain years, the net sample comprises of 7,454 plant-year observations for investor-owned utilities and 2,416 plant-year observations for municipality-owned utilities.[24] Table 4 presents summary statistics for the investor-owned plants in the net sample. The data show that the average investor-owned plant is about 44 years old, has 3.7 turbines with an overall capacity of about 450 MWh, and uses 142,930 BTUs of fuel to generate a kWh of electricity.[25] About 20 to 30 percent of investor-owned plant-year observations had a month or more in a given year with zero or negative generation respectively, indicating a temporary shutdown. Over 80 percent of the investor-owned plant-year observations are multi-plant observations, which indicate a prevalence of horizontally-integrated firms in U.S. electricity generation. Table 5 presents summary statistics for the municipality-owned plants in the net sample.

4. RESULTS

The empirical model and data are used to examine the effects of market restructuring initiatives that introduced competition into electricity markets on the

23. This effect can run either way. Plant efficiency can increase when downtime is used for maintenance programs. However, efficient plants are often selected for downtime because it is less costly to shut them down and start them up again.

24. The additional observations from the gross sample are used for robustness checks for attrition bias in Section 4.

25. There are 15 observations with values for *EFF* that are below the lowest possible heat rate of 3,412.3 and, as such, violate the first law of thermodynamics. These values are most likely due to reporting or recording error. Estimates of the efficiency equation without these 15 observations, not reported, are similar to those presented in Section 4.

Table 4: Summary Statistics: Investor-owned Plants

Variable	Mean	S.D.	Min	Max
EFF	11910.85	19637.34	165	1133333
PCOMP	0.49	0.47	0	1
FCOMP	0.26	0.44	0	1
CAPACITY	0.45	0.43	0.00	2.60
UNITS	3.67	2.45	1	32
MULTI PLANT	0.87	0.34	0	1
ZERO OUTPUT	0.20	0.40	0	1
NEG OUTPUT	0.32	0.47	0	1
AGE	0.44	0.19	0	1.06
MULTI PRIME	0.48	0.49	0	1
FIXED COSTS	12.71	16.30	–4.43	307

NOTES: Number of observations is 7,454. S.D. is standard deviation.

Table 5: Summary Statistics: Municipality-owned Plants

Variable	Mean	S.D.	Min	Max
EFF	1182.22	6610.43	316.25	96799.60
PCOMP	0.40	0.49	0	1
FCOMP	0.14	0.35	0	1
CAPACITY	0.23	0.28	0.00	1.80
UNITS	3.22	1.97	1	8
MULTI PLANT	0.70	0.46	0	1
ZERO OUTPUT	0.23	0.42	0	1
NEG OUTPUT	0.36	0.48	0	1
AGE	0.38	0.17	0	1.06
MULTI PRIME	0.42	0.49	0	1
FIXED COSTS	7.61	10.91	–0.19	115

NOTES: Number of observations is 2,416. S.D. is standard deviation.

thermal efficiency of generation plants. We estimate the baseline model of the efficiency equation for investor- and municipality-owned plants. We then estimate a selection model that controls for attrition bias, and also re-estimate the efficiency equation for subsamples of natural gas-, petroleum-, and coal-fired plants.

Because our observations represent plants in geographic markets, it is possible that there are shocks or unobservables that are common or correlated across nearby markets. While this does not affect the consistency of our estimator, it does impact the standard error. To address this issue, we allow correlations in the residuals across plants in the same state when computing these standard errors. This is reasonable, for example, if some unobservable characteristics of plant efficiency are determined at the state level.

