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

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Market Restructuring, Competition and the Efficiency of Electricity Generation: Plant-level Evidence from the United States 1996 to 2006[1]

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Abstract

The paper examines the effects of market restructuring initiatives that introduced competition into the United States electricity industry on the thermal efficiency of electricity generation. A difference-in-differences model is estimated on annual data for over 950 plants from 1996 to 2006. Model estimates show that restructuring increased the efficiency of investor-owned plants by about thirteen percent and that these gains stem from organizational and technological changes within the plant. Instrumental variables approaches indicate that estimates may be lower bounds of efficiency gains. 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.

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## I. INTRODUCTION

Electricity is a fundamental input for almost all economic activity. By reducing the retail prices faced by consumers, and the emission of greenhouse gases during production, the efficient generation of electricity has substantial potential to increase societal welfare. This paper examines empirically the effects of state market restructuring initiatives that introduced competitive forces into the United States (U.S.) electricity industry on the thermal efficiency of generation plants. Thermal efficiency is measured by the heat rate; the amount of energy wasted in the form of heat during electricity generation.

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 (hereafter "investor-owned utilities") or publically owned by cooperatives, municipalities, state and federal governments (hereafter "municipality-owned utilities"). 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 (United States Government Accountability Office, 2002). 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. More recently, some states also experimented with incentive regulations that made the utility the residual claimant to their cost-reducing effort and innovation.[2]

[2] 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.

Market restructuring commenced with the passing of the Federal Energy Policy Act of 1992 and FERC Order No. 888 in 1996. These measures permitted nonutilities to enter wholesale markets and placed greater emphasis on market-determined prices.[3] In 1996, California became the first state to pass independent market restructuring legislation that introduced competition into retail markets. The initiative was aimed directly at investor-owned plants and included increased use of wholesale trading of electricity, the unbundling of generation, transmission and distribution so that consumers could choose a supplier of generation services and the abolishment of cost-based regulation. Table I shows that 23 states followed California between 1996 and 2002 by passing similar restructuring initiatives. By the end of 2002, 17 of these states[4], along with California, had actually implemented restructuring and permitted retail competition in electricity markets. By removing restrictions on revenue and exposing plants to competitive forces, market restructuring should have incented managers to increase plant efficiency in order to decrease costs. We use variation in the timing of the implementation of market restructuring initiatives across states from 1996 to 2006 to identify its effects on the efficiency of investor- and municipality-owned generation plants.

Several recent papers study the efficiency of investor-owned plants. Using data from coal and natural gas fueled 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

[3] Nonutilities are firms that generate, buy and/or sell electricity but are not involved in transmission.
[4] The District of Columbia is included as a one of these 17, and will counted as a state hereafter

transitioning toward 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 3 to 5 percent lower than similar plants in states that did not pass legislation. Furthermore, these efficiency gains almost double when compared to the municipality-owned plant benchmark. Fabrizio et. al. conclude that investor-owned plants in restructuring regimes increased their efficiency "in anticipation of increased competition." Zhang (2007) estimates a reduced-form model on 73 nuclear plants from 1992 to 1998 and shows that the passing of market restructuring legislation was associated with a reduction in fuel, operating and maintenance costs by about 11 to 23 percent.[5]

In addition to research on cost savings and efficiency improvements, many papers have looked at the effect of restructuring on prices. Joskow (2006) offers an investigation of industrial and residential retail prices following restructuring. He finds that wholesale and retail restructuring lead to lower retail prices. Taber et. all (2006) investigate prices for residential, industrial, and commercial prices, finding that results "do not support a conclusion that in aggregate deregulation has lowered electricity rates relative to those rates in still-regulated states."[6] For a more full review of the results of restructuring on prices and pitfalls associated with investigation read Kwoka (2008).

We contribute to this literature by developing a unique and comprehensive annual data set for of over 950 coal, natural gas and petroleum fueled generation plants from

[5] Kleit and Tecrell (2001) use data from 78 gas plants at 1996 to estimate the possible cost savings from restructuring the electricity industry. Results from a Bayesian stochastic frontier cost model suggest that restructuring could reduce production costs by up to 13 percent.

[6] Taber et all. pg. 29

1996 to 2006. The data represent six different types of generation technology and measure efficiency by the heat rate; the number of British Thermal Unit's (btu's) of fuel used to generate a megawatt hour (mWh) of electricity. In contrast to existing studies, our sample period spans beyond 1999 and covers the entire population of states that actually implemented market restructuring and permitted retail competition.[7] As such, we measure the effects of anticipated and actual competition. Because we have multiple plant observations within each state from 1996 to 2006, we are also able use state-specific time trends and instrumental variables to control for potential bias from unobserved factors that partially determine a state's restructuring decision and plant efficiency. Next, we use information on exiting and surviving plants to assess the extent to which efficiency gains are driven by the competitive effects of market restructuring within the plant, and by market selection or merger effects, whereby low-efficiency (low-profit) plants shut down or exit the market, or mergers are carried out to improve efficiency (Olley and Pakes, 1996; Disney et. al., 2003; Syverson, 2004). Finally, we use include alternative measures of restructuring as a further robustness test to investigate whether efficiency gains were from retail restructuring or other restructuring initiatives.

We estimate a difference-in-differences (DID) model that shows that thermal efficiency is about 13 percent higher in investor-owned plants which are located in states that implemented market restructuring. The resulting fuel savings from these efficiency gains roughly translates to the removal of 9 to 14 million cars from U.S. roads and highways. Surprisingly, thermal efficiency is also about 12 percent higher in municipality-owned plants located in states with restructuring. This latter effect suggests

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[7] Only seven states actually permitted retail competition in Fabrizio et. al.'s (2007) sample; four in 1998 and three in 1999. A maximum of four states permitted retail competition in Zhang's (2007) sample.

that the efficiency gains from restructuring may have spilled over to non-restructured, publically-owned plants.  We also estimate a selection model that measures the effect of market restructuring on efficiency, given the observable plant was an efficient producer to begin with.  The results from this model suggest that the efficiencies from market restructuring stem from internal organizational and technological changes within the plant and are not due to plant attrition or mergers[8] over time.

The paper is organized as follows.  Section II describes the competition-efficiency hypothesis in the context of U.S. electricity generation and outlines the empirical model we used to test the hypothesis.  The data are described in Section III.  Section IV presents the empirical results and Section V uses the results to calculate the potential reduction in greenhouse emissions due to market restructuring.  Section VI concludes.

