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Deregulation, Restructuring and Changing R&D Paradigms in the US Electric Utility Industry*

Paroma Sanyal#
Dept. of Economics & IBS
Brandeis University

Linda R. Cohen
Dept. of Economics, UC Irvine.
University of Southern California Law School

Abstract:

This paper studies the impact of electricity deregulation and restructuring on research and development (R&D) expenditures of investor owned utilities. The differing pace of deregulation in the fifty states provides heterogeneity in institutional structure and competitive forces, and showcases the response of R&D funding to changing institutional environments. Based on a panel of all major investor-owned utilities from 1989-1997, this paper analyzes various political constraints, institutional change, and firm-specific financial and structural factors that have contributed to the decline of R&D expenditure in the U.S. electric utility industry. R&D is modeled as a two-stage process where firms first decide whether to invest in research depending on their critical mass and state characteristics, and then conditional on a positive decision, decide on the level of expenditure. A variation of the Heckman model is estimated in a panel data setting, allowing for separate effects of selection and intensity. The primary findings are: First, greater deregulation and competition has a positive effect on R&D whereas a higher probability of deregulation adversely affects research spending. The start date for retail competition and level and policies for stranded cost recovery do affect spending. Second, the response of R&D to financial and other firm attributes varies with the state of deregulation and provides insights into firm behavior in a regulated context. Third, the institutional and competitive factors interact in a way that suggest that full deregulation, coupled with effective retail competition may mitigate the problem of declining electricity R&D by the utilities.

Key Words: Electricity Deregulation, Competition, R&D

JEL Codes: O30, O31, L50, L94, L97

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"Research and development is our nation's investment in its own future. America's science and technology base may well stand as our most important renewable resource. The overarching public goal of US R&D policy, of which energy R&D is a major component, must be to assure for future generations that our Nation's capacity to shape the future through scientific research and technological innovation is continually being renewed."[1]

Introduction

Throughout the course of history, investments in research and development (R&D) activities have been rooted in the belief that generous R&D funding leads to economic progress through technological innovations. As early as the 1940's economists pointed out that invention and technical progress were the true engines of economic growth and R&D was their primary fuel (Schmookler, 1966). This view was further reinforced when the precipitous decline in private industrial R&D expenditure in the early 1970's was followed by a productivity slowdown in the US from 1977-1981.

For electric and electric equipment, total R&D as a percent of sales, has declined from 7.9 in 1986 to 6.9 in 1996. The Department Of Energy's funding has decreased by 3 percent between1993 and 1999. State electricity R&D funding has declined by 30 percent during the same period.[2] R&D funding by the electric utilities has fallen by 33 percent to about $476 million between 1993 and 1998. EPRI's (Electric Power Research Institute) budget has also dropped by 71 percent because of fall in contribution from major utilities.[3] If this trend continues, this "would result in slowing technology development, sacrificing future prosperity to meet short-term goals, and failing to meet national energy goals" (GAO/RCED-96-203). The

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[1] Final Report of the Task Force on Strategic Energy Research and Development, Secretary of Energy Advisory Board, U.S. Department of Energy, June 1995.
[2] EPRI (1997), GAO (1998)

magnitudes of these changes are alarming and raise questions about the factors behind the decline and mitigating factors that may stem this. This has focused attention on the changing institutional and market environment in the US electricity industry and their influence on the conduct of R&D.

Considerable theoretical and empirical attention has been focused on the linkages between market structures, innovation, productivity and R&D.[4] Particular industries like telecommunications and electronics have been studied extensively to examine the role of various institutional and firm specific factors in the conduct of research in these industries. However, relatively little attention has been devoted to the impact of restructuring on R&D activities in the electric utility industry. Restructuring is likely to lead to substantial changes in the structure and conduct of R&D, particularly regarding investments in science, long-term projects, and projects involving environmental benefits that cannot be internalized. Thus it is important to analyze how various market and non-market forces interact in the deregulated environment to impact research expenditure by utilities.