4.1 Investor-owned Plants

Ordinary Least Squares (OLS) estimates of the efficiency equation for investor-owned plants are presented in Table 6. Column one presents the baseline specification where we regress plant efficiency (log*EFF*) on partial competition (*PCOMP*), full competition (*FCOMP*), the vector of time-invariant plant characteristics (*W*), the vector of time-varying plant characteristics (*X*), state-specific linear time trends, and state and time fixed effects.[26] The model is reasonably well specified; the coefficients on many of the important control variables have plausible signs and magnitudes. The estimated coefficient on *CAPACITY* is negative and is not statistically significant, and the coefficient on $CAPACITY^2$ is positive and again not statistically significant. However, the estimated coefficient on *UNITS* is positive and statistically significant which, holding *CAPACITY* constant indicates that an increase in the number of turbines used within the plant decreases thermal efficiency. Both of the coefficients on *ZERO OUTPUT* and *NEG OUTPUT* are negative and significant, and suggest that down time is used for maintenance programs that increase plant efficiency. The estimated coefficients on *AGE* and AGE^2 indicate that older plants are relatively more efficient which is not altogether surprising given that older plants have, by definition, survived longer because they are relatively good at generating electricity. The estimated coefficient on *MULTI PRIME* is negative and significant. Holding *CAPACITY* and *UNITS* constant, this result indicates that it is more efficient for the plant to have different types of multiple prime movers (*e.g.*, gas, petroleum, coal, *etc.*) rather than the same type of multiple prime movers.

The important parameters of interest in the baseline model, α and β, are both negative, but the estimate of α is not statistically different from zero. The estimated coefficient on *FCOMP*, $\beta = -0.0891$, is significantly different from zero at the five percent level and indicates that market restructuring is associated with an increase in the thermal efficiency of investor-owned plants of about nine percent. The finding of $\alpha = 0$ and $\beta < 0$ supports the hypothesis that it is the com-

26. We follow Ziliak et al. (2000) and Grogger (2003) by estimating the efficiency equation with linear time trends and then with log-linear time trends. For the log-linear specification of *TREND*, $TREND_{1st}$ is log one for state one at 1996, log two for state one at 1997,…, log eleven for state one at 2006, and zero otherwise. Similarly, $TREND_{2st}$ is log one for state two at 1996, log two for state two at 1997,…, log eleven for state two at 2006, and zero otherwise. The Akaike Information Criterion and Bayesian Information Criterion indicate that the inclusion of linear time trends was more appropriate.

Table 6: Estimates of Efficiency Equation

	IOU	IOU	IOU	MUNI	MUNI	MUNI
	Baseline Efficiency Equation	First Step Selection Equation	Second Step Efficiency Equation	Baseline Efficiency Equation	First Step Selection Equation	Second Step Efficiency Equation
PCOMP	−0.0426 [−1.319]	−0.0138 [−0.020]	−0.0380 [−1.07]	−0.0338 [−0.875]	−0.1725 [−1.110]	−0.0316 [−0.750]
FCOMP	−0.0891** [−2.318]	−0.0843** [−2.390]	−0.0948** [−2.33]	−0.0928*** [−2.956]	−0.6870 [−1.330]	−0.0857** [−2.640]
CAPACITY	−0.0693 [−0.944]	5.7877*** [5.200]	−0.1051 [−1.15]	−0.2844 [−1.446]	1.8750 [0.610]	−0.3487** [−2.340]
CAPACITY^2	0.0081 [0.239]	−2.5500 [−5.550]	−2.1700 [0.520]	0.0988 [0.804]	−4.1800 [−1.520]	1.5500 [1.710]
UNITS	0.0120** [2.544]	−.0540** [−2.430]	0.0101** [2.150]	0.0181 [1.341]	−0.0408 [−0.490]	0.0172 [1.13]
MULTI PLANT	−0.0123 [−0.471]	0.5384** [2.53]	−0.0164 [−0.590]	−0.0056 [−0.147]	−0.0859 [−0.350]	−0.0259 [−0.680]
ZERO OUTPUT	−0.1532*** [−4.547]	−0.1766 [−0.93]	−0.1311*** [−4.190]	−0.1573*** [−3.127]	−0.3239 [−0.990]	−0.2020*** [−4.120]
NEG OUTPUT	−0.1899*** [−5.649]	0.0442 [0.020]	−0.2137*** [−6.97]	−0.1984*** [−3.320]	0.6555** [1.97]	−0.1873** [−2.78]
AGE	0.3088 [1.379]	1.4316 [1.300]	0.3474 [1.41]	−0.0558 [−0.249]	−1.8221 [−0.740]	−0.1064 [−0.460]
AGE^2	−0.3324* [−1.876]	−0.5995 [−0.55]	−0.3767* [−1.98]	−0.2160 [−0.761]	1.1670 [0.500]	−0.1721 [−0.580]
MULTI PRIME	−0.0485*** [−2.777]	1.2450*** [4.77]	−0.0667*** [−2.79]	−0.0036 [−0.079]	−0.2938 [−0.960]	−0.0126 [−0.280]

