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Excessive Entry and Investment in Deregulated Markets: Evidence from the Electricity Sector

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There is a substantial theoretical literature explaining excessive entry and overinvestment in industries with free entry. The restructuring of U.S. state electricity markets, beginning in the mid-1990s, provides a unique opportunity to empirically estimate the impact of free entry on investment in a large industrial sector. Leveraging the staggered restructuring by US states as an identification strategy, this paper shows restructuring, after controlling for important factors, such as retail sales growth and fuel prices, was associated with an average annual increase of 600 megawatts of state power plant capacity over the period 2000-2006. This investment explains the size and duration of the US Gas Boom, where over $240 billion was invested in gas-fired power plants. The increase in capacity investment associated with restructuring can be considered excessive, or uneconomical, given it was not due to fundamentals, such as retail sales growth, and was later associated with owner bankruptcies and financial distress. This paper reviews alternative theoretical models of overinvestment and finds the experience of the U.S. electricity industry is most consistent with market coordination failure, falling long-term real interest rates and a contagion effect. (JEL L51, L94, L22, Q40)

1. Introduction

Free entry is a necessary, but not sufficient, condition for decentralized decision-making maximizing social welfare. When, for example, competitive pricing behavior is absent, free entry can result in inadequate or excessive entry, relative to the socially optimal amount. [1] Additionally, simultaneous entry of firms into a market can result in a coordination failure, also leading to non-optimal outcomes.[2] Empirical evidence for these effects has been less clear, with the majority of papers focused on the well-established result of S-shaped entry and exit in new product markets.[3]

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[1] See Spence (1976) and Dixit and Stiglitz (1977) for heterogeneous products and Weizsacker (1980), Perry (1984) and Mankiw and Whinston (1986)

[2] See Dixit and Shapiro (1986), Bolton and Farrell (1990) and Cabral (2004).

[3] See Jovanovic (1982), Jovanovic and MacDonald (1994), Klepper (1996), and Klepper and Simons (2000). Berry and Waldfogel (1999) is one of the few papers to provide empirical evidence using the radio broadcasting industry.

This paper uses the restructuring of the US electricity industry to provide evidence that free entry led to overinvestment in electricity generating capacity and social inefficiency.

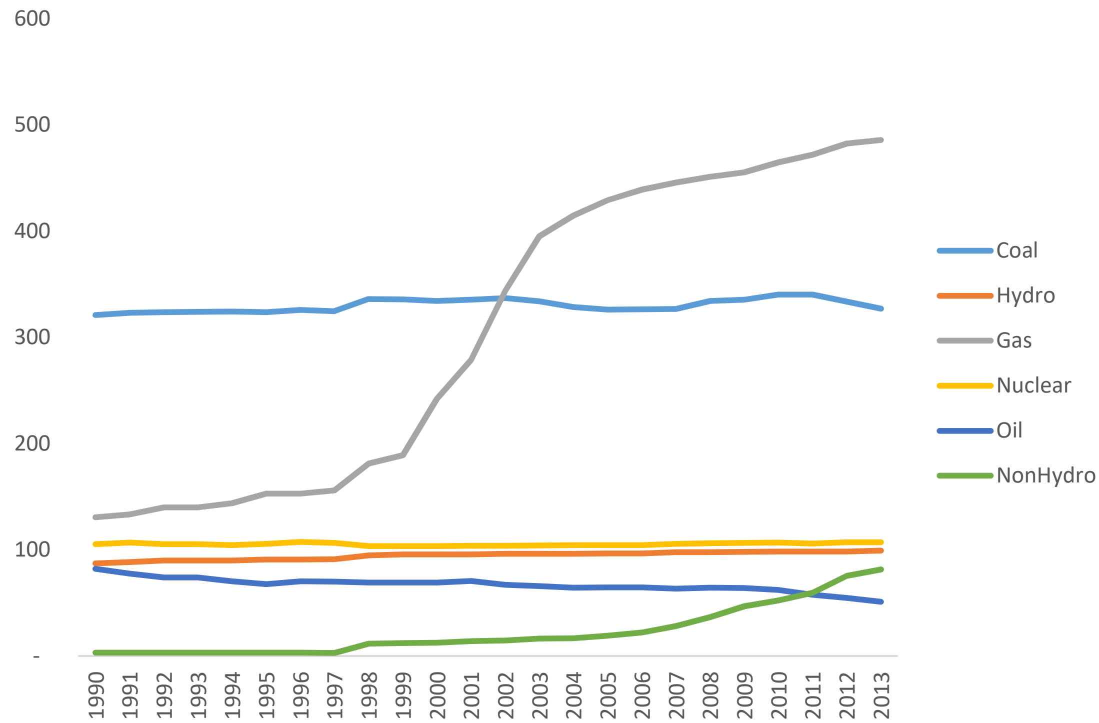
The electricity industry is a unique and important study of free entry for several reasons. First, it is a major US industrial sector. On average, the US electricity sector annually accounts for over $390 billion in sales, $70 billion in investment and 39 percent of energy use. Second, the electricity sector possesses two characteristics mentioned in Berry and Waldfogel (1999) as being critical to free entry leading to social inefficiency: the entrant's product can substitute for the incumbent's and average costs are decreasing in output. Average costs decline in both generation and transmission and the product is homogenous. Finally, free entry was the result of restructuring, as opposed to product innovation in other industries.

In addition to providing evidence of the impact of free entry on the electricity sector, this paper contributes to the growing literature on the cost impact of electricity market restructuring. The improvement in the marginal cost of power plants following electricity market restructuring is a well-established result (Fabrizio et al 2007; Davis and Wolfram 2012; Cicalla 2015). However, the impact of competition on plant manager decision-making was expected to be a small part of the benefit of restructuring (Joskow 1997). The larger impact was predicted to be from long-term decision-making by firms on plant construction. This paper is the first analysis of this longer-term impact.

State-level electricity market restructuring began in California and Texas in 1995. From 1995 to 2002, 22 states and DC began restructuring with the goal of increased generation and retail competition. During this time period, the US electricity industry experienced an investment boom. Due to changes in the structure of state electricity markets and relative fuel prices, the investment was primarily in gas-fired power plants. From 1999 to 2006, there was a net addition of over 250 gigawatts (GW) of gas-fired capacity to the U.S. electricity market (See Figure 1). The share of total US capacity using natural gas as a primary fuel increased from 23.7 to 41.5 percent and represented an investment of over $240 billion. Surprisingly, while many explanations have been put forward for the dash for gas in the UK and the gas boom in the US, [4] careful empirical analysis has been lacking. In particular, very little has been written on the connection between the gas boom in the US and the restructuring of state electricity markets.

[4] See Winskel (2002) for a description of the dash for gas in the UK. See Kaplan (2010) and Macmillan (2013) for a review of the industry explanations for the gas boom in the US.

Figure 1: U.S. Generating Capacity (MW) 1990-2013



Source: EIA (2016)

Prior to restructuring, critics of electricity industry regulation argued that cost-of-service regulation distorted incentives for firms to profit maximize, both in the short-run and long-run. In the short-run, firms may not operate plants using the cost-minimizing amount of labor and maintenance. In the long-run, firms lack pressure to invest in the lowest cost form of generating capacity and may suffer from the Averch-Johnson effect, biasing investment decisions towards capital (Joskow 1997). Based on these incentive problems, states were encouraged to restructure their electricity markets by allowing retail competition. The decision, by almost half of US states, to restructure their electricity markets created an opportunity to evaluate the impact of restructuring in both the short-run and long-run. Topics investigated include the impact on efficiency of power plants operations (Bushnell and Wolfram 2005; Fabrizio, Rose, and Wolfram 2007; Davis and Wolfram 2012; Cicalla 2015), efficiency of wholesale electricity markets (Borenstein, Bushnell, and Wolak 2002; Bushnell, Mansur, and Saravia 2008), market power (Wolfram 1999; Joskow and Kahn 2002) and capital investments (Ishii and Yan 2007; Fowlie 2010).

This paper makes three contributions to the economics literature. First, it provides an empirical example of an industry experiencing a free-entry "failure." In order to provide structure for this analysis, the paper will test four well-known models of entry and exit: Business-stealing (Mankiw and Whinston 1986), War-of-attrition (Bulow and Klemperer 1999; Cabral 2004), Contagion (Bikchandani et al 1992; Bannerjee 1992), and First-mover (Spence 1977; Schmalensee 1981). Second, it's the first paper to empirically investigate the long-run gains of restructuring proposed in Joskow (1997), while empirically contradicting predictions of either investment efficiency (Joskow 1997) or underinvestment (Borenstein and Holland 2005). Third, it provides a robust analysis of the US gas boom from 2000-2006.

The staggered adoption of restructuring by 22 states and DC provides a setting which allows for identification of the causal impact of restructuring on gas-fired power plant investment in the US.[5] Comparisons are made throughout this paper between states that restructured and those that didn't. Observations are made at the state and year level, with the empirical model treating the state as the decision-level. While individual decisions are made by firms and utilities rather than state governments, the influence of state regulation, the level of the policy variable and the availability of information on a state-level makes this approach more accurate and feasible.

The hypothesis of this paper is restructuring caused a surge in gas-fired power plant investment by encouraging entry by firms without complete information. However, once this surge occurred and margins began to shrink, investment decreased substantially. To identify this investment flow, the preferred specification will include an interaction of the restructuring variable with a binary variable indicating years since restructuring. This specification is preferred over one without an interaction term because it's not assumed in this paper that the nature of restructured markets lead to permanent excessive entry of the type suggested in Mankiw and Whinston (1986) and others.

In each specification, the variable of interest is the annual change in combined cycle natural gas (CCGT) power plant capacity in each state. This paper shows that, compared to the non-boom period, restructured states built, on average, 593 MW more combined cycle gas capacity than non-restructured states each year. This investment is more than $700 million annually, per state, and over $95 billion total over the period. The result holds in a number of specifications that include differences in demand, prices, capacity needs and levelized costs, leading to the conclusion that

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[5] This paper focuses on investment in gas-fired power plants because over 84 percent of investment in capacity during this period was in plants fueled by natural gas, as opposed to coal, nuclear, or renewables (Energy Information Administration (EIA), 2016).

there was excessive entry in restructured markets.[6] The implication is the nature of restructured markets lead to overinvestment in power plant capacity. The existence of large excess reserves, in comparison to non-restructured states, and a string of bankruptcies of firms that owned power plants in restructured markets, are further evidence of the excessive nature of the investment boom.

The details of the gas boom during the restructuring period are consistent with the Contagion model of entry and exit. In this model, firms react to false information indicators and the actions of other firms, rather than market fundamentals. In addition to the contagion effect, firms in this industry suffered from a coordination failure. Unlike regulated utilities, individual plants lack information on market demand projections, supply increases and transmission networks, which contributed to a failure by the market to optimally invest. A third factor, which amplified the effect of the previous two, was the availability of cheap credit due to a decline in long-run global interest rates.

A formal welfare analysis of the excessive investment into restructured markets is the final result of this paper. Two separate effects of free entry on total welfare were identified. The first is the impact of restructuring on the price and quantity in the market. The second is the total welfare loss from other investments crowded out by the overinvestment in electricity generation. Using synthetic control to estimate counterfactual prices and investment, excessive entry in electricity generation is estimated to have led to a total welfare loss from 1998-2013 of $11.2 billion.

The structure of this paper is organized in the following manner. Section 2 provides information on the electricity market setting of this paper. Section 3 outlines the four models of electricity industry entry that are tested in this paper. Section 4 presents the methodology and model used to analyze the research question in this paper and introduces the data. Section 5 presents the empirical results of the paper. Section 6 tests the predictions of the four models. Section 7 shows the results of alternative specifications. Section 8 presents the framework and results of the welfare analysis of excessive entry. Section 9 concludes.

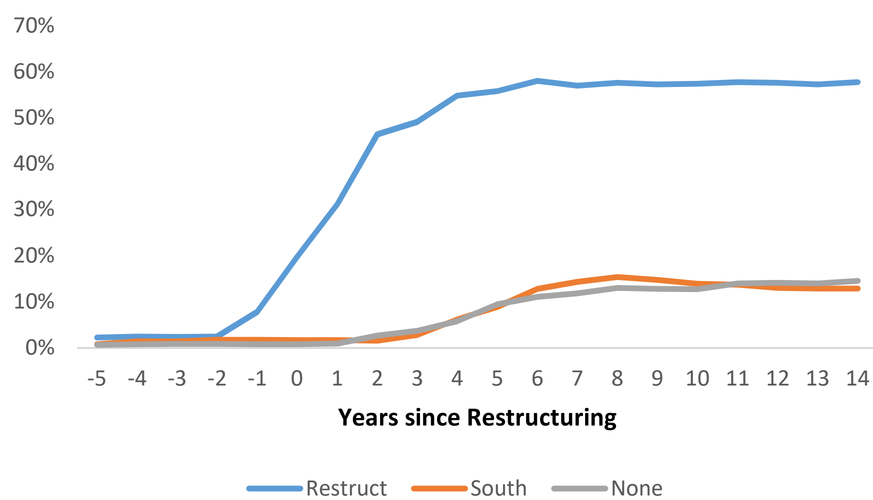
2. Background

Prior to the mid-1990s, electricity generation in the US was primarily supplied by regulated vertically-integrated public utilities. Prices were set by cost-of-service regulation, with utility rates

[6] Excessive entry and overinvestment are defined in this paper as the difference between the CCGT capacity increase of a state and what its synthetic control counterfactual would have built.

determined by expenditure on fuel and Operations and Maintenance (O&M), prudent capital investment, and a reasonable rate of return on capital. This system succeeded for several decades, but faced pressure in the 1980s as prices rose for consumers. The increase in prices was largely the result of idle capacity built to meet electricity demand growth, which slowed in the late 1970s. Rising prices and two energy laws in 1978 (Public Utility Regulatory Policies Act) and 1992 (Energy Policy Act) led to the expansion of merchant gas-fired power plants built by independent power producers (IPP), which received further support from Federal Energy Regulatory Commission (FERC) orders 888 and 889 in 1996. While the impact of these orders was small (See Figure 2), the combination of changing prices, policies and excess capacity created an environment where many states were prepared to restructure their electricity markets.

Figure 2. IPP Penetration by State Group, 1990-2014[7]



Source: EIA Form 860 (2016)

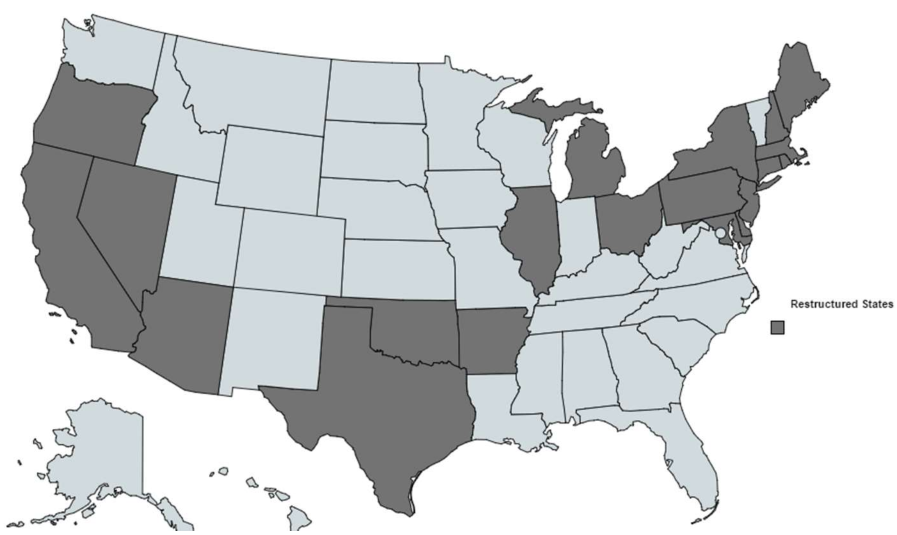
State-level electricity market restructuring split the industry into three components: generation, transmission and distribution, and retail. Transmission and distribution continued to operate as regulated monopolies due to the efficiency of high voltage power lines and the undesirability of several local utility power lines crisscrossing neighborhoods. Electricity generation and retail, however, were capable of operating in a competitive market (Joskow and

[7] The running variable in this figure measures IPP penetration since the year a state started restructuring. For the South and None regions, 1996 is year 0, since this is when FERC began enforcing open access to transmission lines.

Schmalensee 1983), particularly with new gas-fired plants not requiring the same economies of scale and build times as previous coal, gas and nuclear plants. Opening electricity markets to generation and retail competition was the final step in the attempt to provide power producers with an incentive to cost minimize, with previous attempts including state adoption of incentive regulation, where capped rates allowed utilities to earn rents by cost minimizing (Joskow 1997).

The process of restructuring varied by state, with all 50 states beginning the process and 22 states plus DC opening to retail competition (see Figure 3).[8] Early stages in the process included hearings, retail pilot programs, and submitting of plans by state regulatory commissions. States that continued restructuring passed legislation empowering regulatory commissions to create and enforce a timeline for the divestiture of assets and opening of retail markets to competition.[9] The restructuring process concluded with utilities divesting a majority of their assets and power marketers operating. A fully restructured market was intended to spur generation competition between utilities and IPPs and retail competition between utilities and power marketers.

Figure 3. Map of Restructured U.S. States



Source: EIA (2016)

The California Electricity Crisis of 2001 created concerns over the effective operation of restructured markets in several states, which led to a pause in restructuring in these states (EIA

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8 See Joskow (2008) for a list of rules for successful restructuring of electricity markets.

9 Divestiture of assets was one of the crucial requirements noted in Joskow (2008) because of the ability of utilities, which owned the majority of generation facilities, to use their share of the market to raise prices.

2016). As noted in a number of papers on the crisis,[10] a combination of high demand due to unusual summer weather, reduced hydro generation due to low rainfall the previous winter, and strategic activity by firms created a series of blackouts and sent wholesale electricity prices soaring. This led several large California utilities to or near bankruptcy, as the utilities were not allowed to raise prices by the state regulatory commission but had to purchase electricity from the wholesale market, where prices were high. The crisis was seen as vindicating the concerns of restructuring opponents, who were focused on inherent volatility in restructured electricity markets and many states which were considering restructuring decided to continue regulation (EIA, 2016).

There were unique reasons behind each state's decision to restructure, but several trends are worth noting. First, high electricity prices were creating consumer discontent, resulting in a correlation between electricity prices and state decisions to restructure. Second, as summarized in Joskow (2008), there were well-founded economic arguments for opening the generation and retail components of the electricity industry to competition. Of the many arguments made, the most prominent are: 1) Generation competition incentivizes plant operators to choose the cost-minimizing quantities of labor, fuel, materials and maintenance and plant owners to choose the cost-minimizing amount and type of generating capacity. 2) The Averch-Johnson effect distorts capacity choices towards more capital-intensive technologies. 3) Competitive retail and generation markets insulate electricity generation from politics. 4) Competition encourages the retirement of uneconomical plants. Third, the mid-to-late 1990s was a period of market deregulation, both in the US and internationally. The UK deregulated its electricity market in the early 1990s, while deregulation of telecommunications and finance were taking place in the US simultaneously.[11] This environment served as encouragement for restructuring of electricity markets.[12]

Restructuring was one of several changes in U.S. electricity markets during this time period. A combination of technological improvements, supply choices on the state level, and demand-side changes occurred during this time period which had a substantial effect on gas-fired capacity. Table 1 shows the average annual net capacity addition, by state group, of both CCGT and CT plants during three periods: pre-boom (1990-1999), boom (2000-2006), and post-boom

[10] See CBO (2001) and Joskow (2008) for more detailed descriptions.

[11] The Telecommunications Act of 1996 removed barriers to entry in telecommunications markets, while the Gramm-Leach-Bliley Act of 1999 repealed several regulations dating back to the 1930s. Most prominent of these was the Glass-Steagall Act of 1933.

[12] See White (1996) and Joskow (1997) for a description of the deregulation process and the political influences.

(2007-2013). While the boom is identifiable in both CCGT and CT additions in the table, the amount of CCGT capacity added in restructured states from 1999-2006 is the clear outlier.

Table 1. CCGT and Gas CT Capacity Additions by State Group

	Restruct	None	South
CCGT			
1990-99	8,418	1,219	5,008
2000-06	129,381	16,332	45,128
2007-13	17,074	4,851	21,059
CT			
1990-99	19,349	8,367	12,861
2000-06	26,597	19,918	27,955
2007-13	10,358	3,876	4,201

Source: EIA (2016)

2.1 Explaining the Gas Boom

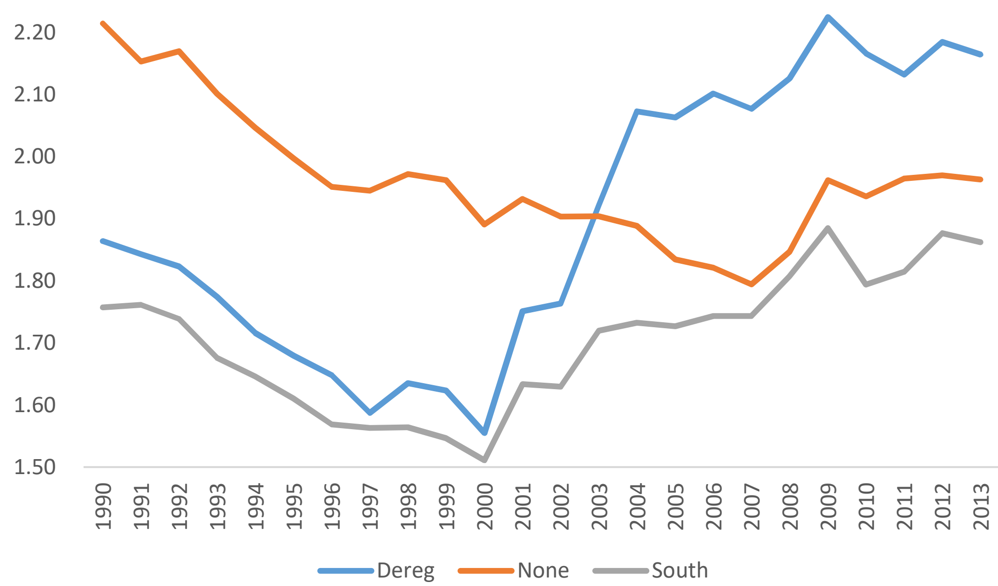
The shift towards gas-fired power plants is noted in both the economics and industrial literatures.[13] Five prominent explanations are offered for the expansion of US gas-fired capacity. 1) The adoption of new combined cycle technology and low gas prices made gas-fired plants more cost effective relative to coal and nuclear plants. 2) Deregulation of natural gas markets in the 1980s lifted restrictions on the use of natural gas in electricity generation. 3) An increase in electricity demand created a need for new investment. 4) Environmental concerns favor gas plants over coal plants. 5) Gas plants can be built much quicker than coal plants. As noted later in this paper, each of these explanations are not consistent with the timing, size and cross-section of the boom, so this paper provides a more-consistent sixth explanation: the nature of restructuring in electricity markets lead to excessive entry in these markets and facilitated a boom.