This paper focuses on the total research expenditure by investor owned utilities (IOUs). It analyzes how ongoing deregulation, changing market arrangements and the expectation of future retail competition affect the R&D response of utilities. It also studies whether firm characteristics and financial factors have a differential impact after deregulation. This paper is organized into five sections. The first section briefly outlines the deregulation process and the nature and organization of R&D activities in this US power industry. The second section explains the incentives to conduct R&D in a regulated and market framework and the R&D model. Methodological issues, data sources and the specifics about variables used in the R&D model are

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[3] GAO (Appendix II, 1996), Moore (1995)

presented in the third section. The fourth section explains the empirical results and the last section concludes.

Section 1: Background

The Energy Policy Act (EPACT) of 1992 gave impetus to wholesale power competition by creating a new class of power producers called the exempt wholesale generators (EWGs) and creating open-access transmission grids for wholesale transactions. In 1995, FERC Orders 888 & 889[5] encouraged retail competition for the first time, while furthering wholesale competition[6]. Restructuring involves two main phenomena - divestiture and merger. In the US power sector there has been a large number of voluntary and mandatory divestitures of generating capacity by IOUs. States promoted this trend because the simultaneous ownership of generation and transmission capacity by the same company could lead to discrimination against third parties who wanted to use their transmission networks.

All these changes point to a very different structure of the power industry[7] than that of the traditional regulated monopoly (Blumstein, 1997; Blumstein & Bushnell, 1994; Borenstein, &

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[4] For a complete discussion on this topic please refer to Kamien & Schwartz (1975) - "Market Structure & Innovation: A Survey", JEL, 13:1.

[5] Order 888 – "Promoting Wholesale Competition Through Open Access Non-Discriminatory Transmission Service by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities" and Order 889 – "Open-Access Same-Time Information System". For a detailed provision of the orders please refer to DOE/EIA (1997)

[6] The main provisions of Order 888 are that utilities that own transmission networks must provide transmission services to other power generators at cost-based non-discriminatory prices. Provisions were also laid out governing the recovery of stranded costs by utilities. Order 889 required each public utility to participate in an Open Access Same-Time Information System (OASIS), to facilitate wheeling by third parties that did not own transmission capacities. These orders taken together provided impetus to wholesale competition and initiated an effective groundwork to begin retail wheeling; whereby retail consumers could shop around for the best rates while purchasing power much like the present telecom situation.

[7] Currently there are about 3200 electric utilities in the US of whom only about 700 generate power. In the generation sector there are two broad groups – the utilities and the non-utilities. The utilities consist of the five distinct groups, the investor owned utilities (IOUs), federally owned utilities, other public utilities (state, municipal etc.) and co-operatives and power marketers. The non-utility group comprises qualified and non-qualified cogenerators, small power producers, exempt wholesale generators and non-qualified non-cogenerators. The non-utilities are "privately owned entities that generate power for their own use and/or sale to utilities and others"

Bushnell, 1997; Bushnell & Stoft 1995; Hogan, 1997; Jordan, 1994; Joskow, 1989, 1997, 1999; Moyer, 1993; Sloan, 1994; Smith, 1998; Taylor, 1998; Wolak, 1997). Presently there are 244 IOUs in the US and they operate in all states except Nebraska. They are for-profit privately owned entities who have service monopolies in particular geographical regions. In this paper we shall concentrate on the IOUs as they are major power generators and account 90 percent of all electricity research undertaken by power producers.

There are four major entities that carry out research in the power industry related research – the IOUs, DOE, EPRI and manufacturers of electrical equipment such as General Electric. In this paper, we are interested in analyzing direct electricity research in areas such as generation and transmission by the utilities – since these were the entities most directly affected by the deregulation and restructuring process. R&D was primarily conducted by big vertically integrated firms that owned generation, transmission and distribution. Companies that were solely distribution or transmission companies, invested very little in research.