## II. EMPIRICAL MODEL

### II (i). *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 and the steam from the boiler rotates 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 thermal efficiency, have a lower fuel cost of producing a single unit of output and, potentially, higher profits.

Owners and managers of investor-owned plants in states without market restructuring are protected from competition and have limited incentive to maximize thermal efficiency.  Increases in fuel and other variable costs can be passed on directly to

[8] See Kwoka et. all (2009) for a discussion of mergers and efficiency

consumers through regulated prices. In contrast, managers in states with market restructuring are subject to entry, exit and competitive pricing. For example, 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.

Because they are subject to competitive forces, plant managers that are located in states with restructured electricity markets have a strong incentive to increase efficiency by reducing their plant's heat rate. This is achieved by implementing industry best-practice maintenance and operational procedures, downsizing, upgrading to higher quality fuel, and/or by introducing new technologies. For example, refined technology equipment components provide a more reliable and accurate damper control of boiler temperature. This helps the plant optimize the combustion of air and flue gases and reduces the heat rate.[9] It is also possible that the efficiency gains from market restructuring may have indirectly spilled 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 introduction of competition.

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[9] *S*ee Entrepreneur http://www.entrepreneur.com/tradejournals/article/92887353.html 2002

II (ii). *Model*

We test the competition-efficiency hypothesis with a DID model that compares the efficiency of generation plants located in states with market restructuring to the efficiency of similar plants in states without restructuring. The model for plant $i$ = l, …, $n$ in state $s$ = 1, …, $S$ at year $t$ =1, …, $T$ is:

$$logEFF_{ist} = \beta RESTRUCTURE_{st} + W_{is}\delta + X_{ist}\gamma + \alpha_s + \eta_t + \varepsilon_{ist} \qquad (1)$$

where *EFF* is thermal efficiency, *RESTRUCTURE* equals one when the plant is located in a state with market restructuring, as defined by state initiated major retail choice, and zero otherwise[10], *W* is a vector of time-invariant plant characteristics, *X* is a vector of time-varying plant characteristics, the $\alpha$'s are unobserved state fixed effects, the $\eta$'s are unobserved time fixed effects and $\varepsilon$ is an error.

The parameter of interest is $\partial logEFF/\partial RESTRUCTURE = \beta$, which indicates the percentage difference in efficiency due to market restructuring. A finding of $\beta < 0$ supports the hypothesis that the competitive forces from market restructuring lower the heat rate and increase thermal efficiency. The DID estimate of $\beta$ is 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 production costs, are positively correlated with changes in *RESTRUCTURE,* the estimate of $\beta$ will be biased downwards. One way to minimize this bias is with instrumental variables. We employ an instrumental variable approach where the first stage is composed as:

[10] We will explore alternative measure of restructuring later

$$RESTRUCTURE_{ist} = \omega Z_{st} + W_{is}\delta + X_{is}\gamma + a_s + \eta_t + \sigma_{ist} \qquad (2)$$

Where again *W* is a vector of time-invariant plant characteristics, *X* is a vector of time-varying plant characteristics, the $\alpha$'s are unobserved state fixed effects, the $\eta$'s are unobserved time fixed effects and $\sigma$ is an error. The vector of instruments used is Z, and comes from predictors found by Craig (2009) used to predict state restructuring. We estimate the first stage using linear regression instead of Hazard or probit estimation following along with the findings of Angrist & Krueger (2001) and Kelejian (1971), which conclude that using a linear first stage on dummy variables produces consistent second stage estimates.

Alternatively, it is possible to decompose the error term into observed and unobserved state-time components that may be correlated with *EFF* and *RESTRUCTURE* so:

$$\varepsilon_{ist} = TREND_{st}\tau + e_{ist} \qquad (3)$$

where *TREND* is a vector of state-specific time trends that control for unobserved state effects that vary through time and *e* is an error term that is not correlated with *RESTRUCTURE*, *X*, and *W*.

There are two specification issues we must address when estimating equation (1). The first concerns the elements within the *TREND* vector. We follow Ziliak et. al. (2000) and Grogger (2003) by estimating equation (1) with alternative state-specific time trends. 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.  The second issue concerns attrition bias whereby the dependent variable, thermal efficiency, is observed for a restricted non-random sample of annual observations for plants that survive the entire sample period.  We address this potential bias with a selection model that estimates the effect of market restructuring on efficiency given the observed, "surviving" plant was a relatively more efficient generator of electricity to begin with.

## III. DATA

### III (i). *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, chemical, and fission energy into electric energy.  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 this data is not publicly available.

Annual data on location, ownership structure and production for 977 steam-cycle plants were sourced from Ventyx Energy.[11]  717 plants are investor owned and 260 are municipality owned.  These plants are used for the empirical analysis because they are observed at the beginning of the sample period and have no missing or unusual observations in subsequent years.  The data are from 1996 to 2006 and represent plants in all 50 states and the District of Columbia.  The sample plants are fired by coal, natural

[11] Ventyx Energy (formerly Global Energy Decisions) gather data from FERC and other reporting services, and package these data to private and government entities.

gas and/or petroleum and accounted for about 48 percent of total U.S. net generation by all energy sources at 2006, and about 67 percent of total U.S. net generation by coal, natural gas and petroleum (Ventyx Energy, 2007; Energy Information Administration (EIA), 2009).[12]

We merged our plant data with state-level information on median personal income, the relative size of industrial customers, electric utility revenue and policy makers' preferences for competition, obtained from the EIA (2009), Federal Communications Commission (FCC, 2007) and the U.S. Census Bureau. These data were then merged with information on the timing of the implementation of market restructuring across states, obtained from the National Association of Regulatory Utility Commissioners (NARUC, 2009), the National Energy Affordability and Accessibility Project (NEAAP, 2009) and state PUC web sites.

Table II presents selected characteristics for states that implemented market restructuring during the sample period and states that did not. Restructured and non-restructured states are reasonably similar in terms of their net generation of electricity, geographical area, median household income and their political makeup. Restructured states have higher population and population density. The average population density for restructured states is about 330 persons per square mile, while the average density for non-restructured states is about 100 per square mile.