It's important to note, when analyzing these explanations, that during the period of the gas boom, there was a need for new investment in generation capacity. Figure 4 shows a measure of excess reserves for the three different groups of states. The measure of excess reserves in this paper is the ratio of megawatt hours (MWh) of generation potential to electricity retail sales (ERS). [14]

[13] Kaplan (2010), Macmillan (2013), and Knittel et al (2016) summarize the gas boom.
[14] Generation potential is calculating using EIA state capacity factor assumptions. Gas CT plants are capable of operating at a capacity factor of .85, but they are not built to be run consistently, so the EIA assumes a capacity factor of .3. Biomass, coal, gas, geothermal, nuclear and oil plants do not have state specific capacity factors as they

This ratio is split into three groups to gain perspective on the scale of the buildout in restructured states. The South is separated from the None group to provide more context.

Figure 4. Capacity to ERS Ratios by Group, 1990-2013



Source: EIA (2016)

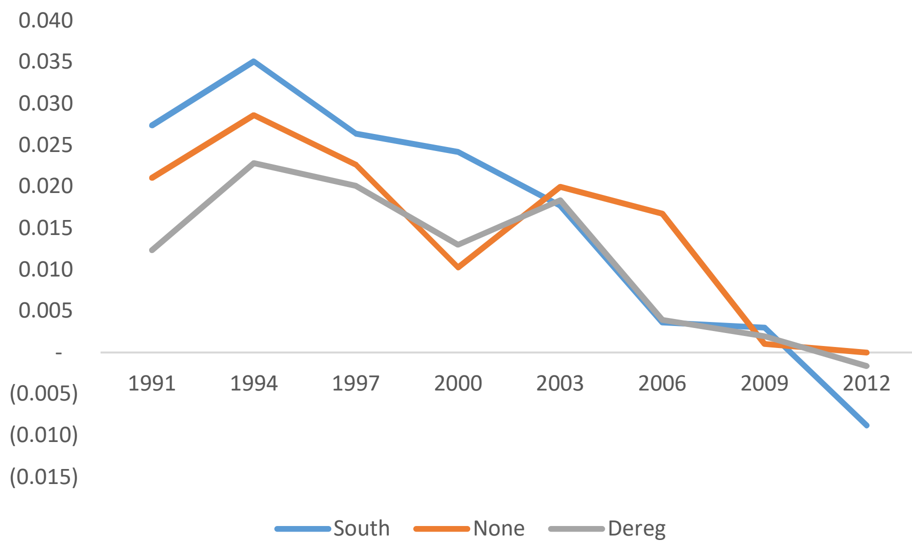
During the period 1990-1999, utilities across the US were not building new capacity due to idle capacity from the 1980s. While it's difficult to know what the optimal capacity to ERS ratio was during this time period, these actions confirm that it was below that in the early 1990s.[15] Of the three state groups, the None group has the largest ratio. This is mostly due to the inclusion of states like West Virginia and Wyoming, which are large electricity exporters. At the turn of the century, all three groups of states constructed new power plants, which is evidence that capacity to ERS ratios were too low. However, while the two non-restructured groups reached similar levels, there was a much larger increase in the restructured states. In fact, the ratio of capacity to ERS in these states reached historic highs (EIA Annual Energy Outlook (AEO), 2006). There is evidence that, prior to the Great Recession in 2008, state electricity markets attempted to reduce

are assumed to have the potential to operate at the same capacity factor. Hydro, solar and wind have state specific capacity factors due to individual state weather patterns and resource reserves.

[15] Joskow (2008) notes that the early 1990s were a period of excess capacity and the period up to 1998 can be seen as a drawing down of that additional capacity. This explanation is present in all of the EIA's Annual Energy Outlooks prior to 1995.

these high ratios, but, as Figure 5 shows, low or negative ERS growth caused capacity ratios to stagnate or increase.

Figure 5. Average 3-year ERS Growth by Group, 1990-2013



Source: EIA (2016)

Individual state ERS data are not available prior to 1990, but national-level data show a sharp slowdown in ERS growth starting in the early 1980s and continuing through the decade (EIA AEO, 1991). As the US economy grew at a faster rate in the 1990s, ERS growth increased unexpectedly, which accounts for the decline in individual state capacity to ERS ratios prior to 2000. When analyzing these data, note that power plant investment involves significant lag times that range from 2-3 years for gas CT and CCGT plants, to 7 year for coal, and up to 15 years for nuclear and is heavily reliant on expectations about future demand (American Electric Power 2016; EIA 2016; Nuclear Energy Institute 2016). Plants that came online in 2000 were reacting to market conditions in 1997 and 1998.

One interesting aspect of the boom period in power plant investment is the failure of industry insiders to predict it. Each year, the EIA gathers information on the US energy sector from both available data and industry experts and publishes their expectations about the future in their AEO reports. Of particular interest to this paper is their projection of generating capacity additions in the country over the next 20 years. These projections are a combination of (mostly) confirmed projects, along with speculation by the EIA about further investments needed to meet demand. The estimates are adjusted annually to reflect changes in either confirmed projects or updated estimates by EIA staff. As is evident in Table 2, the EIA forecasts for CCGT expansion through 2010 were increased continuously throughout the 1990s, as the construction boom was underestimated each year.

Table 2. Annual AEO Generation Capacity Projections for 2000, 2010 (GW)[16]

	Coal		CCGT		Gas CT	
AEO	2000	2010	2000	2010	2000	2010
1991	311	396	13	53	86	102
1992	317	395	15	55	88	109
1993	309	352	19	45	99	112
1994	299	326	27	58	70	87
1995	299	314	23	38	69	92
1996	301	313	23	45	88	135
1997	299	304	43	108	110	153
1998	297	305	41	107	140	191
1999	305	309	40	126	99	151
2000	302	302	51	93	93	154
2001	-	315	-	126	-	164
2002	-	306	-	140[17]	-	129

Source: EIA AEO Archive (2016)

Something in the U.S. electricity market changed in the late 1990s, which caused the EIA to alter their projections. While the restructuring explanation is consistent with this trend, the hypotheses that previous restrictions, low natural gas prices and lack of available technology caused the boom are not. If these hypotheses were true, these plants would have started being built in the early 1990s and would also have been a part of the EIA projections to 2010. Figures 5 and 6 suggest that the majority of US states had a need for capacity additions beginning in the late 1990s, but don’t explain why the majority of plants were fueled by natural gas, the differences in capacity to ERS ratios among groups of states, or the shortfall in EIA expectations about capacity

[16] How to read this table: Each row represents what the authors of the AEO, in that year (1991, for example), thought capacity of each of these fuels would be in 2000 and in 2010.
[17] Actual Gas CC GW capacity in 2010 was 239 GW. Actual Gas CT GW capacity in 2010 was 145 GW.

additions. The explanations to these anomalies are central to the conclusions of this paper and are discussed further in section 6. Prior to analyzing these explanations, a framework is necessary for understanding how restructuring could lead to a boom. The following section outlines the possible frameworks consistent with the boom.

3. Competition and Excessive Entry

When states opened their retail electricity markets to competition, the transfer of transmission and distribution assets to non-profit ISOs and the forced divestiture of plants by vertically integrated utilities opened state electricity markets to generation competition. The combination of low state capacity ratios and the profits of merchant gas-fired power plants operating in the wholesale market encouraged entry into the newly competitive markets. Reserve margin requirements, typically set by ISOs around 15 percent of ERS (Joskow, 2008), reduced concerns of inadequate entry.[18] However, no consideration was given to the prospect of excessive entry. This section provides a framework for how electricity market restructuring could lead to excessive power plant investment.

Prior to setting up the framework, a clear definition of excessive entry in the electricity industry is necessary. Mankiw and Whinston (1986) defines excessive entry as an outcome where the equilibrium number of firms exceeds the socially optimal number. Cabral (2004) has a slightly different approach, stating that, if there is an entry tax that strictly increases social welfare, an industry has experienced excess entry. For the electricity industry, the corollary to the fixed cost of entry in the previous two papers is the capacity of the power plant a firm must construct in order to compete in the electricity market. Therefore, the number of firms is not as significant as the amount of capacity (MW) invested in each market. This paper uses the difference between the actual CCGT capacity added compared to the synthetic control counterfactual as a measure of excessive entry. An additional statistic, the ratio of capacity to ERS (capacity ratio), is also useful for measuring industry entry and providing a historical comparison.

[18] There was concern, as markets began to restructure, of an underinvestment in peak resources, due to the difficulty of earning sufficient margins to cover fixed costs and the lack of real time pricing (Joskow, 2008).

3.1 Four Models of Entry

Each of the four models in this section: business stealing, war-of-attrition, contagion, and first-mover advantage, analyze homogenous good market structures where excessive entry is a possible outcome.[19] The purpose of their inclusion in this section is not to prove outcomes theoretically, but rather to provide testable predictions to see which of these models is most consistent with entry and exit patterns following restructuring. The following assumptions are critical to the predictions that originate from the models.

Assumption 1: There are many entrants into each market and all sell a homogenous good.

Electricity is a homogenous good generated and sold by many types of firms, which include utilities, power marketers, federal, state and municipal entities, and financial services and industrial firms.[20] Therefore, a large number of firms were able to enter the electricity market.

Assumption 2: Firms entering the market must construct a new CCGT plant.

While not all firms entering restructured markets built new power plants, as firms could purchase the divested assets of former vertically-integrated utilities, the purpose here is to explain the new construction of power plants, as opposed to the number of entering firms.[21] For those firms that chose to construct new plants, the overwhelming choice for base-load market competitors was CCGT plants. While in a general build choice model, like those of Joskow and Mishkin (1977), firms choose the technology and fuel of the plant, the combination of reduced gas prices, short build times, and improved efficiency led new builders to CCGT.

Assumption 3: Incumbents have a different cost structure than entrants, with higher original investment costs and lower marginal costs.

The share of CCGT plants in restructured states prior to restructuring was very small. The majority of plants in operation during this time were nuclear, coal, and hydro. Each of these plant types have higher capital costs and lower fuel costs than CCGT plants.

[19] A large number of models were considered in this section, with selections based on the following criteria, which matched electricity markets in this time period: 1) Homogenous good. 2) Inclusion of economies of scale. 3) Imperfect information leading to the possibility of coordination failure.
[20] Information on participants in the generation and retail components of the electricity market is available from EIA form 861 and EIA form 860 respectively.
[21] See Ishii and Yan (2007) for an explanation of the build or buy decision facing electricity market entrants.

Assumption 4: Entry suffers from a coordination failure.

Coordination failures come in several forms, ranging from external costs and benefits to Schelling's (1960) where-to-meet problems to multiple entrants in natural monopoly markets.[22] For the electricity industry, utilities traditionally filled the role of social planner, as they were aware of all plants being planned and built as well as what market they were serving. In restructured markets, this information was more difficult for entrants to obtain. Therefore, firms were most likely unaware of the intentions of other entrants as they began their investment.[23]

3.1.1 Business Stealing Entry

Consider a model of simultaneous entry with incomplete information.[24] The actors in this model consist of an incumbent firm with marginal cost c_1 and n identical firms with marginal cost c_2, with $c_1<c_2$. In order to compete in the market, entrants must invest a fixed amount (x_2), which is immediately sunk. The incumbent has already invested x_1, with $x_1>x_2$, and owes a portion of it (l). Prior to the start of the game, a regulator has fixed prices at a level where the variable profit of the incumbent is greater than f. Firms possess full information on past market prices and the cost structure of the incumbent, but are not aware of entry by other firms. Demand is inelastic.

The entry process is modeled as a two-stage game. In stage 1, the market for electricity is restructured, allowing for entry. This encourages m ($m\leq n$) firms to enter the market, each investing x. In stage 2, the m entrants and incumbent produce electricity as Cournot competitors. Variable profit for each firm is a function of the number of firms that enter the market and the marginal cost of the firm [$\pi = f(m,c_i)$].

Proposition 1. Under business-stealing entry,

a) *Output per firm falls as the number of firms increases (business stealing).*
b) *Entry reaches an equilibrium where variable profit equals fixed cost.*
c) *There is idle capacity in the industry following entry.*

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[22] For more on coordination failures in the theoretical literature, see Dixit and Shapiro (1986), and Bolton and Farrell (1990). Cabral (2004) provides several industry examples.

[23] This assumption is consistent with Kydland and Prescott (1982), who state businesses may not be aware of entrants until the selling of goods commences.

[24] This model is most closely linked to Mankiw and Whinston (1986), but is similar in structure to a number of papers, such as Spence (1976), Dixit and Stiglitz (1977), Weizsacker (1980), and Perry (1984).

Following the analysis in Mankiw and Whinston (1986) and the structure presented above, the business-stealing model, applied to the electricity industry, acts as follows. As a state begins the process of restructuring, firms enter the market due to their knowledge of the incumbent's cost structure and previous prices in the market.[25] These firms invest in a power plant with a fixed capacity and it's assumed the cost of investment is sunk.[26] Entering firms are assumed to build gas-fired power plants, which have a different cost structure than the incumbent.[27] As more firms enter, inelastic demand for electricity results in output and price per firm falling. This is the first prediction that will be tested in this paper. Falling output and price reduces variable profit until it equals the cost of investment. At this point, firms stop entering the industry and an equilibrium is reached. This is the second prediction tested in this paper. As shown in Mankiw and Whinston (1986), more firms have invested in investment costs than were necessary to serve the market. This inefficiency increases as the size of the investment cost increases and leaves firm capacity unused. This is a sign of excessive entry and is the third prediction to test.

3.1.2 War of Attrition Entry

Consider a model of simultaneous entry with incomplete information where investment takes multiple periods.[28] There is an incumbent earning positive profit (π_1) and n potential entrants, some ($m \leq n$) of which start investing a portion of the total entry cost (x) in period t. The decision to invest in the market is based on the expected discounted profit of entering the market (π^e), which depends on firm assumptions about three factors: the path of wholesale electricity prices, number of firms entering the market and future natural gas prices. Firms are assumed to possess publicly

[25] Largely this reflects expectations that regulators will fix prices high for a period to allow for utilities with stranded assets to recover their value (Borenstein and Bushnell, 2015).
[26] The firm can sell the plant, but may not be able to get market value for it. This scenario would occur if the firm is attempting to sell the plant during a fire sale, when assets are discounted. Evidence from a string of bankruptcies in 2005 and 2006 suggests that selling off generation assets could not save giants like Calpine (Anderson and Erman 2005).
[27] Marginal costs are higher for entrants than for incumbents due to the price differential between natural gas and coal or nuclear. Investment costs are lower, as large-scale steam plants are more expensive to build per MW of capacity than gas turbine and CCGT plants.
[28] This model is drawn primarily from Cabral (2004). Bulow and Klemperer (1999) summarizes the use of these models in the economics literature.

available information for these factors and base their expectation on past prices and the number of firms observed investing in the market. Once an amount ($\frac{x}{3}$) is spent, it is considered sunk. [29]

A firm will continue investing in each period as long as the expected discounted profit of their project is positive. During the investment period, firms have complete information on the history of firm entry and pricing, but are unaware of the number of firms which invested in the market that period. After three periods of investment, they begin a Cournot competition game with the incumbent and other entrants. Variable profit for each firm is a function of the number of firms that enter the market, the price of electricity, and the marginal cost of the firm [$\pi = f(m,p,c_i)$].

Proposition 2: Under war-of-attrition entry,

a) *As the market adjusts to capacity additions, new investment stops but capacity increases, as firms finish their investment.*
b) *Firms that completed their investment earn variable profit $\geq x$*
c) *Entry leads to excessive spending on investment, as firms invest simultaneously, unaware of other entry*

The structure and play of the game follow from Cabral (2004). The first stage consists of firms, following restructuring, investing in power plants. Construction of CCGT plants takes approximately three years, at which time firms are able to begin producing electricity. When making the investment, it's assumed that firms are unaware of potential competitors investing in the market in the same period. This follows from Assumption 4 of this paper. In the following period, firms are able to observe new entrants that made an investment the prior year and update their expected profit function. If still positive, the firms make an investment in the following year and repeat the process. If the firm makes three investments, it then produces electricity in the following period and competes with the incumbent and other firms in a Cournot game.

Three testable predictions come out of this entry model. Firms in this model rely on their expectation of prices and entry when deciding whether or not to continue investing. As a result, a change in firm investment behavior should be visible when market expectations change, as they did in 2005. This is the first testable prediction. If firms complete the investment process and begin

[29] Utility and EIA data suggest approximately 10 percent is spent in the first year, 50 percent in the second, and 40 percent in the third.

competing, it's assumed that firms unable to earn a profit based on market entry and prices will have left the market. Therefore, the remaining firms in the market should earn non-negative profits. This is the second testable prediction. However, there are still a large number of firms that entered and invested in power plants beyond the socially optimal number. This would be apparent in a large amount of capacity built beyond what is socially optimal and is the third testable prediction.

3.1.3 Contagion Entry and Exit

Consider a sequential entry model with incomplete information where firms make decisions based on the actions of other firms.[30] The players in this model are an incumbent and n potential entrants. The incumbent still owes a portion of its investment in the industry (l) and has marginal cost c_1. Potential entrants have the same marginal cost (c_2). Entrants know only their own cost structure. In order to compete in the market, the firm must make a one-time investment (x). Entry is based on expected future profits (π^e) and a surprise change in the number of firms (N^S_{t-1}).

1) $x_t = f(\pi^e, N^S_{t-1})$
2) $\pi^e = f(p_{t-1}, p_{t-2}, \ldots p_{t-T}, g_{t-1}, g_{t-2}, \ldots g_{t-T})$
3) $N^O_{t-1} - N^P_{t-1} = N^S_{t-1}$

Expected profits are a function of the firm's expectations about future electricity (p_t) and fuel (g_t) prices, which the firm estimates based on prices in previous periods. Firms are unaware of other entrants in the industry due to the coordination failure described in Assumption 4, so they look for other trends in the industry to help guide their expectations. They calculate a number of firms they believe should be operating in the industry based on their expectation of variable profits. The difference between the number of firms observed (N^O_{t-1}) and the number predicted (N^P_{t-1}) is the number of surprise firms in the market (N^S_{t-1}). This is either a response to uncertainty around future electricity and fuel prices or herd behavior and is called the contagion effect.

Firm decisions are made in the following sequence. In period 0, the incumbent sells electricity at a price greater than marginal cost and the regulator signals that, in the following

[30] This model is based off what is used in Geroski and Mazzucato (2001) and Cabral (2004). Seminal papers in this literature include Bikchandani et al. (1992) and Bannerjee (1992). See Geroski and Mazzucato (2001) for a more complete review of the literature.

period, the market will be open to competition. Out of n potential entrants, a portion, m, invest in period 0. In periods 1 through T, firms compete with the incumbent in a Cournot competition. New entrants make an investment to enter in the following period and, due to competition and new entry, prices fall. Falling prices or rising costs lead to negative profits for some firms, which exit the industry.

Proposition 3: Under contagion entry and exit,

a) *Firms continue to invest in markets where large investments have already been made*
b) *Exit occurs by firms previously producing in the market if variable profits fall significantly*
c) *Non-fundamentals decision-making leads to excessive entry*

At time 0, the incumbent is still operating under fixed pricing and earning a return based on cost-of-service regulation. Firms observe the high prices present in restructuring markets and assume they will continue based on the existence of stranded assets, the low capacity ratios in many restructured states, and rules put in place fixing prices to allow stranded assets to recover their value.[31] This encourages the entry of a large number of firms in period 1, which invest in CCGT plants and compete with the incumbent. In the following period, more firms enter as prices have remained high and, due to the coordination failure present in simultaneous entry situations, firms see a surprise number of firms entering the market, which encourages further entry. Firms investing in a market where large investments in CCGT plants have already taken place is the first testable prediction. As CCGT capacity rises, firms compete with each other and price falls in restructured markets. Falling prices lead some firms to leave the industry through an asset fire-sale or declaring bankruptcy. This is the second testable prediction. As firms observe falling prices and other firms leaving the industry, investment declines. At this point, the industry is left with unused capacity due to excessive entry, which is the third testable prediction.

[31] See Joskow (2008) for more on some of the strategies to save stranded assets.

3.1.4 First-Mover Advantage

Consider a model of sequential entry with imperfect information where first-mover advantage affects investment.[32] There is a large incumbent firm with marginal cost c_1 that sells electricity at a price fixed by a regulator. The incumbent has a portion of its fixed cost that have yet to be paid off (lx). There are n potential entrants in the industry, all with the same cost structure and information (c_2). Firms are able to see market prices and investment in prior years before making an investment in each period. In order to compete in the market in period t, each firm must make an investment in period t-1. These investments, x_{it}, are individual to each firm, have increasing returns to scale in the production of electricity [f'(x)>0], and are a function of prices in previous periods and investment in the previous year [$x_{it} = f(p_{t-1}, p_{t-2}, \ldots, p_{t-T}, x_{t-1})$ where $f'(x_{t-1})<0$]. All investments are assumed to be completed before the start of the next period. Actual production of electricity (Z) is a function of variable profits and the size of investment made by the firm. [$Z=f(\pi_t, x_t)$].

In period 0, the incumbent sells electricity at a price greater than marginal cost. The regulator signals that, in the following period, the market will be open to competition. Out of n potential entrants, a portion, m, invest in period 0.[33] In periods 1 through N, controls on prices are lifted and the new entrants compete with the incumbent in a Cournot competition. A number of potential entrants (< n-m) invest each turn based on observed prices and the amount of the investment in the previous period and a number of participants (≤n) leave the industry if variable profits are less than $\frac{x_{it}}{N}$.[34]

Proposition 4: Under a first-mover advantage framework,

a) *The first firms to invest in the new regulatory environment make large investments.*
b) *Investment from entrants exceeds the optimal amount due to excessive entry.*
c) *After the opening of the market to competition, there is a large amount of entry followed quickly by a drop off in investment.*

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[32] See Spence (1977), Dixit (1979), Schmalensee (1981) and Hilke (1984) for prominent theoretical papers in this area. Berger and Dick (2007) provides a good review of both the theory and empirical examples in this literature.
[33] As noted in Gilbert and Vives (1986), some firms are quicker to act to new markets than others. This could be due to private information, low borrowing costs, or a difference in attitudes concerning risk by CEOs.
[34] It's assumed that firms can't continue to not pay off their investment. This assumption is a fixed amount is owed each year.