In the regulated environment, R&D investment was essentially costless and riskless to the utilities. All such investments could be recouped from the ratepayers by means of a cost pass-through; if the Public Utility Commission approved. With deregulation, gaining a competitive advantage through investment in strategic research is going to be in the forefront. Industry watchers and analysts believe that this will decrease overall investment in R&D and collaborative research and classic "public interest" R&D will suffer (Hirsch, 1998; Testimony, 1998). On the other hand, investment from alternative sources may increase innovations. Competition may provide the necessary thrust to electricity research and result in the birth of new technology (R. W. Shaw's - Testimony, 1998). Individual states display differential decline

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(DOE/EIA-X037, 2000). The investor owned utilities are the most important category and they account for 75 percent of power generated in the US.

patterns (Graph 1(b)), although total R&D trends (Graph 1(a)) display a steady decline after the start of 1993.

However, at least temporarily, R&D spending of companies has been adversely affected by deregulation (Blumstein, 1997). Most of the concern about utility R&D seems to be regarding the "R" part. The development and demonstration parts are expected to fare no worse in the deregulatory regime. In fact, in terms of innovation and returns on R&D expenditure, efficiency may be boosted since the utilities will not have a guarantee of recouping all their R&D investments and may choose their projects accordingly. There is major concern, however, about the basic research part since utilities had invested huge resources in both long-term and "public interest" research[8].

Section 2: Layout of the R&D Model

Section 2.1: R&D under Regulation

This discussion suggests two potential types of R&D programs for regulated monopolies. Under "regulatory lag" conditions, a company might perform R&D in order to improve operating efficiencies, consistent with the notion that its incentives are aligned with those of private firms when not subject to rate reviews. But the incentive to perform R&D under these conditions is weak.[9] As is discussed above, electric utilities had franchise monopolies that not only protected their activities from interlopers (obviating the basic Schumpeterian reason for conducting research), but also circumscribed their own business undertakings. Their ability to exploit research results is consequently limited.

[8] Some examples are: investigation of the formation of nitrogen oxide in burners, preventing electricity loss through leakage in residential heating and cooling ducts etc.

[9] During the 20th century, electricity technology underwent enormous technological advance, and regulated utilities are credited with providing a stable, forgiving environment ideal for inducing innovation (of at least some types) from manufacturing firms. This is clearly an important aspect in the role of regulation more generally in innovation, but beyond the scope of this paper. See Ishii (2003) for a related analysis.

Even when formal rate hearings lag company decisions, regulated utilities operate in a shadow of potential regulatory oversight that darkens prospects for R&D. R&D is risky, with the risk justified by infrequent but valuable inventions. But if a utility succeeded in producing, say, some cost reducing innovation, regulators would likely take notice and redistribute exceptional returns to rate-payers. Our data series does not include years during which utilities allegedly enjoyed regulatory lags, but anecdotal evidence suggests that they did not devote unsupervised surplus to the pursuit of research.[10]

The second reason a regulated utility would have a research program is by order, or anticipated order, of its regulatory commission. In this case, we would expect the program to reflect preferences of the commissioners. The discussion above yields some suggestions about how such a program might differ from that of market firms. Schumpeterian analysis predicts that when firms face a relatively elastic demand curve, they will perform more R&D.[11]

<u>Section 2.2: R&D under Deregulation</u>

The process of deregulation is far from complete. This implies that uncertainty will play a major role in a firm's research investment decisions, although apriori, its impact on R&D investment is ambiguous. For example: uncertainty over demand conditions may affect the timing of an investment or the choice of technology.[12] In the electricity industry, for instance, technologically advanced gas generating plants exhibit a tradeoff between the efficiency at which the plant converts fuel to power (the heat rate), and the speed at which it can adjust its output (the ramp rate). Which factor is more valuable depends on market conditions: if demand is

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[10] In contrast, AT&T, while holding down a regulated monopoly on phone service, conducted an extraordinarily successful research program and was among the world's top annual patent recipients. Neither the electric utilities, nor, prior to 1990, their research consortium, the Electric Power Research Institute (EPRI) obtained patents on inventions. See Hirsh (1989); Corey (1997).