(continued)

Table 6: Estimates of Efficiency Equation *(continued)*

	IOU	IOU	IOU	MUNI	MUNI	MUNI
	Baseline Efficiency Equation	First Step Selection Equation	Second Step Efficiency Equation	Baseline Efficiency Equation	First Step Selection Equation	Second Step Efficiency Equation
MILLS			0.0622 [0.079]			0.0132 [0.180]
FIXED COSTS		1.44 [0.0511]			0.4727*** [4.42]	
FIXED COSTS^2		–0.0003* [–1.650]			–0.0044* [–1.73]	
CONSTANT	11.4327*** [107.522]	–3.9237*** [–5.330]	8.990*** [69.740]	8.9234*** [114.524]	0.4346 [0.580]	8.9596*** [110.430]
$\chi^2(2)$		13.50***			19.67***	
Plant prime mover fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State-specific linear time trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,454	8,092	6,623	2,416	2,621	1,943
R-squared	0.163		0.168	0.181		0.169
Pseudo R-squared		0.486			0.534	

NOTES. Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; *t* statistics are reported in brackets. Estimates of fixed effects and time trends not reported. χ^2 tests the hypothesis that the estimated coefficients for *FIXED COSTS* and *FIXED COSTS*^{2} in the first-step selection model are jointly equal to zero.

petitive forces from both wholesale and retail markets together that lower the heat rate and increase thermal efficiency.[27,28]

Our gross sample contains 638 additional plant-year observations for investor-owned plants that did not report operating data during the sample period. Because these excluded firms likely exited the market or failed to report operating data because of poor market performance or mergers, the estimates of the effects from competition for the surviving plants in column two of Table 6 may be biased downwards. As a robustness check, we re-estimate the efficiency equation with Heckman and Lee's two-step estimation procedure for the gross sample of 8,092 surviving and exiting plant-year observations. For identification, we use *FIXED COSTS* (total fixed costs of the plant in millions of dollars) and *FIXED COSTS*^{2} as the excluded instruments in the first-step selection equation. All other things being equal, survival should be more likely for larger plants with larger fixed costs (Hall, 1987; Cabral, 1995). However, fixed costs should not directly impact plant efficiency.

Column two and column three of Table 6 present two-step estimates of plant efficiency.[29] We first note in column two that the coefficients on the excluded instruments in the selection equation, *FIXED COSTS* and *FIXED COSTS*^{2}, have the expected signs and are reasonably precisely estimated. A χ^2-test ($\chi^2(2) = 13.50$; Prob $> \chi^2 = 0.00$) rejects the hypothesis that the estimated coefficients for *FIXED COSTS* and *FIXED COSTS*^{2} are jointly equal to zero. All other things being equal, survival into the net sample is more probable for firms with

27. Because most states implemented wholesale competition before retail competition, it is possible that the estimate of β is predominantly measuring more experience with wholesale competition. To investigate this possibility, a new variable *YEARS PCOMP* (i.e., the number of years since the implementation of partial competition) was added to the efficiency equation. The estimated coefficient on *YEARS PCOMP* is not statistically significant from zero, and all other coefficient estimates are qualitatively similar to those reported in Table 6 and Table 7. Similar results are also obtained when *YEARS FCOMP* (i.e., the number of years since the implementation of full competition) was added to the efficiency equation. These results indicate that the average effect of *FCOMP* is the same regardless of the number of years since implementation.