Entry in this model is ignited by the opening of the market to competition and the existence of variable profits in excess of investment costs. [35] In period 0, entering firms are encouraged to build large plants due to the combination of increasing returns to scale and the deterring effect of previous investment.[36] The existence of these large investments is the first testable prediction. Firms that build large gas-fired power plants in a given electricity market send a signal to future entrants that entry into this market may not be profitable, given the presence of a large power plant supplying electricity. Throughout the literature, the advantage is more significant if the firm is the first-mover and the investment large. The combination of increasing returns to scale and the opportunity to gain market share[37] by deterring future entry incentives firms to overinvest, leaving the market with capacity that outstretches demand. This is the second testable prediction.

In the following period, prices fall due to increased competition, driving variable profits below $\frac{x_{it}}{T}$. This leads to firms leaving the industry, as variable profit is not high enough to pay creditors and the firms go in to bankruptcy. Additionally, investment falls in the first period in response to the large investments made prior to the first period. The decrease in investment accelerates in the second period, as firms respond to falling prices in addition to the large investments previously made. The quick drop in prices and investment following the first period investments is the third testable prediction.

3.2 Testing Predictions

Each of the predictions of these four models are able to be tested by data available from 1990-2013. Finding the model consistent with the events of this time period is important, as it serves to provide an explanation for how excessive entry can occur in homogenous-good industries with large fixed costs. Prior to addressing each of the predictions in Section 6, a rigorous empirical analysis is performed to show the central result of this paper and the four models above: restructuring of electricity markets led to excessive entry.

[35] There had been some entry into the market prior to regulation by merchant gas-fired plants, which made large profits selling electricity into the wholesale market. The reason for these profits was the high cost-of-service prices enforced by regulators to allow utilities to recoup large capital expenditures on coal and nuclear plants. Therefore, firms would have estimated their variable profits based on the high prices that existed prior to restructuring.

[36] As noted in Spence (1977), the effectiveness of this strategy relies on homogenous good markets with economies of scale, which are both features of electricity markets.

[37] The actions of Enron suggest that gaining market share was a factor in the gas boom.

4. Methodology and Data

The impact of electricity market restructuring on power plant investment is identified through the variation in investment decisions to build gas-fired plants in states over the period 1990 to 2013.[38] A reduced-form panel model with state and year fixed effects is used to measure the impact of restructuring on the annual change in state gas-fired capacity. This capacity measure is split by technology, as the motivation for building CCGT plants is assumed to be different from that for building gas CT plants. The choice in this paper of using a panel model to explain generation investment decisions departs from the previous literature. Joskow and Mishkin (1977) and Ellis and Zimmerman (1983) used a conditional logit (CL) model for estimation. The choice of using a cost-based, discrete-choice model was due to the nature of the available data and the investment period. Both papers measured the decision of what type of power plant to build and possessed data on actual power plant construction.[39] While this method was appropriate for the time period and data the authors used, there are four problems that make a reduced-form panel framework with a richer explanatory variable set preferable in describing the electricity industry of the last several decades.

First, the discrete-choice model assumes the dependent variable consists of only differences in fuel, with technology differences easily incorporated. This structure entails an analysis at the plant level and requires each plant to be the same size. [40] However, plants are not the same size and an analysis at the plant-level is subject to several problems explained further in the next section.

Second, the discrete-choice literature focused on cost as an explanatory factor for power plant decisions. During this period, the combination of rapidly expanding demand for electricity and cost-of-service utility regulation led cost-based models to largely ignore demand as a factor in power plant investment. While this approach was sensible in the post-World War II period, in the 1980s, electricity industry models expanded beyond the cost-based approach that had previously been standard (Peterson and Wilson 2011). The restructuring of electricity markets in the 1990s created further complexity in the building of these models. A subset of factors considered by planners, starting in the 1990s, included the cost of the plant, expectations about current and future

[38] This time period was chosen due both to it encompassing the restructuring period and the availability of data.
[39] Ellis and Zimmerman (1983) used a combination of actual and expected plant cost data.
[40] If the analysis were done at anything higher than the plant level, the problem is no longer discrete choice, as it entails the amount of investment in generating capacity rather than the decision to build or not.

electricity prices, future expectations of fuel and O&M costs, its ability to meet load requirements, the location of existing transmission lines with spare capacity, the impact of current regulation and possibility of future regulation, the probability of cost overruns, and the location of available land and water.[41]

Third, modeling decisions by firms as if they occur in independent environments ignores the influence of each state on the decision-making process. As a result, discrete-choice estimation may lead to biased coefficients, as well as biased standard errors (Moulton 1990). While states only occasionally make capacity mix decisions directly, the influence of state regulation, topography, transmission and pipeline capacities, load and climate makes it a realistic unit of observation.

Fourth, the authors were reticent about employing expected cost data. Both made use of actual plant data and supplemented with best estimates of capital, fuel and O&M costs. This was largely due to the lack of available expected cost estimates on the detailed level necessary in these studies. These data are essential in a state-level study. Additionally, as Ellis and Zimmerman (1983) notes, using only actual data can lead to truncation bias by restricting the study to the least expensive planned plants.

This section will first motivate the investment problem at the heart of this paper by constructing a structural framework to establish the relationship between restructuring and power plant investment. The result from this setup will be a framework that can be empirically tested using a reduced-form panel approach. Finally, this section concludes with summary statistics on power plant investment to motivate the results.

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[41] For example, consider the decision of where to site wind turbines. The factors involved in this decision include the wind level in the area, location of existing or planned transmission, distance to load centers, environmental impacts, state RPS, cost of materials and labor, availability of subsidies, expectations of future coal and gas prices, and a host of siting concerns explained in PSC (1999). A model based solely on levelized cost will capture some of these factors but not all of them and, as a result, offer poor predictions. To see how these predictions may go awry, consider that, in the last decade, states such as New Jersey, California, Arizona, Nevada and Florida have made large investments in solar energy production facilities despite levelized costs that are significantly higher than traditional coal or natural gas resources (EIA, 2016). Their competition with expensive peaking plants and the need for renewable electricity retail sales to satisfy state RPS programs have spurred their construction, which would not have been predicted in a model based on cost.

4.1 Model Setup

Following the standard neoclassical model of investment and contributions from Bushnell and Ishii (2007), a firm enters the electricity market, or adds to its current position in that market, by constructing a power plant. The firm invests if the expected net present value (NPV) of profit earned from the operations of the power plant exceeds the investment cost. This decision includes both the impact of the power plant on profits, investment and competition today, but also in the future. Firm i chooses the level of its investment by maximizing the following:

$$\max_{I_{i,t},A_{i,t}} E_t[\sum_{s=0}^{\infty} \delta^s \Pi_{i,t+s}(I_{i,t+s}, A_{i,t+s}, X_{i,t+s}, X_{-i,t+s}, \Omega_{t+s})]$$

$$\Pi_{i,t+s} = \pi_{i,t+s}\left(I_{i,t+s}, A_{i,t+s}, X_{i,t+s}, X_{-i,t+s}, \Omega_{t+s}\right) - (\psi(I_{i,t+s}))$$

where δ=discount factor, Π=net profit from the investment at time t, I=size of the power plant, A=prime mover,[42] X_i =generation portfolio of the firm, X_{-i}=generation portfolio of competitors, Ω=market conditions, π=variable profit and ψ(I) is the investment cost function. The additional s subscript is included to show the effect on investment decisions on future profits, investment and competition. While the previous framework is closely linked with that in Bushnell (2007), the goal of this model is to create a framework for an empirical analysis. Keeping the insights from that paper of the inclusion of intertemporal and strategic decision-making a part of the model, the previous equation can be re-written in the following manner:

$$\max_{I_{i,t},A_{i,t}} \sum_{t=1}^{T(A)} [\pi_{i,t}\left(I_{i,t}, X_{i,t}\left(I_{i,t}\right), X_{-i,t}\left(I_{i,t}\right), A_{i,t}, \Omega_t\right) - \psi(I_{i,t}\left(A_{i,t}\right))]$$

$$\psi(I_{it}) = f(A_{i,t} r_{i,t}, p_{i,t}^m I_{t+s}, R_t, Env_{i,t})$$

The first equation specifies the impact of current investments on the generation portfolios of both the firm and its competitors. As the time period moves forward and the generation mixes of all firms change, they are reacting to investment decisions made not only in that time period, but also in past periods and this specification reflects that. The second equation specifies investment as a function of the prime mover, interest rate (r), the price of construction materials

[42] This is the electricity industry term for the turbine technology used in the power plant.

and land (p^m), regulatory environment (R) and environmental regulation (Env). In order to provide a workable empirical model, the specific structure of variable profit is presented below:

$$\pi_i = \sum_{d=1}^{D(t)} \sum_{1}^{24} \{p_{dh}^E \, [x_{dh}^D(Inc, Weat_{dh}, h, ER), X_{id} \ \ (I_i), X_{-idh}(I_i), R] x_{idh}^D(p_{dh}^E, Inc, Weat_{dh}, h, ER)$$

$$- c_i[R, p_i^F(A_i, Res_i), OM_i(A_i, Env_i)] x_{idh}^S[p_{dh}^E, c_i, I_i, X_{idh}]$$

Production constraint: $x_{id}^S \leq \text{f}(I_i)$

Balancing constraint: $x_{id}^D \ = x_{idh}^S$

Financing constraint: $\psi(I_i) \leq f(r, credit)$

where p_{dh}^E=price of electricity in each hour and day, x_{dh}^D= market electricity demand in each hour and day, Inc=income of the region, which is assumed not to change on an hourly and daily basis. $Weat_{dh}$=weather of the market in each hour and day. This is typically captured by the temperature humidity and precipitation of the region in that particular hour and day. ER=economic makeup of the region the market is in, which doesn't vary by hour and day. R signifies whether the market is restructured or still regulated and is assumed not to vary by hour and day. c_i=marginal cost of producing electricity by the firm and is assumed not to vary within a year due to firm fuel and labor contracts. Marginal cost is determined by p_i^F=price of the plant's fuel source, which is a function of the prime mover choice and resource availability (Res), and OM_i=operations and maintenance cost of the plant, which is a function of prime mover choice and environmental regulation. x_{idh}^S=electricity generated by the plant in each hour and day. The production of the plant depends not only on the variable profit of running the plant in each hour and day, but also on the size of the plant and the composition of the firm's generating portfolio.[43] The production constraint places an upper limit on the amount of electricity a firm can supply from the constructed plant. The balancing constraint is necessary as electricity storage is assumed to not be feasible. Therefore, all electricity that is generated must be sold in that period. Additionally, firms face financial constraints based on interest rates and the credit rating of the company.

The importance of expectations complicates this problem for utility planners. The profitability of a plant is based not only on profits this year but is heavily reliant on future profits.

[43] For example, a firm may wish to operate other plants in the market due to the cost of shutting down the plants that are currently operational.

Utility planners must forecast electricity prices and demand, entry of competitors and future plant construction and operation costs. Therefore, each component of this setup beyond t=1 is based on utility expectations, which are derived from past data and future projections. The following equation incorporates these expectations with the profit function above:

$$\max_{I_i, A_i} E_t \sum_{t=1}^{T(A)} \sum_{d=1}^{D(t)} \sum_{1}^{24} \delta^t \{ p_{tdh}^E \left[x_{tdh}^D (Inc_t, Weat_{tdh}, h, ER_t), X_{itd} \ (I_i), X_{-itdh}(I_i), R_{it} \right] x_{itdh}^D (p_{tdh}^E, Inc_t, Weat_{tdh}, h,$$

$$- c_{it}[R_{it}, p_{it}^F(A_i), OM_{it}(A_i, Env_{it})] x_{itd}^S \ [p_{tdh}^E, c_{it}, I_i, X_{itdh}] - \psi[I_i(A_i, r_{it}, p_{it}^m, I_{t+s}, Env_{it}, R_{it})]$$

Production constraint: $x_{itdh}^S \leq f(I_i)$

Balancing constraint: $x_{itdh}^D = x_{itdh}^S$

Financing constraint: $\psi(I_i) \leq f(r_t, credit_t)$

Taking partial derivatives ($\frac{\partial \Pi}{\partial I}, \frac{\partial \Pi}{\partial A}$) and simplifying:

$$I_i^{AF} = f[E_t(p_{tdh}^E, x_{itd}^D \ , c_{it}, X_{itdh}, A_i, r_{it}, p_{it}^m, I_{t+s}, R_t)]$$

The equation above states that the investment (MW) in a particular technology and fuel of power plant (coal, nuclear, CCGT, gas CT, renewable, oil) depends on the expectation of electricity prices, electricity demand, marginal cost of generating electricity, the generation composition of the firm, prime mover, interest rates, price of construction, future investment, and the state of regulation.

This is the individual firm framework that would be used as an estimation tool. However, there are several possible observation levels for this analysis. The micro-level consists of individual plants or firms, which may own several plants across the country. Intermediate-level observations include states or utility balancing areas, which can cross state boundaries. High-level observations consist of either North American Electric Reliability Corporation (NERC) regions, which encompass multiple states, or interconnects (East, West and Texas). A natural observation level for explaining power plant investment choices would consist of build decisions made by individual plant owners, as detailed above. These are the decision-makers that determine the characteristics of the investment and possess the most information about that investment.

However, the firm-level observation faces several problems. First, individual firm data on levelized cost, RPS, regulatory environment and demand forecasting are not available and the rise of single-plant firms makes assembling a panel challenging. Second, firms often own plants in different states, making data sets inconsistent with the introduction of restructuring. Third, there is a problem with identifying the correct electricity market a plant is built to serve, as electricity flow data from individual plants is not available. This problem is less severe the larger the region of analysis and explained further in the empirical model explanation. Based on the insights available through cross-sectional variation and the reduced impact of cross-border flows through the location of restructured states, the state is the most preferred level of observation of this group. The role of the state in determining regulation only adds to the advantages of a state-level analysis.

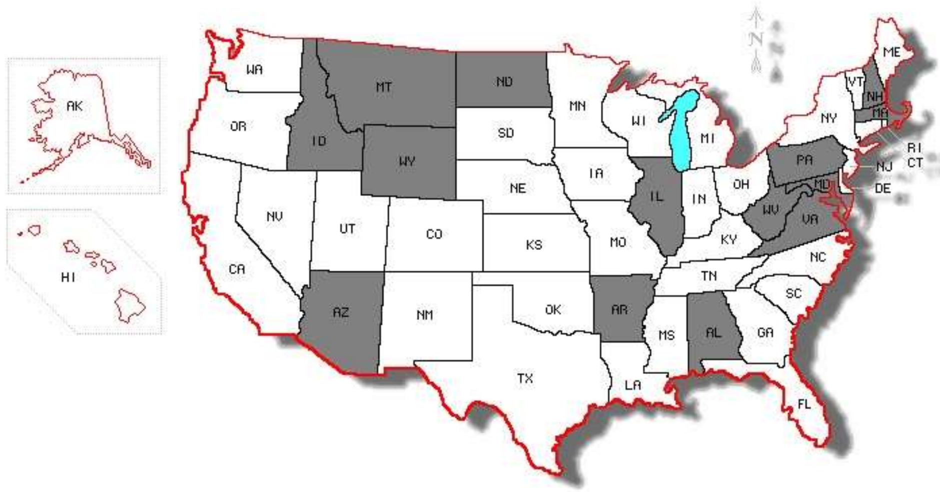
The framework above needs to be altered for the state level, as some of this information is not available to firms and not accessible at the state level. First, price expectations are based primarily on what utilities project about future entry (CAP) and demand (EIA 1997). Including these factors instead of prices provides a more accurate model. Second, the hourly demand is less important than its variability (VAR) and overall level (ERS). Therefore, hourly electricity demand expectations with expectations about future electricity retail sales and variability. Third, investment, operating and interest costs are included in firm levelized cost calculations. Substituting these factors into the previous framework results in:

$$I_i^{AF} = f[E_t(ERS_{st}, VAR_{st}, X_{st}, CAP_{st}, R_t), LC_{st}^{AF}]$$

4.1.1 Cross-Border Flows

States often experience large cross-border flows of electricity, as shown in Figure 6. For example, more than 20 percent of the electricity generated in Arizona is transmitted to California (EIA, 2016), with Wyoming and West Virginia experiencing even larger flows out of state. Capacity investment in these states, therefore, are often intended to serve other electricity markets, creating measurement error in the data. This problem is most severe on the plant or firm level, where electricity is impossible to trace. Using higher-level observations, such as the state, NERC region, and interconnect level, are an improvement. However, as the unit of observation increases in size, the number of observations shrinks. There are 51 annual observations for states, 10 for NERC regions, and 3 for interconnects. As the number of observations available for the analysis falls, the power of the study is reduced, revealing a tradeoff between measurement accuracy and power of the test.

Figure 6. States with Significant Cross-border Flows of Electricity in 2014[44]



Source: EIA (2016)

Measurement error in generation capacity due to cross-state electricity flows exists in several regions. While Texas is largely self-contained and all of the New England states except Vermont restructured, which lessens the impact of cross-state flows, borders like Illinois-Indiana and Virginia-North Carolina are a challenge for proper estimation. This requires identifying the state electricity market each plant was built to serve. While a significant amount of electricity in both regulated and non-regulated markets is sold in wholesale markets, the intended flow of electricity upon construction is what is important. There are two approaches used to estimate the intended state market for each plant. The first uses long-term power purchasing agreements (PPA), beginning upon construction of the plant, to infer which state the power plant was built to serve. The second uses ownership share data to assign capacity to each state. For example, investors in the large Palo Verde nuclear power plant in Arizona included several California utilities. A portion of the electricity produced at this plant is sent west to serve the California market. While these approaches do not capture every investment decision, their accuracy with large-scale plants ensures that the majority of cross-state flows are attributed to the intended state.

[44] Significant defined as difference between ERS and electricity production greater than 10 percent of state ERS.

4.2 Empirical Model

The choice of size, prime mover, and fuel type of a power plant depends on the factors included in the investment equation:

$$I_i^{AF} = f[E_t(ERS_{st}, VAR_{st}, X_{st}, CAP_{st}, R_t), LC_{st}^{AF}]^{45}$$

The goal of this analysis is to estimate the impact of restructuring on power plant investment. The change in CCGT and gas CT capacity are the dependent variables of interest instead of the change in all generating capacity, change in all gas capacity, or total CCGT and CT capacity. Gas capacity is the focus because there is little to explain about power plant investment during this period outside of gas-fired plants.[46] Capacity is split between CCGT and CT because this allows for better identification of the factors behind the investment decision in each prime mover. Finally, the change in the variable is analyzed, as opposed to the level, because the focus of this paper is on additions made to utility capacity portfolios beginning in the 1990s. Analyzing the level includes past investment decisions, which are outside the scope of this paper.

The definition of electricity market restructuring in the economics literature is focused on the opening of retail choice to consumers. However, the choice to build a power plant is influenced by generation competition, not retail competition. What allows this comparison to be made is the influence of retail competition on generation competition. As previously mentioned in Section 2, concerns about market power in generation led to state utility commissions requiring vertically-integrated utilities to sell significant assets to new and existing power producers. Figure 2 showed the effect of this policy, which increased IPP penetration to an average of over 50 percent in restructured states. Non-restructured states peaked at 15 percent, despite efforts by FERC to open transmission lines to new generation sources. Therefore, using retail and generation competition interchangeably in this analysis is feasible.

The primary equation for the panel model is presented below. State fixed effects are included in some specifications to control for possible time-invariant state differences which may bias the results. For example, a state's resource endowment will be captured in these fixed effects.[47]

[45] Levelized cost of electricity contains expectations in it, so including it in the expectation formula is redundant.
[46] 84 percent of net capacity additions in the US from 1990-2013 were in gas-fired power plants. Leaving out renewable additions from 2007-2013, which are largely attributed to state RPS requirements, increases this amount to 95 percent (Powers and Yin 2010).
[47] An important component of these fixed effects is California's preference for natural gas over coal due to environmental reasons.

Year effects are also included to capture broad trends occurring in the United States during this time period, such as changes in technology and booms and busts in the business cycle.

$$\Delta MW_{st}^{G} = \alpha Restruct_{st} + \beta RestructxPeriod_{st} + \delta X_{st} + \theta_s + \omega_t + \varepsilon_{st}$$

In the equation above, s indexes states and t indexes years. ΔMW refers to the nameplate capacity of a plant in megawatts (MW) and is measured as the change in gas capacity in a state in a given year.[48] This equation is analyzed separately for CCGT capacity changes and gas CT capacity changes. Restruct is a binary variable detailing whether the state's electricity market was restructured. RestructxPeriod measures the impact of restructuring on power plant investment in groups of years after restructuring. This enables the model to capture short run dynamics of restructuring. Given the role of expectations in the impact of restructuring, the two restructuring variables have a lag to account for time to complete the power plant and begin when a state sends a strong signal it will restructure by passing legislation. X represents a set of controls in this regression, which include lagged capacity to ERS ratio (a ratio of available supply of electricity to demand (CapERS)), expected lagged electricity demand growth, expected lagged load variance, and levelized costs of competing fuels and technologies.

The coefficient of interest in this paper is the interaction variable (RestructxPeriod). The choice to include a variable separating time periods following restructuring tests whether investment decisions in restructured versus non-restructured states differed based on the time period. This test the well-known theory of new-market investment following an S-shape, with rapid entry, a shakeout as firms leave, and an established equilibrium (Klepper and Miller 1995).

Firm expectations about future supply and both the level and variation of demand are important components of the investment decision. While firms assume that a decline in the CapERS ratio will be corrected in the future, as it encourages entry, their investment also serves to deter future entry by increasing the ratio. As a result, they are assumed to take advantage of decreases in this ratio by investing, with expectations about the ratio in the future being less important due to their impact on other firms' investment. However, the firm does rely on expectations about future demand, as declining or slow growth in electricity demand reduces the

[48] This functional form uses change instead of log due to the extreme swings in the data, with some states having no capacity prior to the gas boom.

profitability of plants. The level of growth is important to ensure higher prices and prevent idle plants, while the variance determines what the market for the plant will be. Each of these are lagged to correspond with when the decision to build the plant was made. In the dataset for this paper, the observation is when the plant began operation, not when construction started.