### III (ii). *Variables and summary statistics*

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

The unit of observation is plant $i = 1, \ldots, n$ in state $s = 1, \ldots, S$ at year $t = 1, \ldots, T$.[13] The outcome variable of interest is thermal efficiency, or, the net heat rate (*EFF*). This is the number of Btu's of fuel used to generate a mWh of electricity that is sent from the generation plant to the grid.[14] The key explanatory variable of interest is *RESTRUCTURE*, which equals one when the plant is located in a state that implemented market restructuring, and this restructuring remains active, and zero otherwise.[15]

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 a 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 dummy variables.[16]

[13] Additional investigation of restructuring effects was pursued at the firm level. Similar results to those reported throughout the paper were found, with magnitudes of coefficients comparable. These results are available at the reader's request.

[14] 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. *S*ee Joskow and Schmalensee (1987) for a study of the determinants of thermal efficiency based on gross generation. Net generation is the electricity 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.

[15] Two states in our sample, Arizona and California, implemented, and then subsequently suspended, market restructuring prior to 2006.

[16] Estimates of equation (1) with the original six technology dummy variables, not reported, are similar to those reported in Section IV.

The vector *X* contains time-varying plant characteristics that may affect efficiency. *CAPACITY* (maximum sustainable amount of *mWh* of electricity generated per hour by the plant)[17] 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 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[18]. *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. *MULTI PRIME* (equals one when the plant has more than one type of prime mover for generating electricity) controls for plant heterogeneity.[19]

The vector *Z* contains observed state-time determinants of the state's decision to implement market restructuring (Craig, 2009). *RES PRICE* (the average price of residential consumers in cents per kilowatt hour), *STATE INCOME* (median income of the state's population in thousands of dollars), and *STATE INCOME*RES PRICE*, control for the political influence of residential customers. *SIZE INDUST* (the average amount of megawatt hours purchased by industrial customers in the state) controls for the influence of industrial customers. *REP GOV* (equal to one when the state has a republican governor

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[17] This is calculated during summer months when electricity generation is at a maximum.
[18] 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.
[19] Because of coordination problems, efficiency may be lower in plants with several different types of prime mover.

and zero otherwise); *REP PUC* (equal to one when the state has a republican dominated PUC and zero otherwise[20]) control for political influence on restructuring. *STATE REVENUE* (revenue from the state's total electricity sales in millions of dollars), *CAPACITY STATE* (maximum sustainable amount of mWh of electricity generated per hour for the entire state), *FIXED COSTS* (total fixed costs of the state in millions of dollars), and *FUEL COSTS* (total fuel costs of the state in millions of dollars) control for electricity utility influence. Table III provides a detailed description of the variables used in the empirical analysis and their sources.

In summary, the gross sample comprises of 8,092 plant-year observations for investor-owned utilities and 2,621 plant-year observations for municipality-owned utilities from 1996 to 2006.[21] Because of missing data, due to plant exit or because some firms did no 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.[22] Table IV 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 three turbines with an overall capacity of about 450 mWh, and uses 11,911 btu's of fuel to generate a mWh of electricity. 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 shut down. 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.

[20] In the case of ties or when independents were present 0.5 was assigned.

[21] We also have 1,459 (703) plant-year observations for investor-owned (municipality-owned) plants that dropped out of the database during the sample period. We use these additional observations for robustness checks in Section IV.

[22] The additional observations from the gross sample are used for robustness checks in Section IV.

Table V presents summary statistics for the municipality-owned plants in the net sample. Interestingly, the typical municipality-owned plant has similar operating characteristics to the typical investor-owned plant, but has smaller operating capacity (228 mWh vs. 449 mWh) and is younger (38 years vs. 44 years).

## IV. RESULTS

The empirical model and data are used to examine the effect of market restructuring on the thermal efficiency of electricity generation plants. We estimate several alternative model specifications of the efficiency equation (1) for investor-owned and municipality-owned plants, respectively. We then estimate a sample selection model that controls for attrition bias, and re-estimate the efficiency equation for subsamples of natural gas-, petroleum-, and coal-fired plants.

### IV (i). *Investor-owned plants*

Estimates of equation (1) for investor-owned plants are presented in Table VI. Column (i) presents the most parsimonious specification. We regress plant efficiency (*logEFF*) on market restructuring (*RESTRUCTURE*), the vector of time-invariant plant characteristics (*W*), the vector of time-varying plant characteristics (*X*), state and time fixed effects. 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 significant at the five percent level, indicating economies of scale in electricity production. However, the estimated coefficient on *UNITS* is positive 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 *MULT 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 parameter of interest in model (i), $\beta$, is negative, significant at the one percent level, and supports the hypothesis that the competitive forces from market restructuring lower the heat rate and increase thermal efficiency. All other things being held constant, this result from the baseline specification shows that investor-owned plants in states with market restructuring are about 13.5 percent more efficient than similar plants located in states without restructuring.

To address concerns with omitted variable bias, we first include linear time trends[23]. The results, reported in column two, are qualitatively similar to those reported for the baseline model (i). The estimated coefficient on *RESTRUCTURE*, $\beta = -0.136$, continues to show that market restructuring is associated with about a 13.6 percent increase in plant efficiency.

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[23] Model testing using Akaike Information Criterion and Bayesian Information Criterion, indicated that for IOU's this was the most appropriate specification of time trends.

Model (ii) IV uses the vector *Z* as instruments in the first stage and reports the results in the third column of table VI.[24] The coefficients on vectors *X* and *W* come out almost identically and the coefficient on *RESTRUCTURE*, $\beta$ = -0.166. Additionally the joint F test that the instruments are equal zero indicates that our instruments predict the decision to restructure quite well, and overidentification tests indicate that the instruments are valid. This estimate is not as precise as other specifications, but indicates that when not controlling for possible omitted variable bias, and endogeneity concerns biases the coefficient downward in magnitude, meaning that our estimates can be seen as lower bounds of the effect of restructuring on efficiency.

The efficiency gains reported above could be driven by the competitive effects from market restructuring within the plant and/or by attrition effects, whereby low-efficiency plants shut down or exit the market. The efficiency gains could also have been driven by the effects of mergers[25]. Testing for attrition or merger effects amounts to the same thing. Our gross sample contains 638 additional plant-year additional 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, our estimates of the effects of market restructuring for the surviving plants in Table VI may be biased downwards. As a robustness check, we use Heckman's two-step estimation procedure for the gross sample of 8,092 surviving and exiting plant-year observations. 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

[24] First stage results are available on request.
[25] Kwoka et. all (2009) find that mergers did not improve efficiency.

and/or reported no observations for continuous years during the sample period. 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.