28. For robustness, we also estimated the efficiency equation on the sub sample of states without retail competition and tested the efficiency effects from wholesale competition only. The estimated coefficient on *PCOMP*, $\alpha = -0.0426$, is not significantly different from zero and implies that we cannot reject the null that wholesale competition does not affect thermal efficiency of investor-owned plants. A similar finding is also found for municipality-owned plants where the estimated coefficient on *PCOMP*, $\alpha = -0.0245$, is not significantly different from zero. These results, not reported here, are consistent with the findings from Table 6 that show that access to wholesale markets alone has no significant impact on plant efficiency.

29. We initially estimated the two-step model on the gross sample of 8,923 plants for all states. In the first step, the state indicator variables for Connecticut, Delaware, Kansas, Montana, Rhode Island, South Carolina, Utah, West Virginia, and D.C. predicted success perfectly and were dropped from the probit model, along with their corresponding 831 observations. As such, we estimated the first-step probit model without these states on the smaller sample of 8,092 observations. We then estimate the second-step price efficiency equation on the reduced sample of 6,623 observations for surviving plants and report these results as a test for potential selection bias.

large fixed costs. The estimated coefficient on the selection term, *MILLS*, is not statistically different from zero and suggests there is no problem with attrition bias. Moreover, as expected, the estimated coefficient on *FCOMP* of $\beta = -0.0948$ is similar to the single-equation OLS estimates reported in column one. Overall, the two-step results suggest that efficiency gains from competition stem from internal organizational and technological changes within the plant, and are not due to the attrition of inefficient plants from the sample over time.

We now examine whether the competitive effects from market restructuring are different for plants with different fuel sources.[30] Table 7 reports estimates of efficiency for subsamples of gas, petroleum and coal plants. The estimated coefficient on *FCOMP* for the gas subsample, $\beta = -0.1023$, is reported in column one and is marginally insignificant at the ten percent level. The estimated coefficient on *FCOMP* for the coal subsample, $\beta = -0.0794$, is reported in column two and is significant at the five percent level. These results suggest that the efficiency gains from full competition are most prominent for gas and coal-fired plants.

4.2 Municipality-owned Plants

Policy makers and regulators aimed the competitive initiatives from market restructuring squarely at investor-owned plants. However, it is possible that the efficiency gains from market restructuring indirectly spill over to non-restructured, publically-owned utilities. To test for potential spillover effects, we estimate the efficiency equation for all the municipality-owned plants in our sample. Column four through Column six of Table 6 show that the overall pattern of results is very similar to those for investor-owned plants. All other things held constant, municipality-owned plants in states with both wholesale and retail competition are about nine percent more efficient than plants located in states without full competition. In addition, as shown in column four through column six of Table 7, the efficiency gains from restructuring are also most apparent in municipality-owned, gas- and coal-fired plants.[31]

4.3 Sensitivity Analysis

We conclude this section with some additional analysis that examines the sensitivity of our key findings to several additional or alternative measures of market restructuring. These measures include:

30. Chow tests rejected the equality of the estimated coefficients in the efficiency equation between oil, gas and coal investor-owned plants ($F(116, 7338) = 8.19$; $Prob > F = 0.00$), and for municipality owned plants ($F(116, 2300) = 3.33$; $Prob > F = 0.00$).

31. Because they predicted success perfectly, several state indicators were dropped from the probit model, along with their corresponding 831 observations. As was the case for investor-owned plants, we estimated the first-step probit model without these states on the smaller sample of 2,621 observations. We then estimate the second-step price efficiency equation on the reduced sample of 1,943 observations for surviving plants and report these results as a test for potential selection bias.