A critical undertaking in this paper was constructing cost data for each type of generating plant in each state and year, which did not exist in a complete panel. The structure of levelized costs can be modeled in the following way:

$$LC_{st}^{AF} = f[CapCost_{st}^{A}, Life^{A}, DiscRte^{A}, E(p_{st}^{AF}, O\&M_{st}^{A})$$

where CapCost is the cost of plant by primemover, Life is the plant life by prime mover, and DiscRte is the discount rate applied to the plant by prime mover. Expectations only factor into levelized cost for fuel and O&M, as these are the costs of the plant impacted by future events. Plant life and discount rate vary little across time and state and only fuel prices are influenced by the choice of fuel. The other factors are distinguished by prime mover. Power plant investments are impacted by many factors, due partly to their size, but also because of their length. Planning and construction alone take 7 years for coal plants and up to 15 for nuclear plants. Once online, a plant will operate, in the case of some coal and hydro plants, for as long as 70 years. Plant owners rely heavily on expectations of future fuel prices and regulation and are wary of the near bankruptcy of many nuclear power plant builders in the 1980s due to unexpected cost overruns.

In a regulated state electricity market, utilities were confident in making these investments, as they could expect to be reimbursed for large capital outlays through cost-of-service regulation. There were no guarantees in restructured markets, which experienced a reverse Averch-Johnson effect. Capital intensive investments were a liability in markets where electricity prices could rapidly rise or fall, as they did in the mid-2000s. In these markets, expectations of fuel prices were key in new power plant investment.

4.2.1 Restructuring Exogeneity

A critical assumption in this model is the restructuring process had an exogenous influence on changes in state gas-fired capacity. If another factor was responsible for the gas buildout decision in restructured states, the empirical results of this paper would be spurious. These concerns have undergone extensive vetting in the restructuring literature, as policy variables are often endogenous (Fabrizio et al 2007; Davis and Wolfram 2012; Cicalla 2015). There is evidence that the structure and expertise of state legislatures and high electricity prices in the early 1990s were correlated with state decisions to restructure (White 1996; Ando and Palmer 1998; Damsgaard 2003; Ardoin and Grady 2006). There is no established link between legislature structure and preference for gas-fired capacity, so it is not considered a threat to identification. The link between electricity prices and restructuring is addressed in Fabrizio et al (2007), so it's worth noting how these authors, as well as Davis and Wolfram (2012), address endogeneity concerns.

The restructuring endogeneity concern is there is some factor influencing the decision to build gas-fired plants that changed during the restructuring time period and only for restructured states. Both Fabrizio et al and Davis and Wolfram note that any unobserved differences among states are most likely time-invariant and do not have a plausible connection to the dependent variable. This includes electricity prices, with a gap between restructured and other states existing for a long time period due to previous generation choices. The authors also used alternative methods to account for specific plant and geographic patterns relevant to their papers, but these were in support of their main specification. Instead, both papers rely on observation-level fixed effects to negate potential identification concerns.

While this paper employs a similar strategy, the timing of restructuring is an important factor which reduces the chance of policy endogeneity. The time path for restructuring varies widely among states, with some states choosing to restructure early, some states employing a lengthy process, and others moving quickly to restructure. As a result, several states were still in the exploratory phase when the California Electricity Crisis occurred. This event is noted by several state public utility commissions (PUC) as part of their decision not to restructure. This exogenous event, due in large part to reduced rainfall in the Northwest and a summer spike in load, determined the restructuring path for multiple states. For those states that restructured early, due in part to high electricity prices, there is a question as to what made those states delay. Electricity prices were high for years. It's likely that the deregulatory environment during that time period in the US encouraged states to restructure their electricity markets, which has no plausible connection to states engaging in a large gas buildout.

Although the timing of restructuring is important in the exogeneity of restructuring, the primary evidence of this paper is that states not only built gas, but built it in large quantities. The size of the buildout drastically increased the capacity ratios in restructured states and drove down average capacity factors for power plants. The only reason for these high ratios would have been if these states were large exporters of electricity. However, not only were these states not exporters prior to restructuring, but their low capacity factors following restructuring showed that they were not selling the additional electricity the new plants were capable of producing. Therefore, following Fabrizio et al (2007), Davis and Wolfram (2012) and Cicalla (2015), restructuring is assumed to be exogenous with the addition of year and state fixed effects.

4.3 Data and Summary Statistics

The approach used in this paper to analyze changes in electricity capacity requires a large amount of data on the individual state level from 1990 to 2013. All 50 states were included in this analysis.[49] While it would have been useful to incorporate data prior to 1990 in the estimation process, this is as far back as reliable state-level cost and demand projections are available. Data on plant capacity by state and year and ownership share are from EIA form 860. Additional nameplate capacity, demand and capacity factor information are from the EIA's AEO reports. Load data for state and year are available from FERC.

There is no single source that provides estimates of levelized costs for each fuel and technology in each state from 1990-2013. Actual plant cost observations are available only in certain states, as not all fuels and technologies were constructed in each state every year. Using these estimates also creates the hypothetical bias mentioned in Ellis and Zimmerman (1983). Additionally, relying on estimates from several sources prevents a bias in the data coming from one source.[50] As a result, the data are a combination of both actual and estimated costs. Actual plant cost data are provided by Ventyx. The current and expected future prices of coal, natural gas, uranium, oil and biomass are provided by the EIA Annual Energy Outlook. Estimates of plant life are provided by the National Renewable Energy Laboratory (NREL), International Atomic Energy Agency (IAEA) and the National Association of Regulatory Utility Commissioners (NARUC). Actual and estimated O&M data are provided by Ventyx and the EIA. Finally, capital cost data are from a variety of sources, including the EIA Annual Energy Outlook, the MIT interdisciplinary

[49] The District of Columbia was excluded, as it contains very little capacity, compared to demand, and that capacity did not change during the time period studied. Instead, DC gets its power from neighboring states.
[50] Utilities have frequently complained about the shortcomings in some of the EIA data, to the point where the EIA altered its methodology in 2010.

reports on natural gas, coal, nuclear, geothermal and solar, the University of Chicago report on nuclear power, Ventyx and NREL.

The restructuring variable uses detailed information on restructuring available from both the EIA and individual state regulatory commissions. These data list all of the major steps that states initiated along the restructuring process. These include commissioned reports, pilot programs, legislative action, divestiture of assets, and the opening of markets to retail competition. Dates are provided for each of these events. After confirming with the dates used in Fabrizio et al (2007),[51] a state is considered in this study to have restructured its electricity market after the state legislature passed a law directing the state regulatory commission to open the state's electricity market to retail competition. Assigning years to signal the official start of restructuring is challenging because of the role of expectations in these markets. This information was not hidden, so firms would be aware of the steps taken by states to restructure. Given the lag time in power plant construction, a firm seeking to enter a newly restructured market that is unable, or unwilling, to purchase a divested plant may invest prior to the official start date of the market. This would allow the plant to enter the market sooner than firms that began construction upon the date of retail competition. Therefore, this study assumes that a legislative order was considered sufficiently permanent to incentivize firms to begin construction of new power plants.

Throughout this paper, a comparison is made between three groups of states: Restruct, South, and None. The Restruct group consists of states which started the process of retail competition through legislative or regulatory action. The South group consists of states located in the southeastern part of the United States, none of which restructured. The None group consists of the states that are not part of the South group that didn't restructure. Separating these three groups provides for an intuitive understanding of the changes in this period and differences between the states.

[51] There are a few differences with the Fabrizio et al index, all having to do with the timing of restructuring rather than whether a state is considered to have restructured. The approach of this paper is that restructuring began when legislation was passed. It seems that, in most cases, Fabrizio et al follows this rule but deviates in several cases. This paper only deviates from that rule once, where legislation had been approved late in a previous year but there was a small procedural delay that pushed the official signing into the next month, which was the following year.

Table 3. State Group Characteristics

	# States	ERS	Coal %	Gas %	Nuclear %
Restruct					
1990	20	1,419,891	33.4%	25.1%	16.7%
2000	20	1,726,561	29.9%	36.2%	13.3%
2013	20	1,858,429	21.2%	48.3%	10.2%
None					
1990	21	607,544	65.5%	5.6%	5.7%
2000	21	770,348	59.0%	13.1%	4.7%
2013	21	864,852	45.7%	23.7%	3.6%
South					
1990	9	675,271	44.2%	14.7%	18.7%
2000	9	913,889	38.3%	25.8%	16.3%
2013	9	990,697	26.4%	46.5%	12.6%

Notes: ERS stands for Electricity Retail Sales. Coal%, Gas %, Nuclear % are each fuel's share of capacity for each region. Source: EIA (2016)

There are several differences to note in Table 3. First, note that, despite a similar number of states, the Restruct group has almost double the ERS, compared to the None group. This is due to the Restruct group containing large population states, such as California, Texas, New York, Illinois, and Ohio. Second, ERS growth in the South group was larger than the other two groups from 1990-2008, which is an important component in understanding the increase in gas capacity in the South group. Third, both the initial levels of resources used to generate electricity, and the change during the time period, are relevant to this analysis. The None group consisted of states heavily invested in coal and hydro, with several states exporting significant amounts of electricity to other states. This group also didn't experience as rapid an increase in gas capacity as the Restruct and South groups did. Awareness of these differences adds to the interpretation of statistics presented later in this paper.

5. Empirical Results and Analysis

The results of this analysis are separated between CCGT and CT plants. The explanatory variables in each regression differ slightly, as the two technologies are built for different purposes. Their occasional overlap, particularly in the case of CCGT plants providing peak output, necessitates an analysis of both investments.

5.1 CCGT

Table 4 shows the impact of electricity market restructuring on CCGT capacity. The variable being explained is the change in CCGT capacity in each state in a given year. The columns are differentiated by the number of years after restructuring. The primary explanatory variable, an interaction between restructuring and the post-restructuring time period, is lagged by three years to account for plant construction. Therefore, column 1 shows the average change in CCGT capacity for restructured states four to seven years after restructuring compared to non-restructured states, column 2 shows this change for years four through eight and so on. Years three and below before restructuring are omitted from the table, as there are no significant effects to report. Following the model in the previous section, controls are included for available capacity to meet demand (CapRatio), expected electricity demand (ERSproj), expected distribution of daily load (Varratio) and the ratio of levelized cost of CCGT to coal. State and year fixed effects are included in each specification. For alternate specification and robustness checks, see Section 8.

Table 4. Effect of Restructuring on CCGT Power Plant Investment

Period	(4)	(5)	(6)	(7)	(8)	(9)
Restruct	235.24**	116.83	14.37	37.52	49.25	64.96
	(118.12)	(71.29)	(91.72)	(96.85)	(99.22)	(105.54)
Restruct*Period	223.01	436.2**	593.71**	522.31**	485**	441.52**
	(151.96)	(178.48)	(276.40)	(259.82)	(224.72)	(209.08)
	-	-		-	-	-
CapRatio	277.24***	240.49***	-230.6**	264.64***	293.51***	316.76***
	(87.75)	(82.86)	(87.89)	(87.07)	(91.51)	(95.37)
ERSproj	15.73**	15.18**	14.75**	13.77**	13.53**	13.82**
	(6.39)	(6,504.97)	(6.53)	(6.30)	(6.16)	(6.23)
Varratio	22***	21.54***	21.16***	20.73***	20.69***	20.78***
	(7.43)	(7.24)	(7.11)	(6.87)	(6.73)	(6.77)
Gascoalratio	-4.85	-3.77	-5.87	-8.11	-9.52	-8.68
	(13.45)	12.85	(13.69)	(13.80)	(13.34)	(13.75)
State FE	Y	Y	Y	Y	Y	Y
R^2	0.16	0.17	0.18	0.17	0.17	0.16

Notes: N=1050. Dependent variable is change in CCGT capacity (MW). *** significant at .01 level. ** significant at .05 level. * significant at .1 level

The peak impact of restructuring on CCGT capacity expansion occurs between years four and nine following restructuring (Period 6). Restructured states during this period add 593 MW additional capacity each year compared to non-restructured states throughout the sample period. As the number of years in the period increases, this effect is diluted but still significant 12 years after restructuring and nonexistent in a period of four years or less. RatioCapERS is significantly negative, suggesting that states with large amounts of capacity built very few CCGT plants. The signs and magnitudes of ERSproj and Varratio suggests that more CCGT plants were constructed when expected future demand and demand variance was greater.

There are three important conclusions to gather from the results in Table 4. The first is the magnitude of the CCGT capacity addition difference between restructured and non-restructured states. By 12 years after restructuring, a restructured state added over 4.1 GW of CCGT capacity more than a non-restructured state with similar supply and demand characteristics. Second, the expansion period was lengthy, with peak additions occurring nine years after restructuring and six years after plants began coming online. It was large enough to show a significant differential between restructured and non-restructured states 12 years after restructuring. Third, this relationship holds after controlling for a large number of factors, suggesting it is driven by restructuring and the nature of the market after free entry rather than other changes within the industry to which it was attributed.

5.2 CT

Table 5 shows the effect of restructuring on CT plant investment. The variable explained in this table is the change in CT capacity in each state and year. Unlike CCGT, the effects are not separated by the period of time after restructuring, as there were no significant effects. Instead, each column is separated by the binary variable separating the time period. This setup not only shows what impacts CT construction, but also explains the negative effect of restructuring on CT plant investment. Other explanatory variables are included following the model setup at the beginning of this chapter, with a peaking ratio replacing the total capacity ratio. This ratio is more relevant to the decision to build a CT plant.

Table 5. Effect of Restructuring on CT Power Plant Investment

Period	(1)	(2)	(3)	(4)
Restruct	-101.95**	-123.96***	-110.34***	-126.47
	(42.18)	(36.34)	(46.96)	(82.64)
ERSproject	0.48	0.77	0.45	0.66
	(3.71)	(3.45)	(3.70)	(3.55)
Varratio	9.43	9.87	9.46	9.46
	(6.51)	(6.46)	(6.59)	(6.41)
PeakRatio	-2.32**	-2.51**	-2.39**	-2.16**
	(1.11)	(1.16)	(1.17)	(1.12)
Fuelratio	2.76	3.88	2.59	3.56
	(14.25)	(15.36)	(14.33)	15.26
Interval		-35.34	-30.74	-455.14***
		(28.38)	(27.94)	(92.99)
Restruct*Interval		189.47	14.66	45.17
		(224.14)	(105.79)	(112.97)
State FE		Y	Y	Y
R2	0.11	0.11	0.11	0.12

Notes: N=1100. Dependent variable is change in gas CT capacity (MW). *** significant at .01 level. ** significant at .05 level. * significant at .1 level

Column 1 shows the difference between CT construction in restructured and non-restructured states from 1990-2013. Restructured states built 100 MW less than non-restructured states each year, with the supply of peaking resources (represented by PeakRatio) having a significantly negative impact on CT construction. Given the expansion of CCGT plants detailed in the previous section, there is clearly a relationship between the impact of restructuring on excess CCGT construction and the dearth of CT construction. The nature of this relationship is in question, as it's feasible that either firms in restructured states focused more on CCGT and less on CT construction or the large CCGT expansion created excess capacity, which discouraged CT investment. This effect can be determined by the time period in which it occurred. If it's concentrated during the years of the CCGT expansion (2000-2006), then it was the preference for CCGT over CT that both explains some of the excessive build in CCGT and the lack of construction of CT plants in restructuring states, relative to non-restructured. However, if the effect is concentrated after 2006, the CCGT expansion was due to other factors and caused a later slowdown in CT plant construction.

Columns 2-4 identify the timing of this effect. Column 2 splits the effect of restructuring between pre-2000 and post-2000, with the significance of the restructuring variable suggesting the negative effect after 2000 is still strong. Column 3 increases the split to pre-2006 and post-2006, with similar results. Clearly, there is a negative impact of CCGT construction on CT plant construction post-2006. However, this does not leave out the possibility that CCGT construction was also substituting for CT plants during the boom. Column 4 separates the time periods into the boom period (2000-2006) and the non-boom (pre-2000 and post-2006). The lack of significance on the restructuring variable shows there is not strong evidence for substitution of CT for CCGT plants. Therefore, it's safe to conclude that CT plant construction declined in restructured states because of the expansion in CCGT power plants.

5.3 Analysis

The results in Tables 4 and 5 attribute a significant part of the gas boom to restructuring, with restructuring leading to an excess in CCGT capacity. Previous explanations of the gas boom focused on the adoption of new technology, the impact of low natural gas prices, deregulation of natural gas markets, increasing electricity demand, environmental concerns, and the fast construction time of gas plants. While many factors played a role in the gas boom, the timing and the geographic differences of the previous explanations are at odds with the nature of the boom. Each of these issues are addressed in the following paragraphs.

The introduction of both combined cycle and jet engine technologies into electricity markets had an impact on the cost of power plant construction. For CCGT plants, the levelized cost of capital declined due to the increased efficiency of the technology. [52] For gas CT plants, the introduction of jet engine technology not only reduced construction cost and increased efficiency, but also decreased the start-up time, which is important for plants designed for peak use. Both of these technologies lowered the levelized cost of electricity, making gas cost competitive with coal for the first time. However, this doesn't explain the timing of the gas boom, as these technologies were constructed in Japan, the UK, and the US beginning in the 1980s. Additionally, while this contributes to explaining why the majority of power plants built during the boom were fueled by

[52] In the electricity industry, plant efficiency is measured by heat rates. This is the amount of BTUs of fuel energy necessary to create a kWh.

natural gas, it doesn't explain why restructured states built CCGT plants than non-restructured states.

Similar to the adoption of new technology, the decline in long-run expectations of natural gas prices led to a reduction in the levelized cost of electricity from gas compared to other fuels. This decline was due largely to political factors in the Middle East and the introduction of new sources, both domestically and internationally (EIA, 1994). The combination of the technology change and the long-run expectations adjustment, as well as the flexibility of non-steam power plants, led to natural gas being preferred as a fuel in power plant construction over coal, nuclear and biomass. Therefore, this explains the choice of natural gas across the country, but not why it differed among states. It also conflicts with the timing of the boom, as these changes occurred in the early to mid-1990s.

In the mid-1990s, electricity demand growth began to pick up as a result of the increase in economic growth, as well as the further adoption of household electronics. The increase was largest in the South, both for these reasons and due to migration, but the Restruct group also experienced an uptick in electricity demand growth. Combined with the dearth of power plant construction during the 1990s, this created a need for new generating capacity just as the gas boom began. As a result, the timing of the increase in electricity demand fits the gas boom well, but doesn't explain the difference between investment in the Restruct group and the South group. The South group's electricity demand grew faster than the Restruct group but built fewer power plants in the 1990s than the Restruct group did. Electricity demand growth suggests those states should have built more plants than the Restruct group, while the opposite actually occurred.

Environmental pressure is a factor in the choice of natural gas plants, as they are cleaner burning than coal on a wide range of emissions. While there is no significant change in environmental protection during this time period, measured both in changes to the National Ambient Air Quality Standards (NAAQS) and regional agreements, it's still possible that utilities would be more wary of future regulation and curtail their choice of coal power plants in favor of gas. This could also explain regional variation in choice, with political differences existing between states that restructured, which tended to be left-leaning, and those that didn't, which tended to be right-leaning. However, there was no regional variation in fuel choice, as almost no coal capacity was added during this period. Instead, there was variation in the size of investment, which can't be explained by differences in environmental attitudes.

The ability of gas-fired power plants to be built faster, and started quicker, is significant in the choice of fuel and technology. This is especially important in states that experience greater load variance and for those whose markets are liberalized. The average construction time for a gas CT plant is 2 years, while a gas CC plant can be built in up to 3. This compares favorably to coal, which can take 7 or more years, and nuclear, which began taking 15 to 20 years. This is an important factor for meeting immediate capacity needs but is crucial in restructured markets. Firms operating in liberalized electricity markets no longer receive guaranteed rates from the state regulatory commission. Instead, they are open to market fluctuations, which make it more difficult to pay off the large fixed costs associated with coal and nuclear power plants. The enhanced risk in these type of plants ensured that firms entering newly restructured markets would focus on gas plants. However, gas power plant construction occurred in both restructured and non-restructured markets and their ability to serve restructured markets does not explain why they were built in excess of demand.

The failure of these factors to explain the timing and scale of the gas boom suggests that alternative explanations are needed. This paper has found separate explanations for CCGT and CT plant construction, with Table 4 showing restructuring played a large role in the construction of CCGT plants. The investment paths of the two plant types are explained in the following two sections by combining the explanations of previous analyses with new insights from this paper.

5.3.1 Explaining the CCGT Boom

The South group of states was in need of capacity near the end of the 1990s due to a decade of low power plant investment and high ERS growth. CCGT plants were constructed in the South to meet the need for base load capacity and because the levelized cost of gas had fallen below coal. The leveling off that occurred in the South group's capacity to ERS ratio following 2006 was within the bounds of previously normal ratio levels, suggesting capacity had met its desired level. The increase in this ratio following 2008 is due to declining ERS, not changes in plant capacity.

The None group of states was not in need of capacity additions, in comparison to the Restruct and South groups, because of high capacity to ERS ratios entering the 1990s. As a result, there was significantly less construction in these areas. Power plants that were built during this time period were largely due to state RPS requirements or to meet outside state demand (Indiana, for example). The leveling off of these states at normal ratio levels suggests, as with the South group, that capacity had met its desired level.

The CCGT investment in the restructured states can't be explained by demand or supply factors. ERS growth did increase in the 1990s, but it was less than the South and significantly less than what would have been needed to purchase all of the new capacity coming online. Similarly, capacity ratios in restructured states were low in the late 1990s, but increased well past previously normal levels. Based on the results in Table 4, there is strong evidence of excessive entry into restructured electricity markets, which led to overinvestment.

A statistic used to measure excessive entry in electricity markets is the ratio of generating capacity to ERS. This annual ratio compares the megawatt hours of electricity that can be produced in a state if each plant operated at the planned capacity factor with the megawatt hours of electricity sold in each state. Figure 5 shows a decline in the ratio in both restructured and non-restructured markets from 1990-1998, followed by an increase until 2006, a slight decline from 2006-2008, and then a stagnant period until 2013. The difference in the ratios between the state groups beginning in 2000 provides further evidence that there was excessive entry into restructured markets.