[11] Reinganum (1989). The intuition is that a small success – and small price decrease – will secure for the firm a large number of new customers.

[12] See Ishii and Yan (2003), Macauley (2003), Dixit and Pindyck (1994), Kort (2003).

predictable and sales contracts are long-term, a generating plant with a higher heat rate would be optimal. If the actual nature of the market is unknown, efficient investment principles dictate a delay in investment. This spills over to R&D to the extent that research is conducted in response to demand for technology, or "induced demand" R&D.[13] Thus we expect uncertainty to dampen R&D expenditures.

However, there are forces that work in the opposite direction.[14] Research activities in a firm increase its ability to absorb the research results of others, or its ability to innovate in areas related to, but distinct from, the firm's own research project.[15] Since deregulation causes obsolescence of current plant, and some new technology will be desired, the transition period may be characterized by increases in R&D at the generic end of the spectrum. Second, R&D can be a hedge. A firm may choose to conduct research on both generating options, and thus increase the research budget during the investment delay. How important this effect is depends on the timing of the resolution of uncertainty and on the research production function. If research is in part generic (potentially applying to both options), or if there are high fixed costs to research,[16] the hedging characteristic may dominate the incentive to delay. Third, if a firm delays ordinary investment, it may face fewer budget constraints for other activities. R&D can substitute for investment if it places the firm in a position to invest more rapidly in new technology once the optimal investment strategy is revealed.

Section 2.3: R&D Model

Expenditure decisions on research and development projects by a firm are viewed as a two-step process. First a utility decides whether to invest in R&D or not depending on its

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[13] Newell, Jaffe and Stavins (1999).

[14] A theoretical treatment of some of these issues is presented in Kort (2003).

[15] Dosi (1988) and references cited therein.

expected future benefits from R&D. Benefits in this case do not just imply monetary profits. In a regulated regime, a firm could invest in R&D to gain favor with the regulators or to gain some cost advantage. Thus the first stage decision depends on the nature of the regulatory commission, profits, the generation technology e.g. hydro or fossil fuel, the size of the firm and whether it is a Yankee company. If the PUC's main objective was to keep electricity prices under check, it may not push large R&D spending, leading IOUs to refrain from R&D spending. A Yankee company would spend almost nothing on R&D as they are subsidiaries of other IOUs and the research would be done by the parent company. A low-technology hydro-electric utility, again, would not invest in R&D.

We estimate the selection equation using a random effects probit model in a panel data setting. The latent unobserved variable is net revenue stream. Each year the firm decides to invest in research if such investment is associated with positive net revenues (y_{it}). Thus the decision is modeled as:

$$y_{it}^{*} = x_{it}^{'}\beta + u_{it}, \quad \text{where } i = 1, \ldots n \text{ and } t = 1, \ldots\ldots T_i$$
$$y_{it} = 1 \quad \text{if } y_{it}^{*} > 0, \text{ and 0 otherwise}$$

where: u_{it} is the random error term[17] independent of x_{it}, which are the vector of covariates mentioned above.

The second stage is observed conditional on participation in research activities. Market structure and expectations influence R&D spending by changing the institutional environment

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[16] R&D activities tend to be very stable over time, an effect believed due to the high fixed costs of assembling a research staff and the very low value of the staff in any alternate use. See Hall (2002).