Table 7: Efficiency Estimates for Investor-owned and Municipality-owned Gas, Petroleum and Coal Fired Plants

	IOU Efficiency Equation	IOU Efficiency Equation	IOU Efficiency Equation	MUNI Efficiency Equation	MUNI Efficiency Equation	MUNI Efficiency Equation
	Gas	Petroleum	Coal	Gas	Petroleum	Coal
PCOMP	−0.1060 [−1.594]	0.1992 [0.614]	−0.0263 [−1.140]	−0.0991 [−0.992]	−0.6766 [−1.222]	0.0118 [0.421]
FCOMP	−0.1023 [−1.529]	−0.1803 [−0.623]	−0.0794** [−2.470]	−0.1016* [−1.947]	0.6626 [0.971]	−0.0845*** [−3.142]
CAPACITY	−0.0668 [−0.294]	0.3970 [0.833]	−0.1477** [−2.278]	−0.3472 [−0.450]	25.9426 [0.649]	−0.2626 [−1.274]
CAPACITY^2	0.0169 [0.105]	−0.4379 [−1.494]	0.0391 [1.526]	0.6269 [0.683]	−486.3621 [−0.997]	0.0906 [0.681]
UNITS	0.0102 [1.519]	0.0045 [0.066]	0.0167 [1.058]	−0.0145 [−0.495]	0.3019*** [12.332]	0.0280** [2.339]
MULTI PLANT	−0.0200 [−0.365]	0.1403 [0.848]	−0.0260 [−1.198]	0.0597 [0.800]	−0.0865 [−0.811]	−0.0506 [−0.986]
ZERO OUTPUT	−0.1462** [−2.664]	−0.1659 [−1.173]	−0.1037*** [−2.934]	−0.1231 [−1.295]	0.3138 [1.303]	−0.2604*** [−5.162]
NEG OUTPUT	−0.1978*** [−3.574]	−0.0909 [−0.637]	−0.1902*** [−5.537]	−0.1195 [−1.542]	−0.4284 [−1.643]	−0.1853*** [−3.148]
AGE	0.4288 [1.289]	1.2868 [0.838]	0.2494 [0.719]	−0.9054 [−1.341]	−33.9412 [−1.742]	0.2464 [0.583]

(continued)

Table 7: Efficiency Estimates for Investor-owned and Municipality-owned Gas, Petroleum and Coal Fired Plants *(continued)*

	IOU Efficiency Equation	IOU Efficiency Equation	IOU Efficiency Equation	MUNI Efficiency Equation	MUNI Efficiency Equation	MUNI Efficiency Equation
	Gas	Petroleum	Coal	Gas	Petroleum	Coal
AGE^2	−0.2994 [−1.187]	−2.1877* [−2.013]	−0.3280 [−1.081]	0.8409 [1.282]	33.6150 [1.516]	−0.6007 [−1.165]
MULTI PRIME	−0.0741 [−1.526]	0.2121* [1.926]	−0.0590** [−2.666]	0.0358 [0.349]	−0.2351 [−0.862]	−0.0212 [−0.722]
CONSTANT	11.3091*** [60.933]	9.0737*** [5.341]	11.7327*** [167.707]	9.1961*** [48.556]	20.7913*** [4.108]	8.9684*** [123.013]
Plant prime mover fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State specific linear time trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,748	392	4,314	841	83	1,492
R-squared	0.185	0.344	0.194	0.242	0.711	0.286

Notes: Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; *t* statistics are reported in brackets. Estimates of fixed effects and time trends not reported.

- *CAPACITY MARKET*, which equals one when the plant is located in a state that is a member of ISO-NE, NYISO or PJM and zero otherwise, to control for wholesale markets that permit capacity trading;[32]
- *DIVESTITURE*, which equals the percent of the state's major electricity provider's generating assets that had been divested or sold off, to control for states that required some retailers to divest their generation facilities;[33]
- *PBR*, which equals one when the plant was located in a state with current performance-based regulation and zero otherwise, to control for states that implemented performance based regulations, such as a price cap or profit-sharing agreement, when restructuring electricity markets;
- *RCOMP*, which equals one when ten percent or more of customers have a choice of two or more electricity retailers and no wholesale restructuring, and zero otherwise, to control for states that implemented retail choice prior to wholesale competition; and
- *FCOMP_PERCENT*, which equals the percentage of residential customers in a state with a choice of two or more retailers in states with both wholesale and retail competition and zero otherwise, as alternative to the ten percent threshold.