The large number of bankruptcies, or near bankruptcies, and asset fire sales by both utilities and IPPs provides further evidence of excessive entry in these markets.[53] Descriptions of these firm difficulties regularly mention an oversupply of electricity. Additionally, the timing matches the description in Klepper and Miller (1995) of the shakeout, where less efficient firms leave and the market moves towards a long-run equilibrium. The decline in the capacity to ERS ratio post 2006, combined with the bankruptcies, suggests that the electricity market in deregulated states may have been starting to move to a long-run equilibrium before the combination of the 2008-2009 recession and the increase in energy efficiency programs led to a drop in ERS growth.

The factors mentioned above, combined with observations in papers like Borenstein and Bushnell (2016), which noted that large reserves required by ISOs do not fully explain the level of excess reserves in restructured markets, lead to the belief that restructuring electricity markets resulted in excessive entry and overinvestment. What is not clear, thus far, is the mechanism behind this excessive entry, which contradicts the medium to long-run efficiency gains restructuring was

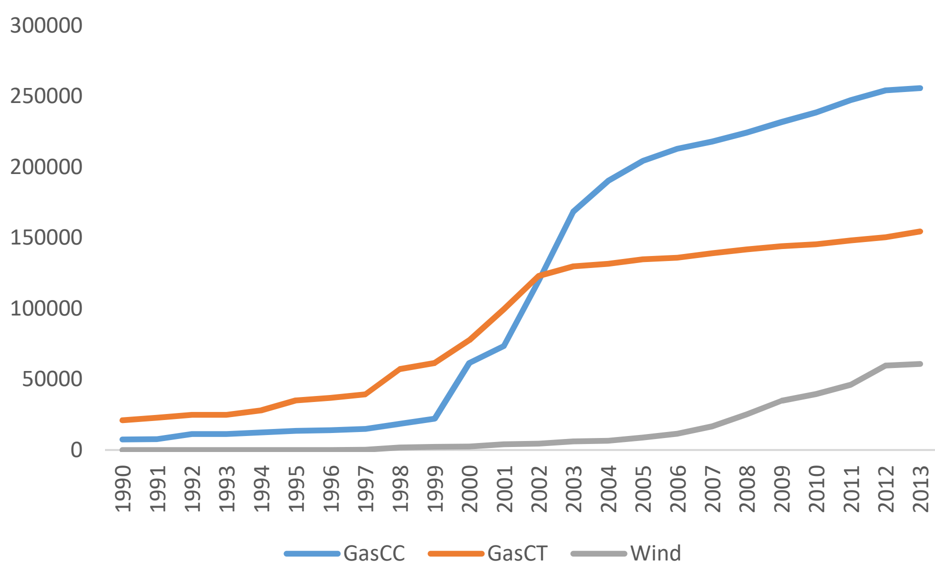
[53] Calpine, Mirant and NRG are a few examples of major bankruptcies occurring in the mid-2000s. Major utilities that were approaching bankruptcy include Pacific Gas & Electric and Southern California Edison. Dynegy, Williams, El Paso Energy and Duke are examples of large power suppliers that engaged in asset fire-sales and halted merchant energy trading. (Anderson and Erman 2006; Wharton 2006)

supposed to provide (Joskow 1997). Section 6 provides four explanations for how restructuring could have led to overinvestment in newly liberalized markets.

5.3.2 Explaining the CT Boom

The increase in CCGT capacity was the most significant part of the US Gas Boom, but there was also a large increase in CT capacity around the same time period (as shown in Figure 7). Despite their similarities, the CT boom differed from the CCGT boom in several important aspects. First, the timing and spatial variation of the two buildouts are separate. Second, restructuring was not an important factor in the CT construction phase, as opposed to the impact on CCGT. Third, the investment decision in CT plants is different from that in CCGT plants. Each of these differences are expounded upon below.

Figure 7. Investment in Generating Capacity by Technology, 1990-2013 (MW)



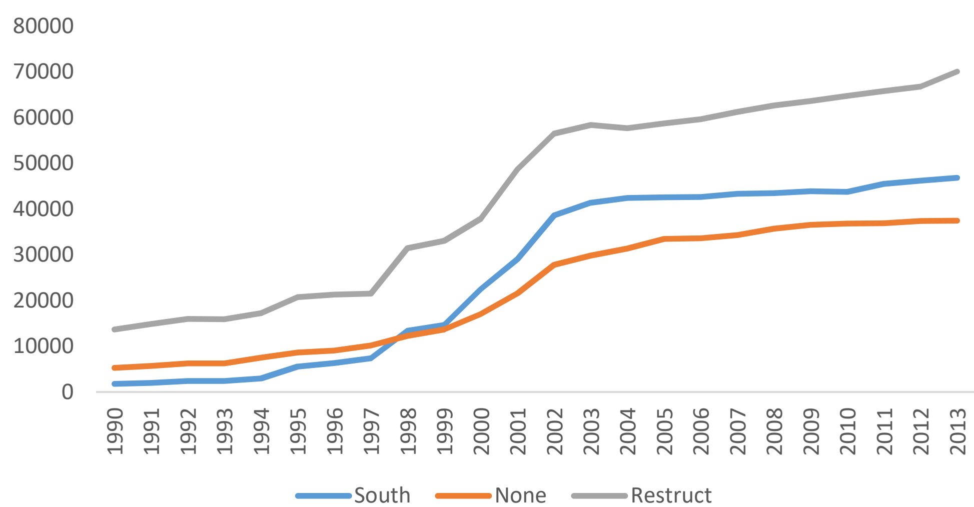
Notes: Wind capacity increase included to provide context on the boom size. Source: EIA (2016)

CT power plants are built to meet intermediate and, particularly, peak load demand. These are low capital, high marginal cost plants with the flexibility to start up quickly. Using the technology from jet turbines, CT plants were introduced in the US in the 1980s as an alternative to oil and gas steam turbine power plants. While the majority of these plants are able to operate using oil or natural gas, the cost difference prompts most utilities to choose natural gas as a fuel.

The typical construction time for a CT plant is 2 years, which is quicker than CCGT (3), coal (6), and nuclear (15+). As Figure 1 shows, there was a large buildout of these plants from 1997-2002. Assuming a 2 year lag between the start of planning and construction and the beginning of operation, the relevant time period when analyzing CT investment is 1995-2000.

The timing and pattern of the CT buildout shown in Figure 1 contradicts the standard assumption that utilities add peaking capacity as needed. This strategy would consist of small additions throughout the years, which would appear as a more linear investment strategy. The actual buildout differs from this linear projection in several time periods, with less capacity added prior to 1997, more added between 1997 and 2002, and less after 2002. Of these three, the after 2002 period is most easily explained, as it was impacted by the large expansion from 1997-2002. With so many plants available from both the CT and CCGT buildouts, there was no need for further significant capacity additions.[54] Therefore, the focus of this section explains the CT investment pattern of 1990-2002.

Figure 8. Gas CT Capacity Additions by Region, 1990-2013 (MW)



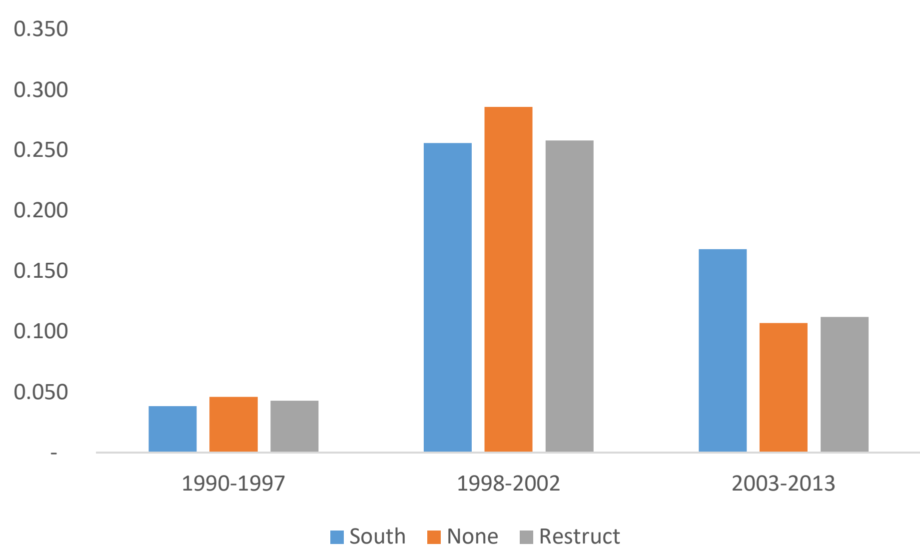
Source: EIA (2016)

Given the significant spatial variation between three groups of states (Restruct, None, South) in the CCGT, the CT buildout would be assumed to follow a similar pattern. Figure 8 shows

[54] This effect is apparent in the results in Table 5.

this variation in CT plants. There are some differences between the groups of states, with the None buildout being smaller in magnitude and scale compared with the buildout by the other two groups. However, CT expansion is influenced by ERS growth in the period. Figure 9 controls for this by showing the change in the ratio of Gas CT capacity to the change in ERS in three time periods. After this adjustment, there is no clear difference between the groups in the first two periods, with the South adding more CT plants in the third period as the only slight deviation. This result is in sharp contrast with the CCGT buildout, which was most heavily concentrated in the Restruct states. Combined with the results from Table 5, it's apparent the CT buildout was a national trend and the focus should be on changes at that level.

Figure 9. Gas CT Ratio by Time Period, 1990-2013



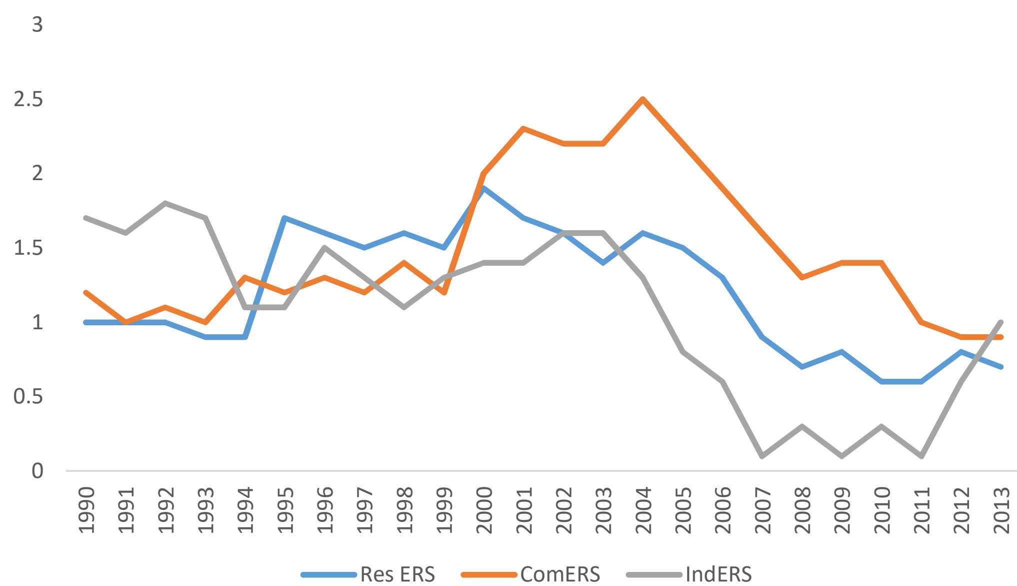
Notes: Ratio constructed by comparing Gas CT and ERS additions. Source: EIA (2016)

Focusing on the national trend, there are three factors that influenced the utilities' and IPP's decisions to construct a large number of CT plants beginning in 1995: 1) a change in residential demand growth forecasts by utilities. 2) Falling relative natural gas price expectations and 3) the impact of the drop in ERS growth starting in the late 1970s. The combination of these factors influenced both the timing and the magnitude of the CT capacity buildout.

Gas CT power plants are built to meet peak load. For most utilities, this occurs during the summer in the late afternoon and early evening.[55] These are the hours of the day where residential demand peaks, as families return home and turn on the lights, TV and air conditioning. Therefore, investment in peaking plants by utilities is sensitive to changes in residential retail sales expectations (EIA 1995). On the other hand, increases in commercial and industrial ERS flatten the load curve, as they peak during the late morning and early afternoon.

Figure 10 shows two trends which significantly impacted the investment behavior of utilities. The first is the increase in residential ERS growth expectations starting in 1995, which coincided with a drop in expectations about the growth of industrial ERS. This would reduce demand during the day and expand it as evening approached, increasing the need for peaking plants. The second trend is the large increase in commercial ERS growth projections starting in 2000 and the beginning of the decline in residential ERS growth projections. The combination of these factors would have flattened the load curve and reduced the need for peaking plants.

Figure 10. EIA 25 Year Projections of ERS Growth by Sector, 1990-2013



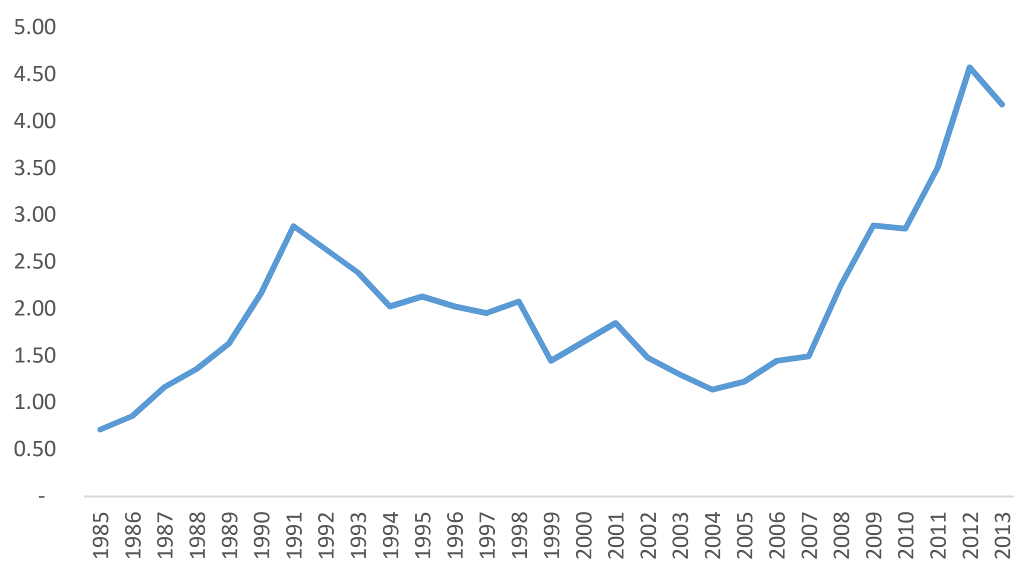
Source: EIA (2016)

[55] While northern US states experience a surge in energy demand in the winter, due to heating, this is largely met through natural gas and propane (EIA 2016).

The timing of both trends fits the CT investment pattern in the previous figures. Low residential ERS and high industrial ERS growth projections in the early 1990s coincided with only marginal investment in CT plants. The boom period of CT construction coincided with the increase in residential ERS growth projections and the decrease in industrial ERS growth projections. Finally, the end of the CT boom coincided with the increase in commercial ERS growth projections and the decline in residential ERS growth projections.

A second factor influencing CT capacity expansion was the change in relative price expectations between older oil and gas steam plants and newer combustion turbine plants. Figure 11 shows the change in the levelized fuel cost of oil and natural gas, beginning in 1985.[56] A high number implies utilities are more likely to switch from oil to gas, while a low number implies more oil and less gas. The acceleration of this ratio in the 1980s led to a value above 2 from 1988 to 1998, which influenced utilities to consider construction Gas CT plants and decommissioning oil plants. While the ratio is not the only factor in the decision to build Gas CT, it significantly influenced the decision-making of utilities (EIA AEO 1996).

Figure 11. Oil to Gas Levelized Fuel Cost Ratio, 1985-2013



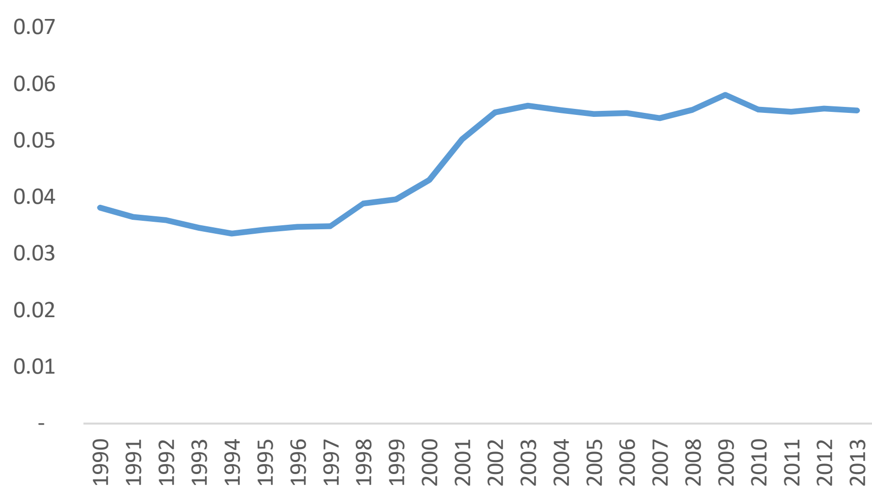
Notes: Switch from steam to CT for gas peaking assumed to occur in 1990. Source: EIA (2016)

[56] This is not a ratio of annual fuel prices, but rather includes projections on what the EIA's best estimate of future prices is. Each is converted from mmBtu to kWh to reflect different heat rates. CT plants are assumed to be available beginning in 1990. The ratio is mostly being driven, however, by changes in the fuel prices themselves.

Despite changes in ERS sector projections, an increase in ERS growth and an increase in the oil to gas fuel ratio during the 1990s, the lack of investment in the early 1990s and the size of the CT boom are not fully explained. The EIA AEO publications in the late 1980s and early 1990s mention repeatedly the hesitancy of utilities to invest in further capacity, even if only for peaking, due to the excess capacity they were left with after ERS growth changed in the late 1970s. This explains the lack of investment in the early 1990s and, due to both the increase in demand and the falling capacity ratios, explains why a surge in CT investment would occur in the mid-1990s.

The nature of other investment booms in electricity generation (coal and gas plants in the 1950s, nuclear in the 1970s, and Gas CC in the 2000s), the uncertainty of relying on ERS projections and the inevitable coordination failure lead one to believe the investment pattern will often be more uneven than the optimal. However, looking at peaking ratios in Figure 12, it appears they reached their highest point in 2002 and have stayed relatively consistent since that time.[57] This suggests that the amount of CT capacity added in the late 1990s and early 2000s was close to the amount utilities required.

Figure 12. Estimated US Peaking Ratio, 1990-2013



Notes: Assumption that oil and gas steam units are used for peaking. Source: EIA (2016)

[57] The peaking ratio consists of the capacity of oil and Gas CT plants divided by ERS. While this is not a perfect peaking measure, as CCGT and older gas steam plants are often used for peaking, it is a strong first approximation and provides insight into the time trend of peaking capacity in the US.

The combination of changes in sector ERS growth projections and the relative fuel cost of natural gas, along with the impact of the excess capacity experience of the 1980s, explains the CT construction boom of the late 1990s and early 2000s. This boom was a national trend, with little difference between the South, None and Restruct groups of states. Following the end of the CT capacity expansion, the estimated US peaking ratio has stayed relatively constant, implying that, unlike the CCGT boom, the desired number of CT plants were built.

6. Entry Model Analysis

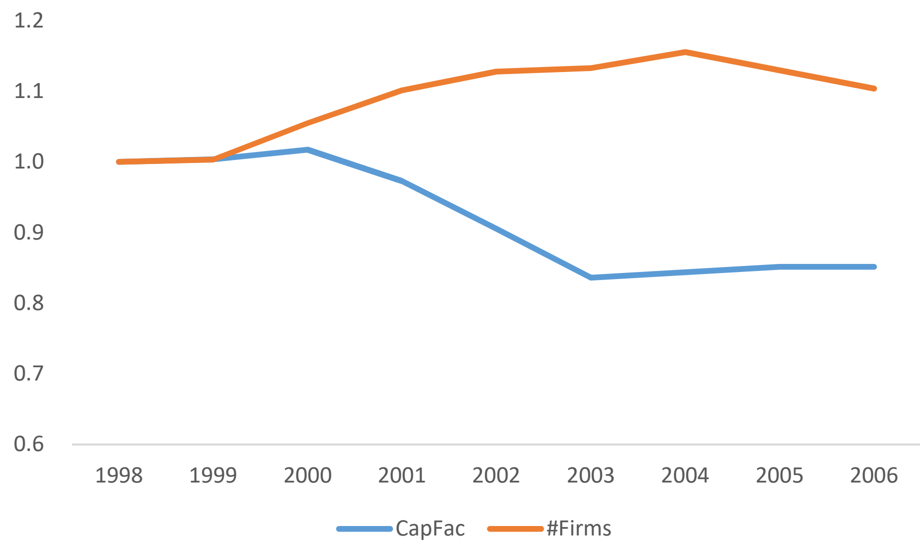
Section 5 presented substantial evidence that restructuring led to overinvestment in CCGT capacity. However, this result is at odds with many economists' conceptions about firm decision-making and operations. For example, in the First Welfare Theorem, free entry is a prominent condition. Additionally, firms are thought to make investments in order to maximize profits. Yet not only did the restructured state capacity ratio exceed those for the two non-restructured groups, but in fact reached a 24 year high. How was it possible for electricity markets with free entry to provide the incentive for so many firms to invest beyond the optimal amount? Section 3 presented four models that provided a structure for analyzing this question. Each of those models generated testable predictions in order to determine which most closely is associated with the events of the electricity industry starting in the late 1990s. This section presents results to test these predictions and identify which model consistently explains the large investment boom in CCGT power plants from 2000-2006.

6.1 Model 1: Business-Stealing

The component of this first model which drives its predictions is the existence of profits from imperfect competition, which encourages entry. As shown in Mankiw and Whinston (1986) and others, excessive entry will occur and social welfare will be reduced due to too many firms paying the fixed cost of entry. In the electricity context, the corollary is plants being built and not used at full capacity. If this model is correct in explaining entry into restructured electricity markets, the following must be true: 1) Output per firm falls as the number of firms increases. 2)

Entry reaches an equilibrium where variable profit approaches fixed cost. 3) There is idle capacity in the industry following entry.