Table VII presents two-step estimates of plant efficiency for model specification (ii). Column one reports the selection equation estimates and column two reports the efficiency estimates. We first note in column one that the coefficients on the excluded instruments in the selection equation, *FIXED COSTS* and *FIXED COSTS*$^2$, have the expected signs and are very precisely estimated. All other things being equal, survival into the net sample is more probable for firms with large fixed costs. The estimated coefficient on the selection term, *MILLS*, is not statistically significant different from zero and suggests there is no problem with attrition or merger bias. Moreover, as expected, the estimated coefficient on *RESTRUCTURE* of $\beta$ = -0.1381 is very similar to the single-equation OLS estimates of model (ii) reported in Table VI. Overall, the two-step, OLS, and IV results suggest that efficiency gains from market restructuring 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.

It is also possible that the effects of market restructuring are different for coal-, natural gas- and petroleum-fueled generation plants. Table VIII reports estimates of model (ii) for subsamples of gas, petroleum and coal plants. The estimated coefficients on *RESTRUCTURE* for the petroleum subsample, reported in column two, is negative and of plausible magnitude, but is not significantly different from zero. The estimates for the gas subsample in column one is statistically significant at the five percent level and larger in magnitude than previous results.[26] Column three estimates show that the efficiency gains from restructuring are most prominent for coal-fired plants. The estimated coefficient on *RESTRUCTURE*, $\beta$ = -0.1215 is similar to the estimate for the full sample and significant at the one percent level.

IV (ii). *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. 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 implementation of competition.

To test for potential spillover effects, we estimate the efficiency equation (1) for all the municipality-owned plants in our sample. Table IX presents OLS estimates of specifications (i) through (ii) IV. Table X presents two-step estimates of model (ii) and Table XI presents estimates of model (ii) for the gas, petroleum and coal plant subsamples. 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 market restructuring are about 12 percent more efficient than plants located in states without restructuring. This result is robust to potential attrition bias. Moreover, the efficiency gains from restructuring are most apparent in municipality-owned, coal-fired plants.

[26] These stronger results may stem from the increased use of combined cycle technology.

IV (iii). *Alternative measures of restructuring*

As pointed out in Kwoka (2008), measuring electricity restructuring is a difficult task. Problems may arise in terms of how restructuring is measured. Restructuring occurred at the national level through wholesale initiatives such as EPAct, open access, and RTOs. Individual states paralleled these movements with efforts targeted at retail access (the focus of this paper), divestiture of generating assets, and occasional centralized markets for wholesale trading. Kwoka also points out that restructuring is often not a simultaneous event measured as either present or not present.

To address both of these concerns we introduce three new variables: *RETAIL*, a variable ranging from zero to one indicating the percent of customers having access to their choice of power providers; *WHOLESALE*, dummy variable equal to one if a majority of states power producers has access to some form of wholesale market; *DIVESTITURE,* a variable ranging from zero to one indicating the percent of a states generating assets had been divested. We then re estimate tables VI and IX, using all three of these measures of restructuring, presenting the results in tables XII and XIII respectively. Focusing first on table XII, the coefficient on *RETAIL* is statistically significant at the one percent level across the first two specifications, and significant at the 10 percent level for the IV specification, and almost identical in magnitude to the estimates coefficients on *RESTRUCTURE* reported in Table VI. The coefficients on *WHOLESALE* and *DIVESTITURE* are not statistically significant for any specification. Turning to table XIII the results for municipally-owned plants differ from earlier results found in table IX. Particularly striking is the fact that *DIVESTITURE* is statistically significant in specification (i) only. Additionally *RETAIL* is statistically significant in specification (ii) only. We read this as evidence that for municipally owned plants it may be that divestiture constitutes a risk that they will be sold off as well if greater efficiency is not achieved.[27] We conclude that misspecification of the variable *RESTRUCTURE* is not an issue for the purposes of this paper.

## V. EFFICIENCY GAINS

The electricity industry is one of the largest contributors to greenhouse gas emissions in the U.S. The National Archives and Records Association (1998) estimate that the generation, transmission, and distribution of electricity accounts for about 30 percent of U.S. annual greenhouse emissions.[28] 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 mega-watt hours of net generation. Applying our estimate of $\beta$ = -0.1365 from column two in Table VI to fuel savings means that enough fuel was saved to generate about 72 million mega-watt hours of electricity. Using estimates from EIA (1999) a mega-watt hour of electricity generation translates into 1,341 lbs of carbon dioxide for the average fossil fuel plant and 2,095 lbs of carbon dioxide for the average coal plant.[29] Because most of the efficiency

[27] Results of specification (iii) for *RETAIL*, *DIVESTITURE,* and *WHOLESALE*, separately show no major differences in results and are available on request.
[28] http://clinton4.nara.gov/Initiatives/Climate/electric.html.
[29] According to 1999 estimates (EIA). To convert this into carbon dioxide pollution we use estimates of an Energy Information Administration (EIA) study conducted from 1999 to 1998 which concludes that one megawatt hour of electricity produces 1341 lbs of $C0_2$ for the average fossil fuel electricity generating

savings in our sample were achieved by plants using coal as their primary input, we will use the coal estimate as an upper bound, and the fossil fuels number as our lower bound for emission reductions.

Table XIV presents our upper and lower bound calculations of pollution savings in terms of: tons of carbon dioxide; cars and light trucks taken off the road; cars converted to hybrids; and airplane flights not taken.[30] [31] The efficiencies from electricity market restructuring translate into 52 to 81 million tons of carbon dioxide abated. In 2006, this was equivalent to nine (six) to fourteen (ten) million cars (light trucks) being taken off the road (or, a 6 to 10 percent decrease in cars or light trucks, respectively), the conversion of 12 to 20 percent of cars on the road to hybrids, or a reduction in 39,000 to 61,000 airline flights.[32]

## VI. CONCLUSIONS

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. A difference-in-differences model is estimated on annual data for over 950 plants from 1996 to 2006. Model estimates show that restructuring increased the efficiency of investor-owned plants by about 13 percent. Instrumental variable regressions indicate that these estimates may be biased towards zero, indicating a possibly stronger result. Using Heckman's two-step estimation we are able to establish

plants and 2095 lbs of carbon dioxide for the average coal electricity generating planthttp://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html

[30] Using the Honda Civic Hybrid 47.73 MPG measurement. (Hybrid Mileage Database) http://www.greenhybrid.com/compare/mileage/

[31] Converted using the Boening B747-200E. (Intergovernmental Panel on Climate Change) http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf

[32] Using 135,399,945 cars and 99,124,775 light trucks (Bureau of transit statistics) http://www.bts.gov/

that these gains stem from organizational and technological changes within the plant, not through attrition effects. 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. Lastly we find that restructuring has additional benefits to societal welfare through reduction of greenhouse emissions comparable to removing approximately 9 to 14 million cars of the road.