[17] We assume that the random effects (u_i) follows a normal distribution N(0, σ^2_u). Therefore we have: $\Pr(y_i \mid x_i) = \int_{-\infty}^{+\infty} \frac{e^{-u_i^2/2\sigma_i^2}}{\sqrt{2\pi}\sigma_u} \left[\prod_{t=1}^{n_i} F(x_{it} + u_{it}) \right] du_i$ where: $F(x_{it}\beta + u_{it}) = \begin{cases} \Phi(x_{it}\beta + u_i) & \text{if } y_{it} \neq 0 \\ 1 - \Phi(x_{it}\beta + u_i) & \text{otherwise} \end{cases}$ (Φ is the cumulative normal distribution). This model is calculated using the Gauss-Hermite quadrature.

within which firms operate. Financial factors like the magnitude of profits determine the amount of resources that a firm has for investing in research projects. Small investments in R&D generally do not yield results. Thus the size of the firm determines whether it has the critical mass to succeed at a research project. The nature of the firm also critically influences R&D. All these factors are incorporated in the second stage model where the dependent variable is positive R&D spending. This is estimated by an error components model[18] given by:

$$\ln RD_{it} = \alpha + \sum_{k=1}^{5} \beta_k M_{it} + \sum_{P=1}^{p} \gamma_P F_{it} + \delta Z_i + \sum_{P=1}^{p} \theta_P D_{1993} F_{it} + \sum_{T=1}^{t} \phi_T T + \lambda t + v_i + \varepsilon_{it}$$

where: M_{it} is a vector of institutional variables, F_{it} denotes firm specific characteristics like profit, Z_i comprises individual firm characteristics that vary between firms but not by year. '*t*' is a time trend and *T* are year dummies. In addition, institutional and market forces may have differing effects on R&D under a regulated and a competitive environment. To take this effect into account we interact a subset of the firm characteristics with a dummy (D_{1993}) that takes the value 1 if year >=1993 and 0 otherwise[19].

Section 3: Data Issues

Section 3.1: Data on R&D Expenditures

The key source of data for this paper is Form 1, which regulated IOUs file with Federal Energy Regulatory Commission (FERC). It contains data on all financial aspects such as debt,

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[18] . The error has two components: v_i - the random disturbance that varies by group but not over time ($v_i \sim N(0, \sigma^2_v)$) and ε_{it} - is the idiosyncratic error component ($\varepsilon_{it} \sim N(0, \sigma^2_\varepsilon)$). We assume that X_{it} and v_i are uncorrelated. In the actual estimation process, the dependent variable and some of the regressors are in logs. This arises from an underlying non-linear model where some variables affect R&D expenditure in an exponential manner while others serve to shift the distribution.

[19] These interaction terms denote how important each effect is post 1992. The interpretation of the coefficients is as follows: For pre-1992, the marginal effects are denoted by the coefficients of the explanatory variables. For post-1992, the marginal effects are denoted by coefficient of variable + coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same marginal effect pre and post 1992.

revenue, equity; generation data, such as amount of electricity produced from steam, nuclear, hydro; customer data about the share of sales and revenue of residential, commercial and industrial customers and expenditure data like R&D, wages and salaries etc. The R&D expenditure data for 1990-1998 was obtained from FERC's online Form 1 database. Data for 1989 was collected from the original company filings. The revenue, customer information and generation data is from two sources – post 1990 it was obtained from Form 1 while 1989 is from the EIA (Energy Information Administration) publication "Financial Statistics of the Major Investor Owned Utilities". Summary statistics are provided in Table 1(a).

Our main focus is to study the effect of deregulation and restructuring on various components of R&D expenditure. To facilitate this and to observe whether there was a fundamental change in the conduct of research after deregulation we use data for the period 1989-1997[20], for all major utilities (199 of them). There is also a problem of missing data. For about 25 companies R&D expenditure data is unavailable for 1989 and a couple of the pre-1993 years. For a few companies where data was missing in a mid-year we imputed the data by trend fitting. But such imputed data does not constitute more than five percent of the entire data set. Merger of companies also contribute to the unbalanced nature of the panel.