Figure 13. Firm Entry and Capacity Factors in Restructured States, 1998-2006



Source: EIA Form 860 (2016) and Author's Calculations

Figure 13 shows the average capacity factor for all restructured states and the number of electricity producing firms in operation in that year. The table shows the steep drop in output per plant starting in 2001 and continuing until 2005. These are the peak years of the boom and the number of firms reflects the level of entry in this period. This result suggests the demand for electricity was insufficient to purchase the electricity capable of being produced by the firms in the industry. This result confirms a key assumption in the Mankiw and Whinston analysis.

The second prediction has a critical impact on the results. Firms are making the profit-maximizing decision to enter the industry. In order for this model to represent the electricity industry at this time, observed firms must earn a non-negative profit. However, this prediction is contrary to the evidence in this period. The string of high-profile bankruptcies in the electricity industry in the mid-2000s showed that not all firms which invested in this market were making profit. The number of entrants, therefore, was not only above the socially optimal level, but also above the level which could be profitably sustained by the industry.

The third prediction is consistent with the primary finding of this paper, which is restructured states experienced excessive entry that led to idle capacity. The results in Table 1 clearly show this result. Capacity factors fell to a two decade low, as there was insufficient demand to use the created capacity, and have yet to recover.

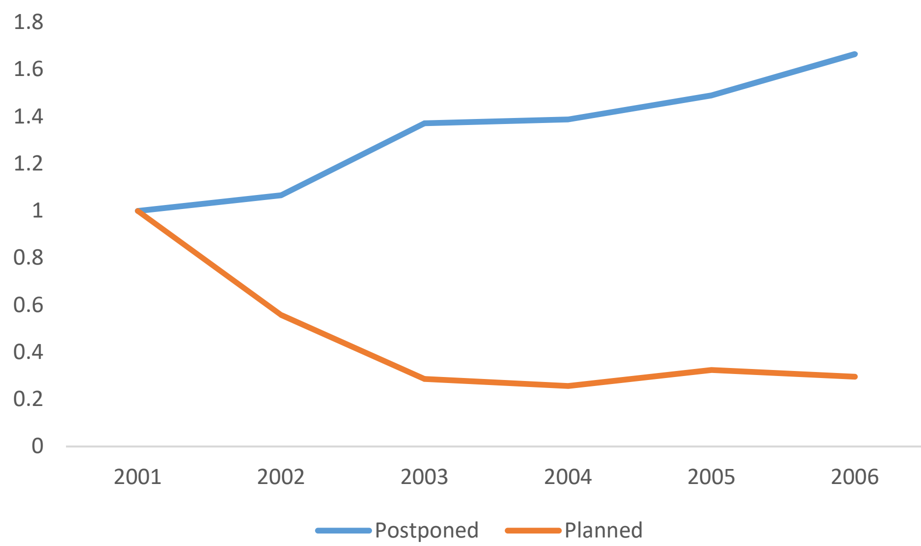
While two of the Business-Stealing model predictions were correct, the third shows the limits of this model in explaining the investment boom. Long-run profits in the industry were not sufficient to support the level of entry in this period. In particular, the Business-Stealing model fails to account for dynamics in entry and exit. The model makes no predictions regarding the path of investment, but rather describes the equilibrium and provides an explanation for how it's reached. In order to explain the timing of entrance and exit, a more robust model is needed.

6.2 Model 2: War-of-Attrition

There are two features of the War-of-Attrition model which set it apart and drive its results. The first is the nature of entry, which is simultaneous. When firms enter, they do so without knowing who else has entered at that time. The second is the investment path, which requires firms to make new cash outlays for several periods prior to entering the market. These model specifics lead to the following three testable predictions: 1) As the market adjusts to new capacity coming online, new investment will stop but ongoing investment will be completed. 2) Firms that have completed their investment will earn non-negative profit. 3) Entry leads to excessive investment spending, as firms invest simultaneously.

The first prediction of this model concerns investment patterns. If the electricity market follows a War-of-Attrition model, market operations lag investment decisions. This implies that firms make decisions in each period whether or not to continue investing if there was a change in market conditions. Given the bankruptcies and market turbulence beginning in 2005, Figure 14 would be expected to show a sharp drop in planned investment and an increase in postponed investment following 2005. However, planned investment fell quickly after a peak in 2001 before stabilizing in 2003. Postponed (or cancelled) investments jumped in two periods, one after 2002 and then again following 2005. While the postponed portion followed the predictions of the model, the planned part differed substantially. Using this data, the model would have predicted the boom was coming to an end by 2003 instead of 2006. Therefore, this prediction contradicts the model.

Figure 14. Investment Planning in Restructured States, 2001-2006



Source: EIA (2016) and Author's Calculations

The second and third predictions are similar to those made in the Business-stealing model. Firms that operate in the market should earn non-negative profit and the lumpiness and timing of firm investment guarantees that some investment spending will not be used. As in the Business-Stealing model, the third prediction is supported by the evidence in this paper, but the existence of large-scale bankruptcies invalidates the second.

The War-of-Attrition model is a dynamic model of entry and exit, where firms are able to react to investment in prior periods and make a decision on the completion of their current project. It's able to explain how excessive entry could occur, but fails to explain the bankruptcies in the mid-2000s, rapidly declining capacity factors and the length of the boom. If this model is correct, firms would have reacted to declining capacity factors by suspending their projects. Instead, the boom continued through 2006. Similar to the Business-Stealing model, this model fails to account for the length of the boom.

6.3 Model 3: Contagion

The Contagion Entry and Exit model is the first encountered thus far with a sequential entry setup. Firms are able to observe entry in the previous period and update their decision framework. The key component of this model is the awareness of firms that they operate in an incomplete information framework. With the market newly restructured, firms must derive expectations about future prices and entry based on limited history. With uncertain fundamentals, firms are subject to fads and herd behavior. Seeing a surprise number of firms enter the electricity industry, in this case, increases the incentive to invest, as firms believe others may have better information. This model, based on surprise entry and exit, provides three testable predictions: 1) Firms continue to invest in markets where large investments have already been made. 2) Exit occurs by firms previously producing in the market if there are changes in price or cost fundamentals. 3) Outside-of-fundamentals decision-making leads to excessive entry.

One of the unique features of the boom is how long it lasted. Large-scale plant construction started in 1997 and continued until 2006. One of the failures of the previous two models was in explaining the length of the boom. Why, for example, would firms continue to build power plants after seeing other large plants already under construction or in operation? The answer, according to the Contagion model, is that firms saw this as a signal that there were opportunities for profit in the electricity market. As more plants began to go online in the early 2000s, this surprise number of firms entering the industry encouraged investment, as opposed to discouraging it. Therefore, the evidence from the early 2000s is consistent with this portion of the Contagion model.

Of the three models discussed thus far, the Contagion model is the only one to predict exit by loss-making firms. The reasoning is fairly clear. As firms began to rely on fads instead of fundamentals, the market became saturated with electricity producing firms. Each of these firms hoped to take part in what was clearly an industry on the rise. However, if they had stuck to a fundamental analysis, firms would have realized that there was insufficient demand to use all the capacity created. The result was shrinking margins and bankruptcies, which began in earnest during the rise in natural gas prices in the latter half of 2004. The existence of these firm failures is consistent with the Contagion model.

The Contagion model, like the previous two, predicts more firms will enter than optimal. There is a diverse literature in economics on bubbles, herd behavior, and firm failure[58] which shows how straying from fundamental analysis can lead to more investment than is socially optimal. The findings of this paper, that investment in restructured markets was more than optimal, are also consistent with the Contagion model.

[58] See, for example, Barbarino and Jovanovic (2007).

This model is consistent with what occurred in restructured electricity markets starting in the late 1990s. In particular, it provides an explanation for the most perplexing issue in this paper, that firms continued to invest even after observing the large power plants either already built or in progress.[59] Any basic fundamental analysis would have concluded that capacity factors would fall significantly, which is what occurred. Lower capacity factors would make it difficult for firms to pay the cost of capital construction. However, if firms did not follow a fundamental approach, entry would continue. Given the events in the telecommunications, technology and housing markets in this time period, this should not be surprising.

6.4 Model 4: First-Mover

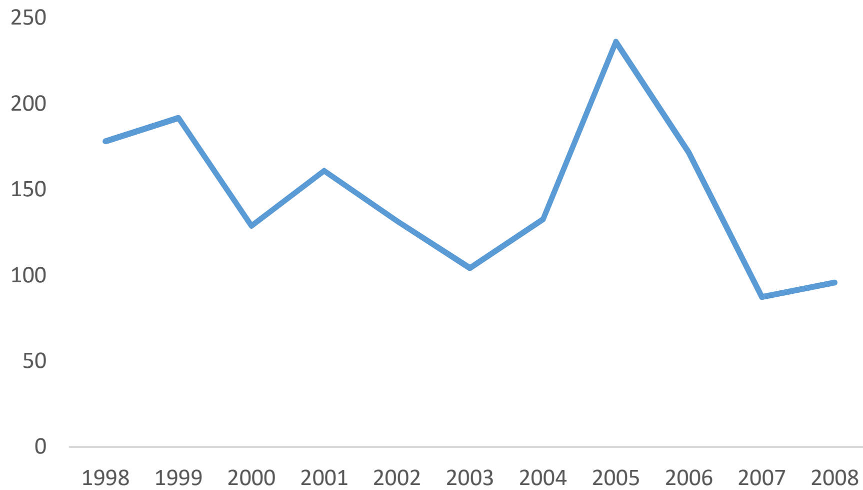
In the electricity generation sector, investments in power plants are often lumpy due to economies of scale. As a result, a firm could gain an advantage by entering a market early and making a large upfront investment. In order to prevent entry, a firm would overinvest to convince other firms that entering the market will only incur losses. Once other firms decide not to enter the market, the firm(s) that overinvested early would then have a degree of market power. If this model is consistent with the investment boom period, the following three predictions must be true: 1) Early entrants make large investments. 2) Investments from entrants exceed the optimal amount due to excess entry. 3) Following restructuring, there is a large amount of entry followed by a sharp drop in investment.

Figure 15 shows the average size of non-renewable plants started in each year from 1998-2008.[60] If the first prediction of the model is correct, the first plants in states that were restructuring their electricity markets should have been large to prevent entry. As the figure shows, the plants started in 1998 and 1999 were larger than the average through the boom, but smaller than those that were started in 2005 and 2006. However, the small difference in average capacity size between the first two years and those that followed was unlikely to convince other firms not to invest. Additionally, this model doesn't explain the rise in investment size in the final years of the boom.

[59] Unlike models of simultaneous entry, the Contagion model doesn't rely solely on a coordination failure. If the boom were caused only by a coordination failure, it would not have stretched into 2006.

[60] Renewable plants were excluded because they tend to be small and are not built as an investment deterrent.

Figure 15. Average Built Power Plant Capacity (MW) in Restructured States



Source: EIA (2016)

While the first prediction of the first-mover model is not consistent with the nature of the investment boom, the second prediction is. The model predicts that firms will overinvest early, leading to excess capacity in an attempt to prevent future entry. This paper has shown that excess capacity did develop, although the length of time in which it occurred suggests firms were motivated by factors other than investment deterrence. This is the essence of the third prediction, which forecasts excess capacity developed early in the boom, followed by severely diminished investment. While there were large net capacity increases in CCGT plants early in the boom, there were still significant investments later. This is inconsistent with the third prediction.

The First-mover model does not resemble the nature of the investment path during the boom. Despite the high-profile case of Enron attempting to use its market share in the California market to exact rents, there is little evidence that plants were constructed to gain market share. As with the first two modes, the failure of the First-mover model is in its inability to explain why net CCGT net capacity grew in the later years of the boom (2004-2006). By this time, any advantage of early entry in the market would have been exhausted.

6.5 Conclusions from Model Predictions

The combination of the size and length of the investment boom contributes to the difficulty in explaining the US Gas Boom. Had the boom been the same size but much shorter, the explanation would have been simple. Simultaneous entry leads to coordination failure, and once firms discovered the size of the investment, entry would have continued at a smaller, sustainable rate.[61] Economies of scale in power plant construction[62] and the importance of future price and demand expectations in entry decisions make the electricity industry particularly vulnerable to problems of coordination. For decades, vertically integrated public utilities acted as important collectors of private information and expertise, which were not easily duplicated by new entrants. Additionally, as noted in Camerer and Lovallo (2000), excessive entry in the early stages of a new industry can occur due to the overconfidence of inexperienced managers in their own abilities. While a coordination problem could theoretically lead to inefficient entry in either direction, the presence of ISO reserve margins ensured the only inefficient entry would be excessive.

The events that transpired in the electricity industry in the late 1990s and early 2000s support the hypothesis that a coordination problem existed. Industry professionals during the early 2000s noted that IPPs were unaware of the over-build in capacity and slowdown in ERS, which led them to react strongly to previous profit margins.[63] In the mid-2000s, large amounts of capacity came online, electricity demand declined and natural gas prices rose, causing profit margins to shrink. This lead to the bankruptcy of several large IPPs, large-scale fire sales of assets by power suppliers, and a significant decline in new power plant investment. In states that maintained regulated markets, these problems were not apparent, as large utilities were better situated to balance changes in demand with new supply coming online.[64]

The length of the boom, however, entails an explanation that goes beyond a coordination problem. Any firm operating under a fundamental approach would have stopped investing once they observed large entry. Instead, investment continued in these markets until a profit squeeze due to a natural gas price spike started a string of bankruptcies. As summarized in Table 6, this matches what the Contagion model predicts. Whether because of lack of faith in available market information or overconfidence in the decision-makers abilities and information (Camerer and

[61] This explanation is not inconsistent with entry and exit findings in new product markets (Klepper and Miller 1995).
[62] While gas-fired power plants are more flexible in size than coal or nuclear plants, there is still efficiency in larger sized plants, particularly for CCGT (MIT, 2011).
[63] See Wharton (2006) for an overview of the industry during this time period and the entrance of new firms. The role of regulatory uncertainty was also noted as a factor in the turmoil of an industry that had previously been relatively predictable.
[64] While the experience of the 1980s shows that utilities are not immune from improper demand forecasting, their information on generation and transmission assets allows for a more efficient transition.

Lovallo 1999), firms abandoned a fundamental analysis and invested based on fads. In this case, the fad was taking advantage of newly deregulated electricity markets. This shift in business strategy led to excess capacity in restructured states.

Table 6. Model Prediction Outcomes

Predictions	(1)	(2)	(3)
Business-Stealing	✓	×	✓
War-of-Attrition	✓	×	✓
Contagion	✓	✓	✓
First-Mover	×	✓	×

While the combination of a coordination failure and contagion effect were the most important factors in the gas boom, it's important to note the period in which this took place. The gas boom took place in the US at the end of the Dot Com bubble and throughout the housing bubble. This is not a coincidence. The period 1998-2006 was one in which there was a change in the nature of global financial markets. Prior to 1998, large investments were made in the South American and East Asian economies. However, the experience of the Latin American Debt Crises, the Tequila Crisis in Mexico, the Asian Financial Crisis and the contagion which followed in Latin America, South America and Russia shifted the flow of global credit away from emerging markets and into the developing markets of Eastern Europe and the developed markets of Western Europe and the United States (Eichengreen, 2008). This flow was magnified by increased saving and reduced investment by the previously booming Asian economies, largely in response to perceived exchange rate vulnerability. The effect of these changes lowered real interest rates in the United States and was dubbed the "Asian Savings Glut" by Ben Bernanke (Bernanke 2005). The lowering of global real interest rates led to a flow of cheap credit to investment projects in many developed countries, including the US. At the same time, a combination of deregulation, a booming economy, and the introduction of new technology created a large number of investment opportunities in the United States. These opportunities were reflected in rapidly increasing asset prices in the United States in the late 1990s and early 2000s.

The link between long-run interest rates and investment is well-founded in the economics literature (Mundell 1963). As interest rates decline, more investment projects are profitable and an investment boom occurs. As Caballero et al (2008) notes, there appears to be a well-founded relationship between lowering global interest rates and increased investment in U.S. assets. In the electricity industry, declining expectations about long-run interest rates lowers the cost of capital for building new power plants. This increased profitability encourages more entrants into the electricity industry, in particular those whose projects may be more risky and less profitable in the long run. This leaves the industry open to speculation and risk-taking, with excessive entry being one of the effects. However, if rates begin to rise, firms will begin to fall out of the industry.

Much has been written about the subsequent bubbles in telecommunications, technology and housing, but the availability of cheap credit and deregulation were also factors in the rapid expansion of investment in the electricity industry (Financial Crisis Inquiry Commission 2011; Mian and Sufi 2014). Nominal 10-year sovereign yields for European and North American countries averaged nine percent in 1995 and four percent in 2003 (CEA, 2015). Industry insiders cite cheap credit as facilitating the investment projects by IPPs (Wharton, 2006). The collapse of Calpine, a large builder and operator of gas-fired power plants, was partly attributed to excessive borrowing during a period where credit was cheap (Tansey 2005).

However, low interest rates, by themselves, do not necessarily lead to excessive entry. The previously cited interest rate has averaged between two and three percent for the past five years without any substantial increase in electricity investment.[65] Utilities in regulated markets also faced similar interest rates in the late 1990s and early 2000s without responding by over-investing in power plants. While low interest rates contributed to the large increase in investment during this time period, they are more likely one of several factors than a primary cause, with restructuring providing an environment for low interest rates to spur investment.

7. Alternative Specification Tests

Section 5 presented evidence of electricity market restructuring leading to a boom in CCGT power plant construction, which exceeded the capacity required to meet demand. To provide further support to this result, a series of alternative approaches are presented which eliminate potential confounding concerns. These include a synthetic control approach, restricted data sets, and modifications to the LHS and RHS variables.

[65] The one exception is in renewable generation, which is largely due to state RPS agreements (Powers and Yin 2010).

7.1 Synthetic Control

The staggered and incomplete adoption of restructuring by states created a reasonable counterfactual for the restructured states. However, synthetic control constructs the counterfactual in a more precise manner. Applying the method present in the literature to electricity markets (Abadie and Gardeazabal 2003; Abadie et al 2010; Buchmueller 2011; Bohn et al 2014), states are divided into restructured and donor groups. For each restructured state, the goal is to construct a counterfactual state from the donor group which shows the amount of CCGT capacity that would have been added in the restructured state if restructuring hadn't occurred. Following the notation in Abadie et al (2010),[66] the change in CCGT capacity can be written in the following way:

$$Y_{it} = Y_{it}^{N} + \alpha_{it} D_{it}$$

Y_{it} is the change in CCGT capacity for restructured states in each year, Y_{it}^{N} is the counterfactual change in CCGT capacity for each state and year, and α_{it} is the impact of restructuring on investment in CCGT capacity. Calculating α, which is the primary goal of this paper, requires knowing Y_{it}-Y_{it}^{N}. Y_{it} is known, leaving only Y_{it}^{N} to be estimated. Estimating Y_{it}^{N} requires three inputs: 1) Important factors which influence changes in CCGT capacity; 2) The relative importance of each of those factors; 3) The weighting of each state in the counterfactual.

The important factors in changes in CCGT capacity, X, are used to match restructured states with the states which they most closely resemble prior to restructuring. These factors are selected from insights in the industrial literature and from the structural model presented in chapter 5 and include ERS projections, capacity to ERS ratio, variance ratio and capacity mix ratios for relevant fuels like coal, gas, nuclear and hydro. Once collected, the importance of each of these factors, V, is estimated by minimizing the mean square prediction error of the change in CCGT capacity prior to restructuring. V is estimated in order to not impose the restrictive assumption that all factors equally affect the outcome variable. Finally, the weights of each state in the counterfactual are solved for by finding W* that minimizes $(X_1\text{-}WX_0)'V(X_1\text{-}WX_0)$, where X_1 is the set of factors for the restructured states and X_0 the set of factors for the non-restructured states. As with the estimation of V, this step ensures the process does not rely on the assumption that all

[66] The explanation provided in this paper is only meant to apply the synthetic control method to the specifics of electricity markets, as that is the contribution of this paper. Those interested in a more robust statistical explanation should consult Abadie et al (2010).

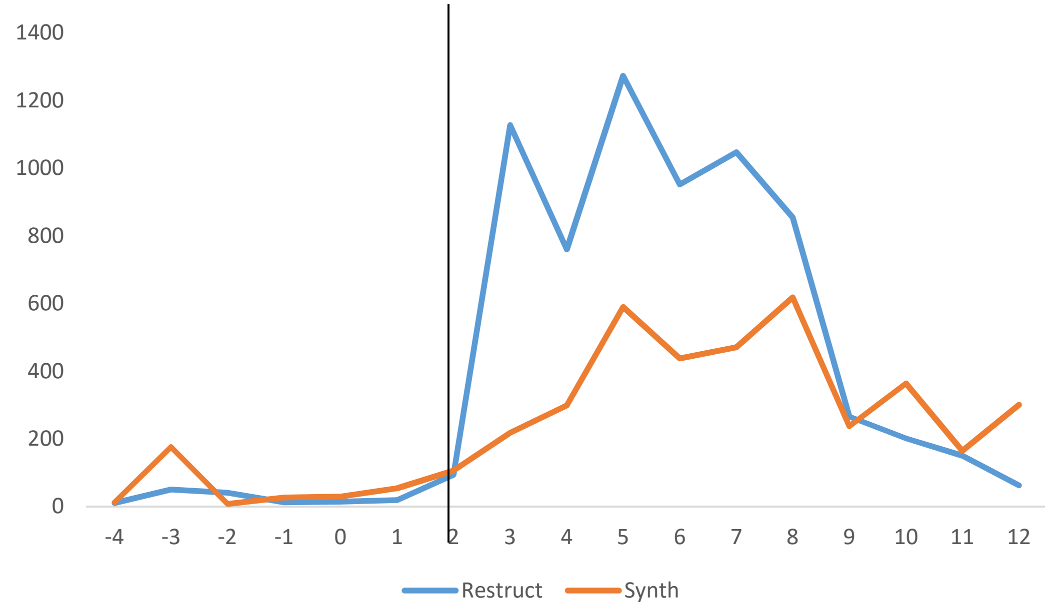
the chosen counterfactual states are of equal importance. Once the weights are calculated, a counterfactual state is formed for each restructured state and α_i is measured.