Future research focuses on 2 main prongs of investigation. First, investigation into whether customers actually realized lower prices for electricity as a result restructuring (one of the major stated goals of restructuring), passing societal gains on to customers. Secondly, what other side effects were a result of restructuring, such as possible inconsistency with access to electricity such as black outs and brown outs.

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TABLE I
STATES WITH MARKET RESTRUCTURING

| Year passed | State | Year implemented | Current status |
|---|---|---|---|
| 1996 | California | 1998 | Suspended |
| 1996 | New Hampshire | 1998 | |
| 1996 | New York | 1998 | |
| 1996 | Pennsylvania | 1999 | |
| 1996 | Rhode Island | 1998 | |
| 1997 | Illinois | 1999 | |
| 1997 | Maine | 2000 | |
| 1997 | Massachusetts | 1998 | |
| 1997 | Montana | 1998 | Suspended |
| 1997 | Nevada | 2000 | Suspended |
| 1997 | Oklahoma | 2000 | Suspended |
| 1998 | Arizona | 2001 | Suspended |
| 1998 | Connecticut | 2000 | |
| 1999 | Arkansas | 2002 | Suspended |
| 1999 | Delaware | 2001 | |
| 1999 | Maryland | 2000 | |
| 1999 | New Jersey | 1999 | |
| 1999 | New Mexico | 2001 | Suspended |
| 1999 | Ohio | 2001 | |
| 1999 | Oregon | 2002 | Suspended |
| 1999 | Texas | 2002 | |
| 1999 | Virginia | 2002 | Suspended |
| 2000 | Michigan | 2001 | |
| 2000 | D.C. | 2001 | |

*SOURCES*: NARUC (2009); NEAAP (2009); State PUC web sites.

TABLE II
STATE CHARACTERISTICS 1996 - 2006

| | All states | | States with market restructuring | | States without market restructuring | |
|---|---|---|---|---|---|---|
| Variable | mean | s.d. | mean | s.d. | mean | s.d. |
| Net generation (1000 mWh) | 1,360.8 | 3,181.9 | 1,267.6 | 3,098.7 | 1,451.6 | 3,258.5 |
| Area (miles$^2$) | 92,760 | 103,670 | 99,553 | 97,231 | 86,141 | 109,179 |
| Population (millions) | 11.100 | 9.927 | 15.400 | 9.976 | 8.813 | 9.097 |
| Population per mile$^2$ | 215.12 | 322.96 | 334.11 | 420.45 | 99.17 | 80.30 |
| Median household income ($) | 43,269 | 6,578 | 45,336 | 5,969 | 41,254 | 6,519 |
| Republican PUC | 0.5847 | 0.4824 | 0.6687 | 0.4556 | 0.5030 | 0.4936 |
| Number of states | 51 | | 18 | | 33 | |

*NOTES*: s.d. is standard deviation. Industrial concentration is the percentage of electricity from a state that goes to industrial customers. Local telephone competition equals one when the incumbent one when the incumbent Bell Operating Company within the state had obtained state and federal approval that its local markets were irreversibly open to competition. Republican PUC equals one when the majority of state's PUC commissioners are Republican.

*SOURCES*: EIA, FCC (2007),.NARUC (1995, 2001), US Census Bureau, Ventyx Energy (2007).

TABLE III
VARIABLE DESCRIPTIONS

| Variable | Description |
|---|---|
| EFF | Number of btu's of fuel used to generate a mWh of electricity that is sent from the generation plant to the grid. Source: Ventyx Energy (2007). |
| RESTRUCTURE | One when the plant is located in a state that implemented market restructuring, as defined by retail choice or competition, and this restructuring remains active, and zero otherwise. Source: NARUC (2009); NEAAP (2009); State PUC web sites. |
| RETAIL | Variable ranging from zero to one indicating the percent of customers having access to their choice of power providers. Source: NARUC (2009); NEAAP (2009); State PUC web sites. |
| DIVESTITURE | Variable ranging from zero to one indicating the percent of a states generating assets had been divested. Source: NARUC (2009); NEAAP (2009); State PUC web sites. |
| WHOLESALE | One if a majority of states power producers has access to some form of wholesale market. Source: NARUC (2009); NEAAP (2009); State PUC web sites. |
| 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 a integrated coal gasification combined cycle turbine or a condensing steam turbine and zero otherwise. Source: Ventyx Energy (2007). |
| CAPACITY | Maximum sustainable amount 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). |
| RES PRICE | Price of electricity for residential customers (cents per kWh): EIA (2007) |
| SIZE INDUST | Size of the average industrial customer (mWh's purchased per industrial customer): EIA (2007) |
| CAPACITY STATE | Maximum sustainable amount of mWh of electricity generated per hour for the entire state. Source: Ventyx Energy (2007). |
| FIXED COSTS | Total fixed costs (million $). Source: Ventyx Energy (2007). |
| FUEL COSTS | Total fuel costs (million $) Source: Ventyx Energy (2007) |
| REP GOV | One when the state has a republican governor and zero otherwise: State Governor websites (2009). |
| REP PUC | One when the state has a republican dominated public utility commission and zero otherwise: State PUC websites (2009);Naruc Blue books (2007); Personal calls (2007). |
| STATE REVENUE | State's total electricity sales divided (millions of $). Source: EIA (2007) |
| STATE INCOME | Median income of the state's population divided by 1,000 ($). Source: U.S. Census Bureau. |
| RES PRICE | Price of electricity for residential customers (cents per kWh): EIA (2007) |
| FIXED COSTS | Total fixed costs (million $). Source: Ventyx Energy (2007). |