Because of market imperfections that led to higher prices and blackouts in California during 2000 and 2001, we also estimate the model on the subsample of data that excludes California plants.

Table 8 summarizes the results from the sensitivity analysis for investor- and municipality-owned utilities. Overall, the findings are similar to those reported in Table 6 and Table 7. The estimated coefficient on *PCOMP* ranges from −0.014 to −0.062 across the alternative specifications and is not precisely estimated. In contrast, the estimated coefficient on *FCOMP* ranges from −0.076 to −0.135, is always larger in absolute terms than the estimated coefficient on *PCOMP*, and is more precisely estimated. In summary, all other things held constant, investor- and municipality-owned plants in states with both wholesale and retail competition are about eight to 13 percent more efficient than plants located in states without full competition.

5. ENVIRONMENTAL BENEFITS

The National Archives and Records Association (1998) estimates that the generation, transmission, and distribution of electricity accounts for about 30

32. Capacity markets are markets where generators of electricity can sell their capacity to retail suppliers. The retail suppliers can then claim this capacity when they need it for a set price often times close to the variable cost of producing the electricity.

33. This particular form of restructuring is unlikely to affect IOUs, especially when paired with other restructuring initiatives. However, generating assets that continue to be municipally owned may feel pressure to improve efficiency or they too may be divested.

Table 8: Sensitivity Analysis

Description	Plant Type	R-squared	Partial competition	Full competition
The variable *CAPACITY MARKET* which equals one when the plant is located in a state that is a member of ISO-NE, NYISO or PJM and zero otherwise, to control for wholesale markets that permit capacity trading is added to the efficiency equation.	IOU	0.163	–0.0529 [–1.370]	–0.0908** [–2.349]
The variable *DIVESTITURE* ranging from zero to one indicating the percent of a state's generating assets that had been divested is added to the efficiency equation.	IOU	0.163	–0.0405 [–1.314]	–0.0845** [–2.037]
The variable *PBR* which is one when the plant was located in a state with current performance based regulation and zero otherwise is added to the efficiency equation	IOU	0.163	–0.0531 [–1.340]	–0.0899** [–2.663]
The variable *RCOMP* which is one when ten percent or more of customers have a choice of two or more electricity retailers and no wholesale restructuring, and zero otherwise is added to the efficiency equation	0.163	–0.0547* [–1.748]	–0.1086*** [–3.105]	
The variable *FCOMP_PERCENT* which is the percentage of residential customers with a choice of two or more retailers in states with both wholesale and retail competition and zero otherwise is used in place of *FCOMP*.	IOU	0.163	–0.0481* [–1.858]	–0.1352*** [–4.476]
When California is excluded from the sample.	IOU	0.164	–0.0269 [–0.734]	–0.0837 [–1.650]
The variable *CAPACITY MARKET* which equals one when the plant is located in a state that is a member of ISO-NE, NYISO or PJM and zero otherwise, to control for wholesale markets that permit capacity trading is added to the efficiency equation.	MUNI	0.181	–0.0624* [–1.790]	–0.1062*** [–3.585]

(continued)

Table 8: Sensitivity Analysis *(continued)*

Description	Plant Type	R-squared	Partial competition	Full competition
The variable *DIVESTITURE* ranging from zero to one indicating the percent of a state's generating assets that had been divested is added to the efficiency equation.	MUNI	0.181	–0.0138 [–0.360]	–0.0759*** [–3.966]
The variable *PBR* which is one when the plant was located in a state with current performance based regulation and zero otherwise is added to the efficiency equation	MUNI	0.181	–0.0622* [–1.817]	–0.1072*** [–3.546]
The variable *RCOMP* which is one when ten percent or more of customers have a choice of two or more electricity retailers and no wholesale restructuring, and zero otherwise is added to the efficiency equation	MUNI	0.181	–0.0365 [–0.944]	–0.0998*** [–3.234]
The variable *FCOMP_PERCENT* which is the percentage of residential customers with a choice of two or more retailers in states with both wholesale and retail competition and zero otherwise is used in place of *FCOMP*.	MUNI	0.181	–0.0369 [–0.965]	–0.0976* [–1.819]
When California is excluded from the sample.	MUNI	0.180	–0.0353 [–0.928]	–0.0913 [–1.496]