Estimating the synthetic control group requires choosing the correct Y to be estimated. In previous studies, the outcome variable has been for one state or region. However, one of the strengths of this paper is the adoption of restructuring by multiple states at different time periods. Therefore, there is not one state for which to construct a counterfactual, but several. This leaves the researcher two options: estimate the average of each individual state's synthetic control or the synthetic control of the average restructured state. In this case, these two are not identical, as restructuring occurred at different times for different states. For example, combining California, which restructured in 1995, with Maryland, which restructured in 1999, would provide a skewed synthetic control. Additionally, the restructured state electricity markets have significant differences in capacity choices and demand profiles, which create separation with the average restructured state. Therefore, a synthetic counterfactual is estimated for each state, with the average effect then calculated and reported. In this estimation, the other restructured states were left out of the donor group for each restructured state. Given that they also received the treatment, they would be unable to provide counterfactual estimates.

7.1.1 CCGT Synthetic Control

The factors included in estimating CCGT capacity were the same as those used in Section 5. However, in Section 5 the weights of all the non-restructured states were equal in the counterfactual. In this method, states received different weights based on factor proximity. Each restructured state was weighted differently to reflect differences in factor values and then averaged together to provide the results in Figure 16 and Table 7.

Figure 16. Average Restructured and Synthetic Control CCGT Capacity Addition (MW)



Notes: Running variable is years since state started restructuring electricity market. Source: EIA (2016)

Figure 16 shows the average net capacity, in MW, added annually in each restructured state compared to the estimated counterfactual. The treatment, restructuring of the electricity market, begins at time zero but is lagged three years. Following restructuring, there is a substantial departure between the outcomes for the two groups. As the synthetic counterfactual illustrates, restructured states would have been expected to significant CCGT capacity in the decade following restructuring. However, the actual amount added in the period following restructuring greatly exceeds the counterfactual. These capacity additions drop considerably in years 8 through 12 and are then under what is estimated in the counterfactual.

Table 7. Restructured and Synthetic Comparison Measures

Time Period	Difference	Other	DD
Period 4	642.8	-6.8	649.6
Period 5	629.6	-39.3	668.9
Period 6	564.2	-55.5	619.7
Period 7	487.7	-60.8	548.5
Boom	473.8	-54.7	528.5

Notes: Period= # of years of the buildout following the three year lag. Boom is 2000-2006. Source: EIA (2016)

Table 7 compares the synthetic control results with several others in this paper. The first column shows the amount of CCGT capacity (MW) added in restructured states compared to the synthetic control for the period defined by the variable. The second column show the same calculation for the years outside the period specified. The third column is the difference between the two, or the difference-in-difference. The main specification of Section 5 is shown in the DD result of the variable Boom. This is similar to what was estimated in the OLS specification presented earlier.

The period results are included to accurately measure the restructuring period, as not all states started restructuring in 1997.[67] The first column period 4 result shows the average difference between capacity added by restructured states and capacity added by synthetic counterfactual states for four years after restructuring. Periods 5, 6 and 7 show this result for five, six and seven years after restructuring. The second column shows this difference for the years outside of the specified period. The results suggest, while the boom was largest in the early years following restructuring, it did not begin to decline substantially until seven years after restructuring.

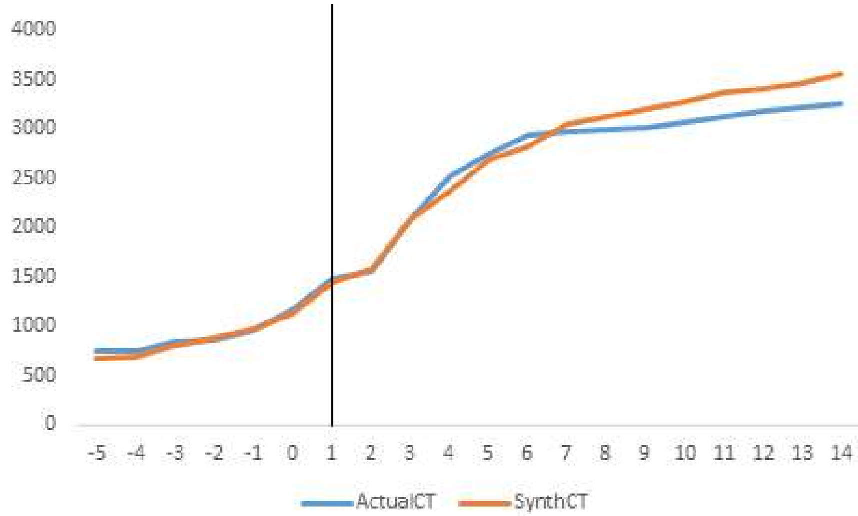
These results are consistent with several of the results found previously in this paper. First, restructuring led to significantly larger CCGT capacity additions. Second, the additions have the pattern of a boom, with a period of large capacity additions followed by a sharp decline. Third, the boom lasted for a long time, suggesting that the Contagion hypothesis is correct. Finally, the decline in years 8 through 12 can be seen as an attempt by electricity producers to try to balance supply and demand through a pause in capacity additions.

7.1.2 CT Synthetic Control

The factors used in the estimate of the change in CT capacity in Section 5 are slightly different in this section due to a change in the estimation variable. Due to their decreased investment period and sensitivity to natural gas prices, capacity additions on the annual level are not a useful dependent variable in synthetic control. Total CT capacity is both more meaningful and easier to measure. Therefore, estimation includes all the previous variables as well as a measure of previous investment.

[67] This is consistent with the assumption throughout the paper that CCGT construction takes three years.

Figure 17. Average Restructured and Synthetic Control Total Gas CT Capacity (MW)



Notes: Running variable is years since state started restructuring electricity market. Source: EIA (2016)

Synthetic control has matched restructured and synthetic states well prior to the start of the treatment (Figure 17). The close relationship between the two continues after restructuring, suggesting that restructuring did not change investment in gas CT plants. However, beginning 7 years after restructuring, the difference between the average restructured and synthetic state in Gas CT capacity widens by a small amount. This suggests that restructured states later in the study time period experienced reduced Gas CT investment, relative to what they should have without restructuring. The interpretation of the small gap during this time period is there was an effect in bidding markets of the large number of CCGT plants on CT plant construction.

7.1.3 A New Approach to Synthetic Control

To date, this study represents a new use of synthetic control, both in its use of multiple treatment states and its application to the electricity sector. Prior to this paper, synthetic control was used for one treated group, like the state of California in Abadie et al 2010. As mentioned previously, this is a complication for multiple treatment groups, as combining the restructured states into one group and estimating the synthetic control is not a robust method of estimation. The strength of the approach taken here is it allows each state to have its own counterfactual. These counterfactuals are estimated using state-specific predictors, rather than a one size fits all approach. As a result, this paper doesn't suffer from the estimator problems inherent in time-series analysis.

7.2 Alternative Specifications

The thesis of this paper is not that restructuring led to a permanent increase in generating capacity, but a temporary surge which declined as time passed. The primary specification structure reflects this dynamic trend between periods. However, a simpler way of identifying this effect, which can be used to analyze changes in specification, is to separate the period 1990-2013 into the boom (2000-2006) and non-boom (all other years). The interaction between the time period and restructuring allows the impact to be separated by restructuring and time period. In Table 8, the restructuring variable refers to restructured states in years outside of the boom, the boom variable refers to non-restructured states during the boom, and the interaction refers to restructured states during the boom. Each of the following specification are based around this structure.

Table 8. CCGT Buildout Alternative Specifications, 1990-2013

	(1)	(2)	(3)	(4)	(5)	(6)
Restruct	332.66***	25.94	16.37	25.59	2.9	-20.88
	(111.96)	(71.98)	(72.55)	(75.33)	(111.08)	(91.42)
Boom		563.24***	200.27	215.76*	325.99***	274.84**
		(191.42)	(116.35)	(118.32)	(104.39)	(131.29)
RestructxBoom		587.59**	577.17**	581.04**	286.26**	551.94**
		(230.80)	(226.42)	(235.00)	(123.64)	(258.26)
CapRatio	-324.37***	-291.67***	-277.58***	-281.69***	-253.93***	-267.46***
	(83.68)	(82.96)	(79.74)	(81.29)	(123.64)	(87.87)
ERSproject	15.3**		13.96**	12.3**	15.93**	14.22**
	(6.55)		(5.95)	(5.67)	(6.80)	(6.39)
Varratio	21.87***	13.85**	21.5***	22.14***	23.27***	24.79***
	(7.61)	(5.55)	(7.03)	(7.23)	(7.40)	(8.06)
gascoalratio	-6.44		-4.33	-10.85	-11.88	-13.83
	(14.54)		(13.38)	(11.27)	(13.05)	(22.29)
FE	Y	Y	Y	Y	Y	Y
Obs	1050	1050	1050	1029	1050	1050
R^2	0.14	0.16	0.17	0.16	0.15	0.21

Source: EIA. Dependent variable is change in CCGT capacity (MW) except in column 6, which is change in total gas capacity (MW). *** significant at .01 level. ** significant at .05 level. * significant at .1 level

Column 1 shows the results of this study if the interaction with the boom is not included. This is measuring the impact of restructuring on CCGT investment across the entire time period.

Not surprisingly, this is large in both magnitude and significance. However, this specification doesn't provide insight into investment path. Column 2 adds the interaction term, showing the significant impact of restructuring on CCGT investment during the boom period. However, demand projections and cost ratios are excluded from the analysis to show their importance in explaining the boom variable, which is the amount of CCGT capacity added in non-restructuring states during the boom. This effect is large in magnitude and significant, suggesting the model is not sufficient in explaining the increase in CCGT capacity in all of the states. Column 3 includes the missing two explanatory variables to show their effect on the boom variable, which is no longer significant. This is evidence that changing demand forecasts and the declining levelized cost of gas were significant in CCGT expansion outside of restructured states. Column 4 eliminates California from the sample to ensure that the largest state in the country is not significantly impacting the results. There is no evidence of any change from excluding California

Column 5 replaces the restructuring index used in this study with one from Fabrizio et al (2007). The two indices are similar, as described in Section 4 of this paper, with only minor differences in the timing of restructuring for a few states. The table shows a restructuring effect which, while still significant, is much reduced and the boom variable has increased in magnitude and significance. This is not surprising, as the Fabrizio index showed delayed restructuring in several states, which would now be included in the boom group. Section 4 provides an explanation for the preference of the restructuring index used in this paper over that used in Fabrizio et al.

Column 6 replaces the standard dependent variable, which is the change in CCGT capacity, with the change in total gas capacity. This includes any changes to CT and gas steam capacity. This specification tests two predictions of this paper. First, if a boom occurred, it would be in CCGT plants, as their increased efficiency would be preferred by plant owners competing to provide intermediate and baseload power in restructured markets. If this is true, the impact of restructuring on the change in total gas capacity should be less significant than the impact on CCGT capacity. Second, this paper predicts that restructuring leads to overbuilding of CCGT plants. This prediction should show a large impact on total gas capacity that overrides the investment in other gas technologies. The results in column 6 confirm both of these predictions. The impact is still large and significant, but not as much as the impact on CCGT capacity. Additionally, the failure of restructuring to explain the increase in CT investment is apparent in this specification, as the boom variable is large and significant.

8. Welfare Effects of Excessive Entry

When California and Texas started restructuring their electricity markets, a primary argument in favor of restructuring was the expected improvement in welfare. As outlined in Joskow (2008), cost of service regulation (COSR) reduced the incentive for utilities to be cost efficient, increasing the price of electricity for consumers and reducing consumer welfare. Moving away from COSR incentivized utilities to manage O&M and fuel costs in the short run, while in the long run, utilities were expected to choose the lowest cost form of generation. Joskow notes that the most significant impact is in the long run, as the largest portion of the levelized cost of electricity for a utility has traditionally been plant expenditure.[68] As a result, welfare improvements were expected to be substantial. What was not expected, however, was the overbuild that occurred following restructuring. This section seeks to estimate the total welfare impact of the overbuild result found in this paper.

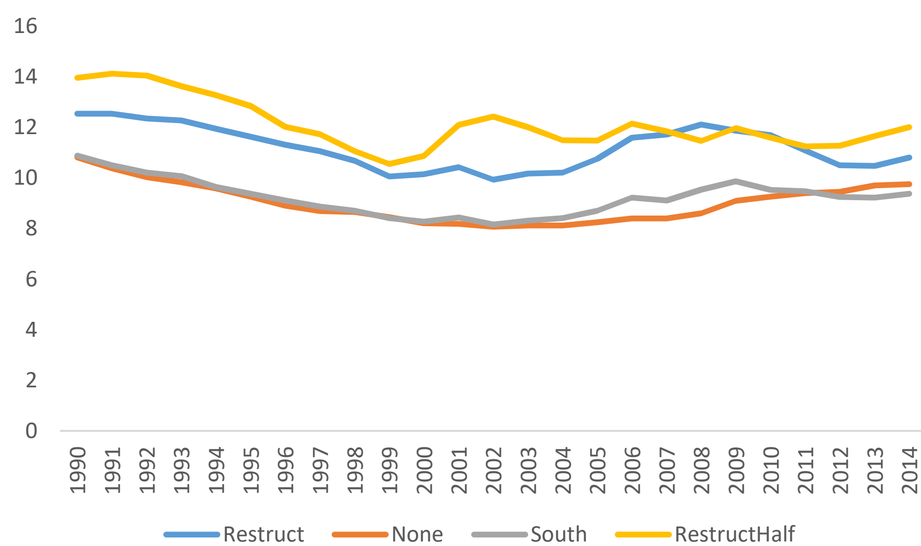
Analysis of the introduction of competition into markets and its effect on welfare has a long tradition, with Schumpeter (1942) among the first seminal contributions. The term "creative destruction" was coined to describe the process of new products and firms replacing older ones. It was assumed that the gains from innovation and price competition outweighed the losses associated with firm failure and malinvestment, increasing total welfare. However, the electricity industry is substantially different from those dominated by new product formation, with the costs of malinvestment potentially very high and the impact of innovation less clear.

When electricity markets opened to retail competition, the number of firms producing electricity in a region increased for two reasons. First, utilities were required to divest large plant capacity to prevent market power formation. Second, this paper has shown that the majority of regions in the US were capacity deficient at the start of the restructuring period, which encouraged entry. Part of this capacity deficiency was intentional, as utilities were deleveraging following the nuclear expansion of the 1970s and 1980s and ERS slowdown of the 1980s and early 1990s. However, the increase in ERS growth in the mid-1990s changed expectations about future growth in the industry, increasing the capacity deficiency in many markets and leading to entry.

[68] While the large-scale adoption of CCGT plants has reduced the capital portion of the cost of electricity, the scale of investment leaves Joskow's point still valid. Additional benefits discussed include insulating electricity generation from politics and increasing retirement of uneconomical plants (Joskow 2008).

The rise in the number of firms should have lowered electricity prices, yet evidence of this effect is lacking. A surprising, but well-known result, is there was not a major change in average US electricity prices following restructuring (Borenstein and Bushnell 2016). Figure 17 shows trends in average electricity prices for four groups: states with restructured electricity markets as of 2015 (Restruct), states that started restructuring but since returned to regulation (RestructHalf), states in the Southeast that never restructured (South), and states not in the Southeast that never restructured (None). As illustrated, the Restruct groups entered the 1990s with higher electricity prices than the other two groups. However, after restructuring occurred in the late 1990s and early 2000s, there doesn't appear to be any convergence among the groups, with each group declining in the 1990s, due to low fuel prices, and rising in the 2000s, due to increasing natural gas prices. The lack of convergence in these groups indicates the benefits of restructuring were secondary to the importance of fuel availability and capacity choice differences between the groups.

Figure 17. Electricity Prices by State Group, 1990-2014



Source: EIA (2016)

8.1 Welfare Problem Setup

There are two markets, Restructured (R) and Synthetic (S), in which firms can choose to operate. Within these markets, there are two goods sold, electricity (x_1) and an alternative good (x_2). In order to produce either good, a minimum investment (X_1, X_2) is required. Any amount,

(Y_1, Y_2), invested beyond the minimum requirement is assumed to go unused. Total investment by each firm, in each period, therefore, is Q=X+Y. It's assumed that firms are able to invest and operate within the same period. Demand for electricity in each region is represented by $D(x_1)$ and demand for the alternative good represented by $D(x_2)$, with $D'(x)>0$ and $D''(x)<0$. Each firm charges a uniform price for each good (p_1, p_2) and earns profit (π_1, π_2) from each good. Total welfare for each market can then be written as follows:

$$W^R = \int_0^{x_1^R} D^R(x_1) - p^R + \Pi_1^R(x_1)dx_1 + \int_0^{x_2^R} D^R(x_2) - p^R + \Pi_2^R(x_2)dx_2$$

$$W^S = \int_0^{x_1^S} D^S(x_1) - p^S + \Pi_1^S(x_1)dx_1 + \int_0^{x_2^S} D^S(x_2) - p^S + \Pi_2^S(x_2)dx_2$$

where $\Pi = \sum_{i=1}^{n} \pi_{it}$ for each good and market. Individual firm profit for each market can be written as follows:

(1) $\pi_i^R = p_{1i}^R x_{1i}^R - \sum_{a=1}^{2} c_{1ai}^R x_{1ai}^R - d_{1ai}^R X_{1ai}^R - d_{1ai}^R Y_{1ai}^R + p_{2i}^R x_{2i}^R - c_{2i}^R x_{2i}^R - d_{2i}^R X_{2i}^R - d_{2i}^R Y_{2i}^R$

(2) $\pi_{it}^S = p_{1i}^S x_{1i}^S - \sum_{a=1}^{2} c_{1ai}^S x_{1ai}^S - d_{1ai}^S X_{1ai}^S - d_{1ai}^S Y_{1ai}^S + p_{2i}^S x_{2i}^S - c_{2i}^S x_{2i}^S - d_{2i}^S X_{2i}^S - d_{2i}^S Y_{2i}^S$

i denotes individual firms, with i = 1,…..,n, t denotes the time period, which in this case is years t = 1,….,T, c the cost of producing a unit of x, and d is the cost of building a unit of X. a denotes which technology is being used to produce electricity (1=CCGT, 2=CT). Prior to reducing the above equations into a welfare function to estimate, the following assumptions are necessary:

Assumption 1: $D^R(x) = D^S(x) = D(x)$

Restructuring doesn't change the value of electricity and the alternative good to consumers.

Assumption 2: $Y^S=0$

Firms in synthetic states do not overbuild capacity in the electricity market. Another way of interpreting this is, there may be overbuilding in regulated markets, but that level serves as a baseline with which to compare the capacity built by restructured markets.

Assumption 3: $d_1^R Y_1^R = d_2^S X_2^S$

The amount ($) firms in restructured markets overinvest in electricity capacity is equal to the amount those firms in synthetic markets could invest in the alternative good. In other words, a full employment economy is assumed where capital is invested in some project, electricity or other.

Assumption 4: $X_1^R = X_1^S$

The amount of capacity needed to meet the demands of the restructured electricity market, before excess capacity is considered, is equal to the capacity needed to meet synthetic electricity demand.

Assumption 5: There are two plant technologies and one fuel type used for new plants.

Changes in the levelized cost of electricity production and length of build time led to over 95 percent of non-RPS plant construction from 1997-2013 to be gas-fired CCGT or CT plants. Therefore, it's safe to assume only CCGT and CT technologies are used for construction and only natural gas is used as a fuel.

Assumption 6: $x_{11} = f(X_{11}, X_{12})$ *and* $x_{21} = f(X_{21}, X_{22})$

Electricity demand can be met by either CCGT or CT plants. While it's more cost effective in the long-run to meet peak load with CT plants and baseload/intermediate load with CCGT plants, the lower marginal cost of CCGT plants allows them to bid lower than the CT plants. This leads to CCGT plants being used for peaking as well if they are sitting idle. While using CT plants for intermediate or baseload needs is less common due to higher marginal costs, it's possible they may be used during unexpected plant outages.

Once these assumptions are implemented in the model and the terms are rearranged (See Appendix 1 for details), the following welfare impacts from restructuring are identified:

$$\Delta W = \int_{x_2^R}^{x_2^S} p_2^S - D(x_2) + \sum_{i=1}^{n} c_{2i}^S x_{2i}^S - p_{2i}^S x_{2i}^S + \sum_{i=1}^{n}\sum_{a=1}^{2}\left(c_{1ai}^S - c_{1ai}^R\right)x_{1ai}^S$$

$$+ \sum_{i=1}^{n}\sum_{a=1}^{2}\left(d_{1a}^R - d_{1ai}^S\right)X_{1a}^S$$

$$+ \int_{x_1^S}^{x_1^R} D(x_1) - \sum_{i=1}^{n}\sum_{a=1}^{2} c_{1ai}^R\left(x_{1ai}^R - x_{1ai}^S\right) - d_{1ai}^R\left(X_{1ai}^R - X_{1a}^S\right)$$

Welfare Effect I: $\int_{x_2^R}^{x_2^S} p_2^S - D(x_2) + \sum_{i=1}^{n} c_{2i}^S x_{2i}^S - p_{2i}^S x_{2i}^S$

This is the total welfare loss from the marginal capital investment in restructured markets not occurring for the alternative good. Investment has already taken place in this market, so the additional investment raises quantity from x_2^R to x_2^S.

Welfare Effect II: $\sum_{i=1}^{n}\sum_{a=1}^{2}\left(c_{1ai}^S - c_{1ai}^R\right)x_{1ai}^S$

This is the change in welfare in the electricity market from improvements in power plant cost efficiency. Several papers in the literature estimated that restructuring reduced fuel and O&M costs for plants operating in restructured markets. Note that it is calculated over electricity demand in the synthetic market. The cost improvements that impacted the difference in electricity demand between restructured and synthetic markets is shown in welfare part V. The papers cited above did not distinguish between these effects.

Welfare Effect III: $\sum_{i=1}^{n}\sum_{a=1}^{2}\left(d_{1a}^R - d_{1a}^S\right)X_{1ai}^S$

This is the change in welfare from the restructuring impact on plant construction costs. No study as of yet has attempted to calculate this differential. As with the previous part, this is only calculated for the capacity built in the synthetic market.

Welfare Effect IV: $\int_{x_1^S}^{x_1^R} D(x_1) - \sum_{i=1}^{n} \sum_{a=1}^{2} c_{1ai}^R (x_{1ai}^R - x_{1ai}^S) - d_{1a}^R \ (X_{1ai}^R - X_{1ai}^S)$

This is the change in welfare from restructuring altering electricity demand due to a change in the price of electricity. The two components of this change are the variable and fixed cost components of electricity production. If restructuring lowered the price of electricity as it was intended to do, consumers would respond by purchasing more electricity, as identified in the difference between X^R and X^S.

8.2 Welfare Impact Estimation

Of the four welfare effects identified above, the focus of this paper is on the impact of excessive entry on welfare, so only I and IV will be estimated. Effects II and III are of interest, but are not directly related to excessive entry.