TABLE IV
SUMMARY STATISTICS: INVESTOR-OWNED PLANTS

| Variable | Mean | S.D. | Min | Max |
|---|---|---|---|---|
| *EFF* | 11,910.85 | 19,637.34 | 13.75 | 1,133,333 |
| *RESTRUCTURED* | 0.3126 | 0.4636 | 0 | 1 |
| *CAPACITY* | 448.62 | 429.02 | 4.925 | 2600 |
| *UNITS* | 3.6662 | 2.4506 | 1 | 32 |
| *MULTI PLANT* | 0.8683 | 0.3382 | 0 | 1 |
| *ZERO OUTPUT* | 0.2000 | 0.4000 | 0 | 1 |
| *NEG OUTPUT* | 0.3283 | 0.4696 | 0 | 1 |
| *AGE* | .4401 | .1916 | 0 | 1.06 |
| *MULTI PRIME* | 0.4844 | 0.4998 | 0 | 1 |
| *STATE INCOME* | 4.2143 | .6870 | 2.5086 | 6.8059 |
| *STATE REVENUE* | 8.375 | 6.759 | .4680 | 35.4482 |
| *FIXED COSTS* | 12.7103 | 16.3033 | -4.4337 | 307.0000 |

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

TABLE V
SUMMARY STATISTICS: MUNI-OWNED PLANTS

| Variable | Mean | S.D. | Min | Max |
|---|---|---|---|---|
| *EFF* | 11820.22 | 6610.43 | 316.25 | 96799.59 |
| *RESTRUCTURED* | 0.2123 | 0.4090 | 0 | 1 |
| *CAPACITY* | 227.47 | 280.16 | 4.5 | 1800 |
| *UNITS* | 3.2222 | 1.9666 | 1 | 8 |
| *MULTI PLANT* | 0.6991 | 0.4587 | 0 | 1 |
| *ZERO OUTPUT* | 0.2252 | 0.4178 | 0 | 1 |
| *NEG OUTPUT* | 0.3613 | 0.4805 | 0 | 1 |
| *AGE* | .3766 | .1701 | 0 | 1.06 |
| *MULTI PRIME* | 0.4205 | 0.4937 | 0 | 1 |
| *STATE INCOME* | 4.1242 | .6216 | 2.5086 | 6.8059 |
| *STATE REVENUE* | 9.3866 | 8.8776 | .4680 | 35.4482 |
| *FIXED COSTS* | 7.6120 | 10.9052 | -.1872 | 115.0000 |

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

TABLE VI
EFFICIENCY ESTIMATES FOR INVESTOR-OWNED PLANTS

| | Model (i) | Model (ii) | Model (ii) IV |
|---|---|---|---|
| *RESTRUCTURE* | -0.1349*** | -0.1365*** | -0.1656* |
| | [0.0375] | [0.0414] | [0.0907] |
| *CAPACITY* | -0.0001** | -0.0001** | -0.0001*** |
| | [0.0000] | [0.0000] | [0.0000] |
| *UNITS* | 0.0117** | 0.0117** | 0.0117*** |
| | [0.0046] | [0.0046] | [0.0045] |
| *MULTI PLANT* | -0.0093 | -0.011 | -0.0116 |
| | [0.0260] | [0.0255] | [0.0252] |
| *ZERO OUTPUT* | -0.1501*** | -0.1529*** | -0.1526*** |
| | [0.0345] | [0.0339] | [0.0331] |
| *NEG OUTPUT* | -0.1868*** | -0.1901*** | -0.1902*** |
| | [0.0325] | [0.0334] | [0.0327] |
| *AGE* | 0.3321 | 0.311 | 0.311 |
| | [0.2244] | [0.2248] | [0.2207] |
| $AGE^2$ | -0.3524** | -0.3316* | -0.3316* |
| | [0.1743] | [0.1744] | [0.1711] |
| *MULTI PRIME* | -0.0403** | -0.0487*** | -0.0487*** |
| | [0.0187] | [0.0175] | [0.0172] |
| *CONSTANT* | 8.9666*** | 8.9393*** | 8.9376*** |
| | [0.1021] | [0.1002] | [0.0990] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State-specific linear time trends | No | Yes | Yes |
| Pass overidentification tests? | | | Yes |
| F test (joint test that coefficients on instruments=0) | | | 129.69 |
| Observations | 7454 | 7454 | 7454 |
| R-squared | 0.1411 | 0.1631 | 0.163 |

*Notes*. Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE VII
TWO-STEP EFFICIENCY ESTIMATES FOR INVESTOR-OWNED PLANTS

| | Model (ii) | |
|---|---|---|
| *RESTRUCTURE* | 0.1799 | -0.1381*** |
| | [0.1218] | [0.0414] |
| *CAPACITY* | 0.0007*** | -0.0001*** |
| | [0.0002] | [0.0000] |
| *UNITS* | 0.0077 | 0.0114** |
| | [0.0094] | [0.0046] |
| *MULTI PLANT* | 0.4157*** | -0.0136 |
| | [0.0664] | [0.0254] |
| *ZERO OUTPUT* | -0.2780*** | -0.1490*** |
| | [0.0770] | [0.0332] |
| *NEG OUTPUT* | 0.1025 | -0.1908*** |
| | [0.0735] | [0.0330] |
| *AGE* | 0.9255*** | 0.2828 |
| | [0.3484] | [0.2314] |
| $AGE^2$ | -0.5579* | -0.3095* |
| | [0.3336] | [0.1784] |
| *MULTI PRIME* | 1.2123*** | -0.0641*** |
| | [0.0687] | [0.0190] |
| *FIXED COST* | 0.1016*** | |
| | [0.0128] | |
| $FIXED\ COST^2$ | -0.0004*** | |
| | [0.0000] | |
| *MILLS* | | -0.06 |
| | | [0.0539] |
| *CONSTANT* | -2.3215*** | 8.9808*** |
| | [0.3205] | [0.1040] |
| Plant prime mover fixed effects | Yes | Yes |
| Year fixed effects | Yes | Yes |
| State fixed effects | Yes | Yes |
| State-specific linear time trends | Yes | Yes |
| Observations | 8092 | 7454 |
| R-squared | | 0.1634 |
| Log likelihood | -22245.7 | |
| F test (joint test that selection criteria coefficients=0) | 70.69 | |