NOTES: Dependent variable is logEFF. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; *t* statistics are reported in brackets. There are 7,454 observations for all IOU specifications except for when California is excluded from the sample when there are 7,162. There are 2,416 observations for all MUNI specifications except for when California is excluded from the sample when there are 2,210.

percent of U.S. annual greenhouse emissions.[34] Because we have a direct estimate of increased thermal efficiency, a natural question arising from our empirical findings above is how much carbon dioxide was abated due to the efficiency gains from electricity market restructuring?

In 2006, 291 of our IOU sample plants were located in states that had restructured electricity markets, producing approximately 524 million MWh of net generation. Applying our estimate of $\beta = -0.0891$ from column one in Table 6 to fuel savings means that enough fuel was saved to generate about 47 million MWh of electricity. The EIA estimates that one MWh of electricity produces 1341 lbs. of carbon dioxide for the average fossil fuel electricity generating plants and 2095 lbs of carbon dioxide for the average coal electricity generating plant.[35] Because most of the efficiency savings in our sample were achieved by plants using coal as their primary input, we will use the coal estimate of pollution as an upper bound, and the fossil fuels number as our lower bound for carbon dioxide emission reductions. Using our estimate of fuel savings equivalent to 47 million MWh translates to 32 to 49 million tons of carbon dioxide abated using our estimates from the EIA study mentioned previously.[36] To translate this to a more tangible savings we use a market value of $11.45 per ton for carbon dioxide under cap and trade to construct a dollar value of the reduction in carbon dioxide from market restructuring.[37] Using this estimate, market restructuring is associated with a reduction in carbon dioxide valued between $361 million and $564 million for 2006.

6. CONCLUSIONS

This paper examined the effects of market restructuring that introduced competition into the United States electricity industry on the thermal efficiency of electricity generation. An empirical model was estimated on annual data for over 950 plants from 1996 to 2006. Model estimates show that both wholesale and retail competition together increased the efficiency of investor-owned plants by about nine percent. These gains stem from organizational and technological changes within the plant, and are not due to the attrition of inefficient firms. Additionally, the gains are most precisely estimated when working with the subset of coal-fired plants indicating much of the efficiency gains come through this subset. Although not directly targeted by restructuring initiatives, we also find similar efficiency effects for municipality-owned plants. This result suggests that the benefits from restructuring have spilled over to public electricity generation.

34. http://clinton4.nara.gov/Initiatives/Climate/electric.html.

35. From a EIA study conducted in 1998–1999. http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html

36. Davis and Wolfram (2010) find that electricity deregulation and consolidation are associated with an annual decrease of 40 million metric tons of carbon dioxide emissions.

37. International Emissions Trading Association report prepared for the World Bank in May of 2006 http://www.ieta.org/ieta/www/pages/getfile.php?docID = 1667

These results are interesting because they imply that wholesale and retail competition together are important for maximizing efficiency gains in electricity generation. Moreover, market restructuring became less popular following the price increases and black outs in California in 2000 and 2001, and many states decided to delay or suspend restructuring. All other things held constant, our results imply that market restructuring is associated with environmental benefits from the 30 to 50 million ton decrease in carbon dioxide emissions over the sample period. The public power sector has also opposed restructuring (Kwoka, 2008). Our results suggest that the efficiency gains from restructuring may have spilled over to the non-restructured, public power sector. This implies that restructuring is good for consumers and society, but perhaps not so good for public power executives who have to work more efficiently.

Finally, by comparing plants in states that permitted competition to plants in states that did not, this paper is important to economists and policy-makers considering the implementation of restructuring initiatives or the lifting of any current suspensions. When competition evolves and more firm-specific data becomes available, future work may want to consider using entrants' market share and/or market concentration to estimate the separate efficiency effects from potential versus actual competition.

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