8.2.1 Effect I

In order to calculate the total welfare change from additional firm investment in the alternative good market, it's worth noting that the economy is assumed to be at full employment. If this is not true, capital not invested in power plants may sit idle. Given that a large amount of the capital invested in the electricity sector originated from financial firms, this capital would otherwise have been invested in the next best alternative. The markets for this capital would most likely have already existed, with the additional amount contributing marginally to the existing market. With no market imperfections assumed outside of the excessive investment in the electricity sector, the increase in consumer welfare would be insignificant and no above-normal profits attainable. Therefore, the total welfare change is essentially equivalent to the net present value of the returns from the investment in the alternative good. This is simplified by summing the following equation over the number of state markets and years (See Appendix 2 for details):

$$\sum_{t=1}^{T}\sum_{s=1}^{S}(1+r)^t r d_{11st}^R (Q_{11st}^R - X_{11st}^S) + \sum_{t=1}^{T}\sum_{s=1}^{S}(1+r)^t r d_{12st}^R (Q_{12st}^R - X_{12st}^S)$$

Construction cost of plants (d) is derived from a mixture of sources detailed in the Data section of this paper, Q_{11}^R is the net CCGT capacity change in restructured states, Q_{12}^R is the net CT capacity change in restructured states, X_{11}^S is the net CCGT capacity change for the synthetic state and X_{12}^{S} is the net CT capacity change for the synthetic state. r is the assumed standard rate of return on capital investments of 10 percent. Since CCGT and CT are substitutes in production, excessive investment in CCGT resulted in insufficient investment in CT, as shown in Section 5 of this paper. As a result, the two equations will have conflicting signs and magnitudes.

Given that power plants, once completed, are a durable investment, there are two underlying calculations. The first is the amount of plants that are still not fully used as of 2013.[69] The second is the cost of constructing plants before they were required. As a result, the NPV calculations in this section will be large and positive in the early years, when excess capacity was added, and negative in the later years, as that capacity is put to use.

Estimating the welfare impact of excessive CCGT and CT construction using synthetic control relies on the following assumptions:

Assumption 7: The synthetic control method properly estimates the CCGT and CT capacity that would have been added by states if they had not restructured.

Estimating the counterfactual is not a precise science, as only one outcome is observed. This paper uses synthetic control, introduced in section 7, to approximate the amount of CCGT and CT capacity added by restructured states if they did not restructure. The strength of this method is it identifies states that most closely resemble the restructured state and assembles a synthetic version of that state. The close match in CCGT and CT capacity additions in the period prior to restructuring provides confidence that this is an accurate counterfactual (See Section 7).

Assumption 8: CCGT and CT net capacity increases equal CCGT and CT capacity additions

As previously noted, the nature of the EIA Form 860 data entails using net capacity additions to substitute for actual new plant builds. While not precisely equal due to the existence

[69] Borenstein and Bushnell (2016) note that capacity factors are still low in many restructured states.

of plant retirements, CCGT was newly introduced in the US starting in the late 1980s and very few CT plants were built until the 1990s, so plant retirements are not a concern.

Assumption 9: EIA construction cost estimates with regional cost adjustment approximate the actual build cost in the restructured states.

With comprehensive data on individual plant builds unavailable, this paper uses EIA (and other sources) estimates of construction costs. The EIA and other entities issues one cost estimate annually for the US, with regional adjustments to distinguish between less costly and more costly states. While this approach is not ideal, if a bias does exist, the direction is unclear. See Section 4 of this paper for a more thorough explanation of these data sources.

Assumption 10: The regulated level of capacity additions is in excess of the optimal amount.

The comparison in this analysis is between the actual added capacity and the regulated amount, not the optimal. As Joskow (2008) notes, the Averch-Johnson effect induces utilities to overinvest in capital, with the result being that utilities were compensated for more capacity than was required to adequately meet load. Therefore, the calculations in this section should be seen as a lower bound of the true welfare impact.

Table 9 shows the results from this calculation.[70] As of 2013, the net present cost of the buildout in restructured states was $13.6 billion. This is largely due to CCGT plants that were built and are still not fully used. As the 1998-2013 summary row shows, the synthetic restructured states would have built over 59 GW less CCGT capacity without restructuring. The cost pattern over the years was as predicted, with losses incurred in the first seven years and the cost reduced in the final nine years, as there was a need for capacity to meet ERS growth. This amount was slightly reduced by the deficiency in CT plants predicted in the synthetic states. Moving past 2013, there are additional benefits to having these plants available which reduces the cost, with a small adjustment due to an increase in CT plant construction to meet the deficiency in the previous period. However, the benefit of having these plants operational is limited by low projected ERS

[70] Further Assumptions: Discount rate=10 percent. No difference in technology between 1998 and 2013. Build time for CCGT was 3 years for 1993-2003, 4 years for 2004-2013. CT was 2 years for 1992-2013. Costs for three year CCGT build period were distributed 40%, 50% and 10%. Costs for CT build period were distributed 50% and 50%. Costs for four year period were distributed 5%, 25%, 55%, 15%. Future projections of construction are from EIA Annual Energy Outlook 2015.

growth in the US, due to the adoption of energy efficiency programs. Given EIA estimates of ERS growth, plant retirement and cost, excess capacity in states that restructured will not be eliminated until at least 2024.[71] Including these years, the net present cost of the buildout is $10.8 billion.

Table 9. Alternative Market Producer Welfare Loss

Year	#states	CCAct	CCSyn	CTAct	CTSyn	PV($mil)
1997	2	0	0	-	286	(52)
1998	3	2,669	7	4,195	2,486	1,072
1999	13	2,371	724	1,187	701	506
2000	17	29,722	4,074	3,326	6,755	5,569
2001	21	7,186	3,833	11,463	7,038	1,533
2002	21	31,230	14,654	7,886	11,883	2,671
2003	21	36,517	16,818	2,565	3,268	3,502
2004	21	13,827	8,781	-	2,060	600
2005	21	7,589	11,407	1,042	1,434	(588)
2006	21	5,897	944	954	846	718
2007	21	2,077	6,098	1,605	1,499	(544)
2008	21	1,539	3,608	1,706	2,602	(380)
2009	21	3,110	10,704	1,139	1,366	(837)
2010	21	4,019	1,427	1,142	1,405	243
2011	21	4,729	6,539	1,038	2,367	(312)
2012	21	2,415	3,957	1,020	186	(78)
2013	21	1,488	3,684	3,231	1,582	(53)
1998-2013	21	156,384	97,257	43,498	47,765	13,570
2014-2024	21	14,951	74,080	6,859	2,597	(2,732)
Total		171,335	171,337	50,357	50,362	10,837

Notes: CC/CTAct is the amount of CCGT and CT capacity built (MW). CC/CTSyn is the counterfactual amount (MW). NPV is the net present value of the investment in millions of 2013 $.

The distributional burden of this buildout is very different from the large increase in nuclear capacity in the 1970s and early 1980s. In the prior nuclear construction period, states were tightly regulated under cost-of-service regulation, with the cost of investment errors often being passed

[71] One confounding fact of the post-buildout period is the construction of CCGT plants, despite the presence of excess capacity. This continues in the post-2014 period, with 15 GW of CCGT estimated to be added. Two reasons explain the continued construction. 1) Regions added capacity in a heterogeneous fashion, with some states adding more capacity than others. Therefore, there are balancing authorities in restructured areas which are in need of capacity. 2) Camerer and Lovallo (1999) suggests managers can suffer from overconfidence in their own abilities. Therefore, CCGT plants will continue to be added by firms that either are low-cost producers or believe they are.

on to the consumer in the form of higher prices.[72] In this case, the costs of the gas boom were on the firms, as consumers were insulated from investment errors through retail and generation competition. While the impact on firms would affect consumers through misallocation of resources, it didn't have the same effect as in the nuclear case.

While Joskow was certainly correct, that COSR incentivized firms to overinvest in capital-intensive methods of electricity generation, there are two other points worth considering. First, the cost of excess investment can be large, as evidenced by a number of events across the world over the last 20 years. Second, while COSR incentivizes firms to be capital-heavy, competitive electricity markets encourage firms to underinvest in capital-intensive plants. Uncertainty and expectations play a large role in the construction of power plants, which has traditionally been minimized by the ability of utilities to recoup the cost of their investment through rate increases. This is precisely why any new nuclear additions are not strongly considered without federal loan guarantees. However, making a large investment in a competitive electricity market is a risky venture and firms may opt for less capital-intensive projects even if they are projected to have a higher levelized cost. It's not surprising, therefore, that plants with quick construction times were chosen over coal and nuclear plants. While these looked like sound investments in the late 1990s, when gas prices were low, the high gas prices of the 2000s led to a string of bankruptcies.

8.2.2 Effect IV

The change in welfare from effect IV is dependent on the impact of restructuring on electricity prices and the elasticity of electricity demand. Theoretically, electricity prices could have increased or decreased as a result of restructuring. However, controlling for changes in fuel and construction materials prices is difficult, so analyses in this area of study must attempt to isolate only the effect on electricity prices of restructuring. This paper identifies two decreasing and three increasing effects.

There are two channels for restructuring leading to falling electricity prices. The first is the reduction in construction and operation costs from competition that Fabrizio et al and others found. Given a downward-sloping demand curve and competitive electricity market that passes cost

[72] As previously discussed in this paper, the cost of nuclear power plants was underestimated due to additional safety measures and optimistic cost efficiency expectations.

savings on to consumers in the form of lower prices, this would increase electricity demand from x_1^S to $x_1^{R_1}$. The magnitude of this effect is unknown, with the competitiveness of electricity markets often in question (Bushnell et al 2008). This effect is also outside the scope of this analysis, which is focused only on the effect of excessive entry on total welfare.

The second effect is the decrease in costs associated with excess capacity. With a larger number of more efficient CCGT plants in a market, the dispatch cost would be reduced, as balancing authorities would receive lower bids compared to less-efficient CT plants. The largest effect of lower CCGT bids would be in peak periods. Competitive electricity markets meet peak demand by enabling peaking plants to charge high prices during the few periods a year in which they operate to recover fixed costs. Peaking plants are able to charge these high prices because they lack competition in these rare periods. With the introduction of more plants, bids during this period would fall, lowering the price of electricity for consumers. In a real-time pricing market, this would influence consumers to increase electricity demand during the peak. However, the majority of markets during this time period did not have access to real time pricing, resulting in a decrease in average electricity prices. Given the assumption of a downward sloping demand curve for electricity, this will increase electricity demand from $x_1^{R_1}$ to x_1^R.

One channel for restructuring increasing electricity prices is the nature of price regulation prior to restructuring. Partly due to increasing nuclear costs and partly to tight price regulation, several utilities across the US received very low grades on their bonds. This suggests investors were wary of low profits in the industry. Following restructuring, firms were freed from price regulation that may have allowed for profits approaching the opportunity cost of capital. This would not have been the first time this occurred in US regulatory history. As noted in Winston (1998), railroads were losing money in the 1970s due to price regulation. Following the Staggers Act of 1980, railroad prices increased initially as firms were freed from being forced to set prices too low. This is attributed to the successful recovery of the industry and a similar effect may have been present in the restructured electricity industry.

A second channel, as noted in Su (2015), is the inclusion of search and switching costs. Traditionally, consumers had one provider for electricity, which eliminated any complications surrounding information gathering and switching by consumers. With more choices, costs can increase for consumers and lead to higher prices. This is particularly true for smaller customers.

A third channel for restructuring increasing electricity prices is the impact of market power on electricity prices. Restructured markets gave firms the freedom to act strategically when providing electricity to the system. The combination of short-run inelastic demand and supply, along with the inability to store electricity, gives firms the ability to manipulate market prices by holding low-cost generation out of the market. The papers mentioned above are a small part of a large literature that has identified the existence of strategic behavior in markets. The increase in bids raises average electricity prices.

The magnitude of these five effects is unknown, as there is no literature present that attempts to estimate each. There is a large literature, however, on the estimation of electricity demand curve elasticity.[73] The studies vary from 0 to -1 in their estimates, with the majority clustered between -.1 and -.4 and the EIA adopting -.3 as an estimate in 2010. Therefore, it's not surprising that, given both negative and positive theoretical impacts and a relatively inelastic demand curve, a number of studies find little evidence for a significant fall in electricity prices following restructuring (Joskow 2008; Su 2015; Borenstein and Bushnell 2016).[74] Additionally, any change in price would be, at least, partly due to increased plant efficiency rather than excessive entry. Lacking evidence in the literature of lower prices due to excessive entry from restructuring, the assumption of this paper is that excessive entry had a minimal impact on prices that is unable to be distinguished from other factors like changing fuel prices, population growth, changes in economic activity, and others. If prices did not change as a result of excessive entry, the quantity of electricity demanded in restructured states would be no different than that demanded in the synthetic state. In this case, welfare effect V is insignificant and, therefore, not a factor in the welfare calculation.

8.3 Total Welfare Effect of Restructuring

The purpose of this section is to identify the total welfare impact of excessive entry due to restructuring. While there were other effects on welfare identified, these are outside the scope of

[73] See Espey and Espey (2004), Paul, Myers and Palmer (2009) and Alberini, Gans and Velez-Lopez (2011) for summaries of elasticity estimates in this literature.

[74] Su (2015) finds short run impacts in the residential market, but these disappear in the longer-run. Commercial and industrial markets do not experience significant impacts. These are consistent with the findings of Apt (2005) and Fagan (2006), which found no difference in industrial electricity prices between restructured and non-restructured states.

this paper, which is focused on the excessive entry caused by restructuring. Two separate effects were considered, with the impact on the alternative market being a negative effect and the impact on prices and quantity in the electricity market a positive effect. This paper found welfare losses of $10.84 billion in the alternative market, with no evidence of a change in welfare in the electricity market due to excessive entry.

9. Conclusion

The consensus of the economics literature prior to restructuring is the US electricity industry would emerge more efficient, both in the short run and long run. Several papers have shown that the short-run cost impact of restructuring was positive, as it increased production and reduced O&M and fuel costs. Up to this point, however, there had been no study of the long-run cost implications of restructuring. It has now been 20 years since the first states began restructuring, which allows this paper to analyze whether the long-run efficiency gains, through more effective plant investment, were present. The conclusion of this paper is that, rather than increasing the efficiency of plant investment, restructuring caused a power plant construction boom that left states with bankrupt electricity firms and stranded power plants.

The natural gas power plant construction boom from 2000-2006 transformed the US electricity industry, which is in the process of switching from generation primarily from coal power plants to generation from cleaner-burning gas-fired plants. This switch, largely due to the low price of natural gas, would not have been possible without the investment boom, which left a number of stranded power plants that are still not approaching their efficient level of use. Explanations for this boom included changes in the levelized cost of gas-fired capacity, natural gas market deregulation, increasing electricity demand, environmental considerations, and the quick build times of gas plants. The timing and geographic nature of the gas boom suggested that these explanations were insufficient in explaining why so many gas plants were constructed during this time period.

This paper shows that electricity market restructuring is an integral part of explaining the gas boom. While changes in technology and long-term price forecasts made natural gas more cost effective, compared to coal, in the 1990s, these changes occurred almost a decade before the boom began and do not explain why there was significantly more investment in restructured states.

Compared to the non-boom period, restructured states built approximately 593 MW more CCGT power plants on average annually than non-restructured states, costing more than $95 billion in total. This boom in restructured states left them with excess capacity which is still evident today.

Overinvestment in restructured states was found to be consistent with three factors. First, restructured markets suffered from a coordination failure, as new firms lacked the information available to utilities when making the decision of whether or not to enter. Second, the pattern of entry suggested there was a contagion effect in the electricity industry, as firms began to enter based on market inertia rather than fundamentals. Third, a decline in long-term interest rates during this period facilitated the boom in a similar manner to the technology, telecommunications and housing booms occurring simultaneously with the gas boom.

The effect of excessive entry on welfare in electricity markets is mostly borne by firms. While electricity prices fell during this time period in restructured states, there is no evidence that they fell more than in other states. This suggests that national factors, such as distance from the nuclear overhang and the decline in the levelized cost of output from coal and gas, may have been more influential than the gains from competition between overbuilt power plants. Therefore, there is no clear indication that consumer welfare improved as a result of the gas boom. Producer welfare, on the other hand, declined substantially during this time period, evidenced by the large number of bankruptcies and plants sitting idle. Despite intervention by state and regional authorities, which kept prices above market during the transition, firms took the largest losses and the total welfare loss from excessive entry was approximately $11.2 billion.

The gas boom provides an informative lesson for policymakers as they consider restructuring other regulated markets. The success of markets in solving the coordination problem is heavily dependent on market information and economies of scale, each of which played a role in the inefficient transition to less-regulated electricity markets. While there is no reason to suspect that the inefficiency in investment by restructured markets is permanent, this paper has shown the transition, when not handled correctly, can impose significant costs. Policymakers were concerned with this transition, but focused entirely on insufficient investment and changes in retail prices for consumers. It’s possible to imagine ISOs imposing an upper bound on regional capacity, in addition to the lower bound they currently impose. The existence of a capacity upper bound during the transition would have prevented the large welfare loss by counteracting coordination and information failures present in electricity investment.

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Appendix 1

$\Delta W = W^R - W^S$

$$= \int_0^{x_1^R} D^R(x_1) - p_1^R + \sum_{i=1}^{n}\sum_{a=1}^{2} p_{1i}^R x_{1i}^R - c_{1ai}^R x_{1ai}^R - d_{1ai}^R X_{1ai}^R - d_{1ai}^R Y_{1a}^R$$

$$+ \int_0^{x_2^R} D^R(x_2) - p_2^R - \sum_{i=1}^{n} p_{2i}^R x_{2i}^R - c_{2i}^R x_{2i}^R - d_{2i}^R X_{2i}^R - d_{2i}^R Y_{2i}^R$$

$$- \int_0^{x_1^S} D^S(x_1) - p_1^S - \sum_{i=1}^{n}\sum_{a=1}^{2} p_{1i}^S x_{1i}^S - c_{1ai}^S x_{1ai}^S - d_{1ai}^S X_{1ai}^S - d_{1a}^S\ Y_{1ai}^S - \int_0^{x_2^S} D^S(x_2)$$

$$- p_2^S - \sum_{i=1}^{n} p_{2i}^S x_{2i}^S - c_{2i}^S x_{2i}^S - d_{2i}^S X_{2i}^S - d_{2i}^S Y_{2i}^S$$

Imposing assumptions 1 through 4 simplifies the expression to:

$$\int_0^{x_1^R} D(x_1) - p_1^R + \sum_{i=1}^{n}\sum_{a=1}^{2} p_{1i}^R x_{1i}^R - c_{1ai}^R x_{1ai}^R - d_{1ai}^R X_{1ai}^R$$

$$- \int_0^{x_1^S} D(x_1) - p_1^S - \sum_{i=1}^{n}\sum_{a=1}^{2} p_{1i}^S x_{1i}^S - c_{1ai}^S x_{1ai}^S - d_{1ai}^S X_{1ai}^S - \int_{x_2^R}^{x_2^S} D(x_2) - p_2^S$$

$$- \sum_{i=1}^{n} p_{2i}^S x_{2i}^S - c_{2i}^S x_{2i}^S$$

Combining and re-arranging terms, the change in total welfare can be expressed as:

$$\int_{x_1^S}^{x_1^R} D(x_1) - \sum_{i=1}^{n}\sum_{a=1}^{2} c_{1ai}^R x_{1ai}^R + d_{1ai}^R X_{1ai}^R + \sum_{i=1}^{n}\sum_{a=1}^{2} c_{1ai}^S x_{1i}^S + d_{1ai}^S X_{1ai}^S$$

$$- \int_{x_2^R}^{x_2^S} D(x_2) - p_2^S - \sum_{i=1}^{n} p_{2i}^S x_{2i}^S - c_{2i}^S x_{2i}^S$$

Which can then be separated into the following five terms:

$$\int_{x_2^R}^{x_2^S} p_2^S - D(x_2) + \sum_{i=1}^{n} c_{2i}^S x_{2i}^S - p_{2i}^S x_{2i}^S + \sum_{i=1}^{n}\sum_{a=1}^{2}\left(c_{1ai}^S - c_{1ai}^R\right)x_{1ai}^S + \sum_{i=1}^{n}\sum_{a=1}^{2}\left(d_{1ai}^R - d_{1ai}^S\right)X_{1ai}^S$$

$$+ \int_{x_1^S}^{x_1^R} D(x_1) - \sum_{i=1}^{n}\sum_{a=1}^{2} c_{1ai}^R(x_{1a}^R \; - x_{1ai}^S) - d_{1ai}^R(X_{1ai}^R - X_{1ai}^S)$$

Appendix 2

The producer surplus part of Welfare Effect I was found to be:

$$\sum_{i=1}^{n} c_{2i}^S x_{2i}^S - p_{2i}^S x_{2i}^S$$

This is the negative of the firm's variable profit from operating in the alternative goods market and can be re-written as:

$$-\sum_{i=1}^{n} r d_{2i}^S X_{2i}^S$$

by assuming a normal rate of return (r) on the capital investment ($d_2^S X_2^S$). Using assumption 3, the amount invested in the synthetic market ($d_2^S X_2^S$) is equal to the amount of excess investment in the electricity market ($\sum_{a=1}^{2} d_{1a}^R Y_{1a}^R$). Plugging this into the previous equation yields:

$$-\sum_{i=1}^{n}\sum_{a=1}^{2} r d_{1ai}^R Y_{1a}^R$$

Since Q=X+Y, Y_1^R can be replaced by ($Q_1^R - X_1^R$) and, according to assumption 4, X_1^R=X_1^S, so the previous equation can be written as:

$$-\sum_{i=1}^{n}\sum_{a=1}^{2} r d_{1a}^R (Q_{1a}^R - X_{1a}^S)$$

This information is not available by firm, so it is aggregated and discounted at the state level over the study time period and the result is:

$$\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{a=1}^{2}(1+r)^{t} r d^{R}_{1ast}(Q^{R}_{1ast} - X^{S}_{1ast})$$

Disaggregating this result by technology, the final equation to be estimated is:

$$\sum_{t=1}^{T}\sum_{s=1}^{S}(1+r)^{t} r d^{R}_{11st}(Q^{R}_{11st} - X^{S}_{11st}) + \sum_{t=1}^{T}\sum_{s=1}^{S}(1+r)^{t} r d^{R}_{12st}(Q^{R}_{12st} - X^{S}_{12st})$$