*NOTES.* Dependent variable for step two is *SURVIVE*. Dependent variable for step two is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE VIII
EFFICIENCY ESTIMATES FOR INVESTOR-OWNED GAS, PETROLEUM AND GAS FIRED PLANTS

| | Model (ii) | | |
|---|---|---|---|
| | Gas | Petroleum | Coal |
| *RESTRUCTURE* | -0.1829** | -0.0102 | -0.1215*** |
| | [0.0688] | [0.3116] | [0.0283] |
| *CAPACITY* | 0 | -0.0001 | -0.0001*** |
| | [0.0001] | [0.0002] | [0.0000] |
| *UNITS* | 0.0098* | 0.014 | 0.0139 |
| | [0.0057] | [0.0692] | [0.0157] |
| *MULTI PLANT* | -0.0181 | 0.1121 | -0.0228 |
| | [0.0537] | [0.1552] | [0.0221] |
| *ZERO OUTPUT* | -0.1473** | -0.1928 | -0.1015*** |
| | [0.0550] | [0.1554] | [0.0347] |
| *NEG OUTPUT* | -0.1997*** | -0.0767 | -0.1886*** |
| | [0.0556] | [0.1465] | [0.0348] |
| *AGE* | 0.4432 | 1.2305 | 0.2727 |
| | [0.3326] | [1.4286] | [0.3490] |
| $AGE^2$ | -0.3104 | -2.2399** | -0.3158 |
| | [0.2518] | [1.0297] | [0.3028] |
| *MULTI PRIME* | -0.0764 | 0.2648** | -0.0552** |
| | [0.0468] | [0.1094] | [0.0222] |
| *CONSTANT* | 8.8219*** | 9.9116*** | 9.2104*** |
| | [0.1649] | [0.3228] | [0.0660] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State specific linear time trends | Yes | Yes | Yes |
| Observations | 2748 | 392 | 4314 |
| R-squared | 0.1848 | 0.3381 | 0.1949 |

*NOTES.* Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE IX
EFFICIENCY ESTIMATES FOR MUNICIPALITY-OWNED PLANTS

| | Model (i) | Model (ii) | Model (ii) IV |
|---|---|---|---|
| *RESTRUCTURE* | -0.0937 | -0.1201** | -0.2640*** |
| | [0.0623] | [0.0569] | [0.0883] |
| *CAPACITY* | -0.0002** | -0.0002** | -0.0002*** |
| | [0.0001] | [0.0001] | [0.0001] |
| *UNITS* | 0.0151 | 0.0171 | 0.0166 |
| | [0.0131] | [0.0132] | [0.0127] |
| *MULTI PLANT* | -0.0155 | -0.0123 | -0.0131 |
| | [0.0367] | [0.0365] | [0.0355] |
| *ZERO OUTPUT* | -0.1622*** | -0.1565*** | -0.1594*** |
| | [0.0513] | [0.0511] | [0.0495] |
| *NEG OUTPUT* | -0.1874*** | -0.1947*** | -0.1953*** |
| | [0.0607] | [0.0604] | [0.0586] |
| *AGE* | -0.0139 | -0.0339 | -0.0318 |
| | [0.2173] | [0.2238] | [0.2178] |
| $AGE^2$ | -0.2321 | -0.2259 | -0.2234 |
| | [0.2782] | [0.2822] | [0.2728] |
| *MULTI PRIME* | -0.005 | -0.0045 | -0.0055 |
| | [0.0418] | [0.0456] | [0.0442] |
| *CONSTANT* | 9.1911*** | 8.9057*** | 8.9045*** |
| | [0.0784] | [0.0765] | [0.0731] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State-specific linear time trends | No | Yes | Yes |
| Passed overidentification tests? | | | Yes |
| F test (joint test that coefficients on instruments=0) | | | 75.13 |
| Observations | 2416 | 2416 | 2416 |
| R-squared | 0.1611 | 0.1803 | 0.1784 |

*Notes*. Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE X
TWO-STEP EFFICIENCY ESTIMATES FOR MUNICIPALITY-OWNED PLANTS

| | Model (ii) | |
|---|---|---|
| *RESTRUCTURE* | 0.2057 | -0.1201** |
| | [0.3449] | [0.0569] |
| *CAPACITY* | -0.001 | -0.0002** |
| | [0.0015] | [0.0001] |
| *UNITS* | -0.0353 | 0.0171 |
| | [0.0241] | [0.0132] |
| *MULTI PLANT* | -0.0559 | -0.0123 |
| | [0.0901] | [0.0365] |
| *ZERO OUTPUT* | -0.3327** | -0.1565*** |
| | [0.1469] | [0.0511] |
| *NEG OUTPUT* | 0.6621*** | -0.1947*** |
| | [0.1604] | [0.0604] |
| *AGE* | -2.4775** | -0.0339 |
| | [1.2497] | [0.2238] |
| $AGE^2$ | 1.8383 | -0.2259 |
| | [1.1853] | [0.2822] |
| *MULTI PRIME* | -0.3000*** | -0.0045 |
| | [0.1066] | [0.0456] |
| *FIXED COST* | 0.4915*** | |
| | [0.0821] | |
| $FIXED\ COST^2$ | -0.0053*** | |
| | [0.0009] | |
| *MILLS* | | -0.0016 |
| | | [0.0743] |
| *CONSTANT* | 0.726 | 8.9057*** |
| | [0.7899] | [0.0765] |
| Plant prime mover fixed effects | Yes | Yes |
| Year fixed effects | Yes | Yes |
| State fixed effects | Yes | Yes |
| State-specific linear time trends | Yes | Yes |
| Observations | 2621 | 2416 |
| R-squared | | 0.1803 |
| Log likelihood | -710.892 | |
| F test (joint test that selection criteria coefficients=0) | 36.93 | |

*NOTES.* Dependent variable for step two is *SURVIVE*. Dependent variable for step two is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE XI
EFFICIENCY ESTIMATES FOR MUNICIPALITY-OWNED GAS, PETROLEUM AND GAS FIRED PLANTS

| | Model (ii) | | |
|---|---|---|---|
| | Gas | Petroleum | Coal |
| *RESTRUCTURE* | -0.2184* | 0.4456 | -0.0717** |
| | [0.1106] | [0.7538] | [0.0325] |
| *CAPACITY* | 0 | -0.0093 | -0.0001*** |
| | [0.0003] | [0.0090] | [0.0000] |
| *UNITS* | -0.0146 | 0.3347*** | 0.0270** |
| | [0.0286] | [0.0317] | [0.0124] |
| *MULTI PLANT* | 0.0591 | -0.0848 | -0.0591 |
| | [0.0741] | [0.1176] | [0.0522] |
| *ZERO OUTPUT* | -0.1284 | 0.4390** | -0.2592*** |
| | [0.0941] | [0.1811] | [0.0518] |
| *NEG OUTPUT* | -0.1194 | -0.4975* | -0.1799*** |
| | [0.0789] | [0.2309] | [0.0574] |
| *AGE* | -0.8396 | -33.8965* | 0.2707 |
| | [0.6210] | [16.6996] | [0.4355] |
| $AGE^2$ | 0.7675 | 33.673 | -0.6075 |
| | [0.5954] | [19.5825] | [0.5231] |
| *MULTI PRIME* | 0.0295 | 0.0498 | -0.0185 |
| | [0.1014] | [0.1363] | [0.0298] |
| *CONSTANT* | 9.1559*** | 16.9575*** | 8.9401*** |
| | [0.1732] | [3.4115] | [0.0496] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State specific linear time trends | Yes | Yes | Yes |
| Observations | 841 | 83 | 1492 |
| R-squared | 0.2422 | 0.6873 | 0.2849 |

*NOTES.* Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE XII
EFFICIENCY ESTIMATES FOR INVESTOR OWNED PLANTS USING THREE MEASURES OF RESTRUCTURING

| | Model (i) | Model (ii) | Model (ii) IV |
|---|---|---|---|
| *RETAIL* | -0.1389*** | -0.1498*** | -0.1802* |
| | [0.0326] | [0.0332] | [0.1059] |
| *DIVESTITURE* | -0.0123 | 0.0268 | 0.0814 |
| | [0.0309] | [0.0421] | [0.1438] |
| *WHOLESALE* | 0.0046 | -0.0589 | -0.0645 |
| | [0.0386] | [0.0414] | [0.1839] |
| *CAPACITY* | -0.0001** | -0.0001** | -0.0001*** |
| | [0.0000] | [0.0000] | [0.0000] |
| *UNITS* | 0.0118** | 0.0118** | 0.0117*** |
| | [0.0046] | [0.0046] | [0.0045] |
| *MULTI PLANT* | -0.0109 | -0.0125 | -0.0122 |
| | [0.0256] | [0.0252] | [0.0254] |
| *ZERO OUTPUT* | -0.1499*** | -0.1512*** | -0.1512*** |
| | [0.0340] | [0.0336] | [0.0324] |
| *NEG OUTPUT* | -0.1878*** | -0.1920*** | -0.1922*** |
| | [0.0325] | [0.0333] | [0.0320] |
| *AGE* | 0.3276 | 0.3103 | 0.3108 |
| | [0.2250] | [0.2247] | [0.2205] |
| *AGE2* | -0.3480* | -0.3307* | -0.3311* |
| | [0.1747] | [0.1743] | [0.1712] |
| *MULTI PRIME* | -0.0410** | -0.0491*** | -0.0492*** |
| | [0.0186] | [0.0176] | [0.0173] |
| *CONSTANT* | 8.9671*** | 8.9391*** | 8.9396*** |
| | [0.1099] | [0.1027] | [0.0996] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State specific linear time trends | No | Yes | Yes |
| Pass overidentification tests? | | | Yes |
| F test (joint test that coefficients on instruments=0) | | | 173.77, 119.92, 66.61 |
| Observations | 7454 | 7454 | 7454 |
| R-squared | 0.1414 | 0.1632 | 0.163 |

*NOTES.* Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

TABLE XIII
EFFICIENCY ESTIMATES FOR MUNICIPALLY-OWNED PLANTS
USING THREE MEASURES OF RESTRUCTURING

| | Model (i) | Model (ii) | Model (ii) IV |
|---|---|---|---|
| *RETAIL* | -0.0425 | -0.0607 | 0.1379 |
| | [0.0450] | [0.0373] | [0.3620] |
| *DIVESTITURE* | -0.1626** | -0.0676 | -0.3803 |
| | [0.0722] | [0.0511] | [0.3812] |
| *WHOLESALE* | -0.0292 | -0.0764** | -0.146 |
| | [0.0363] | [0.0353] | [0.1710] |
| *CAPACITY* | -0.0002** | -0.0002** | -0.0002*** |
| | [0.0001] | [0.0001] | [0.0001] |
| *UNITS* | 0.016 | 0.0174 | 0.0179 |
| | [0.0130] | [0.0131] | [0.0125] |
| *MULTI PLANT* | -0.0144 | -0.0117 | -0.0117 |
| | [0.0362] | [0.0362] | [0.0350] |
| *ZERO OUTPUT* | -0.1569*** | -0.1541*** | -0.1511*** |
| | [0.0512] | [0.0511] | [0.0490] |
| *NEG OUTPUT* | -0.1909*** | -0.1966*** | -0.1995*** |
| | [0.0611] | [0.0606] | [0.0589] |
| *AGE* | -0.0361 | -0.0326 | -0.0323 |
| | [0.2195] | [0.2235] | [0.2169] |
| *AGE2* | -0.2154 | -0.2292 | -0.2315 |
| | [0.2763] | [0.2816] | [0.2716] |
| *MULTI PRIME* | -0.0014 | -0.0041 | -0.0039 |
| | [0.0425] | [0.0457] | [0.0440] |
| *CONSTANT* | 9.1727*** | 8.8969*** | 8.8758*** |
| | [0.0760] | [0.0745] | [0.0688] |
| Plant prime mover fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| State fixed effects | Yes | Yes | Yes |
| State specific linear time trends | No | Yes | Yes |
| Pass overidentification tests? | | | Yes |
| F test (joint test that coefficients on instruments=0) | | | 110.31, 90.78, 56.69 |
| Observations | 2416 | 2416 | 2416 |
| R-squared | 0.1642 | 0.1812 | .1734 |

*NOTES.* Dependent variable is log*EFF*. *** significant at the 0.01 level;** significant at the 0.05 level; * significant at the 0.1 level; Robust standard errors in parenthesis are clustered at the state level. Estimates of fixed effects and time trends not reported.

| TABLE XIV<br>ESTIMATES OF SAVINGS FROM ELECTRICITY<br>RESTRUCTURING IN 2006 | | |
|---|---|---|
| Savings achieved | Lower Bound | Upper Bound |
| Tons of $CO_2$ | 52,228,192 | 81,594,378 |
| Cars off the road | 9,122,828 | 14,252,293 |
| Percent of cars off road | 6.74 | 10.53 |
| Light trucks off the road | 6,514,274 | 10,177,035 |
| Percent of light trucks off road | 6.57 | 10.27 |
| Flights not taken | 39,321 | 61,430 |
| Cars switched to hybrids | 16,907,799 | 26,414,496 |
| Percent of cars traded for hybrids | 12.49 | 19.51 |

## Appendix