Section 3.2: Market Institution Variables

Deregulation Variable

Over the past several years the electric utility industry has been in a state of flux. Deregulation, mergers, acquisitions and divestitures have dramatically changed the landscape of the industry. Each state is at a different level of deregulation and restructuring. Any one variable

[20] Although available, we do not use post 1997 data as it contains a downward bias for the R&D expenditure data. Around 1998, big R&D spenders like Southern California Edison divested their generation assets, concentrated on distribution and transmission, cut back research spending and spawned private entities (like Mission Electric), which

is not adequate to capture the dynamic nature of this change. Thus we use five variables that, we believe, characterize the change to a large extent, within the constraints imposed by the data.

One of the primary variables of interest is the status of deregulation in different states. The decline in R&D expenditure that has accompanied the deregulation process would imply that it has had a negative impact on research spending by IOUs. In the regulated regime, firms often invested in R&D following the implicit dictates of the regulators. If we ignore government failure models and consider regulators to be social utility maximizers then it stands to reason that the R&D undertaken under the regulated regime will be optimal for society. Anytime, we move away from it, firms will either under or over-invest in research.

We use a dynamic deregulation index to capture the different stages. This traces the path through which the states traveled to reach their current status. The dynamic index is constructed from EIA's publication "Status of State Electric Industry restructuring Activity as of May 2000"[21]. This index is coded as zero for 'No Activity', 1 for 'Investigations Ongoing or Orders and Legislation Pending', 2 for 'Order Issued for Retail Competition' and 3 for 'Legislation Enacted to Implement Retail Access'. This index is zero for those states that have not taken any action about deregulation till 1997. Table 1(b) shows the status of deregulation in 1997.

However, deregulation did not happen overnight, and the deregulation index alone will not capture the impact of regulatory changes on research expenditures. Discussion about deregulation preceded the passing of EPAct in 1992 and firms would have formed expectations about the status of deregulation in their state in years to come and tailored its R&D investment accordingly. To capture this forward-looking behavior, we use the predicted probability of

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would now do the bulk of its R&D. Since these companies are not under FERC jurisdiction, they do not need to file Form 1. Thus data is unavailable. So we restrict our sample to 1989-1997.

[21] This publication outlines the regulatory orders, legislations and the investigative studies that have been undertaken by each state till present.

deregulation in a state in 1998, based on state characteristics such as the price, presence of municipal power plants etc[22]. This variable captures the fact that if a firm expects a state to be deregulated in the near future, then it may start cutting back on its R&D spending even before the actual order was passed. This is a state level variable and we assume that there is no asymmetric information between firms. Thus they all have the same expected probability of deregulation.

In addition we use the permitted level of stranded cost recovery to capture another facet of deregulatory activity. It is conceivable that an IOU in a state which allows hundred percent recovery through, say, a wire charge, will decrease its R&D budget by less than one where full recovery is not allowed or there is uncertainly about the recovery mechanism. So far only 14 states have taken steps to mandate the level of permitted stranded cost recovery and its composition. We use data from DOE/EIA to generate an indicator variable that takes values from 0 to 3 (increments of 0.5) and denotes the level of stranded cost recovery[23].

Competition Variables

To effectively capture competition in a state, we use two primary variables. These are – the mandated start date of retail competition and the percentage of customers eligible for retail

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[22] This probability of deregulation is obtained from modeling deregulation in a state. The deregulation model is based on the economic and political factors that affect the pace of deregulation in a state. As the dependent variable we consider the status of electricity deregulation in a state at the end of 1998. The independent variables (price, import and export price gap, weighted standard deviation on prices, share of municipal power entities in state, power of industrial and other customer groups, LCV rating) are from 1993 – before EPACT had any significant influence. The model is estimated as an ordered probit and predicted probabilities of deregulation are generated from this. This variable captures the single realization of a firm's expectation about full deregulation (index =3) being achieved in the state in 1998 based on the information in 1993. It is zero before 1993, takes the constant probability value from the model for all periods after 1993 until deregulation index=3. Once the state reaches full deregulation (deregulation index=3) this variable takes the value 1.

[23] This variable takes the value 0 if there is no recovery mechanism in place, 1 if such a mechanism is in place, but full recovery not guaranteed and varies with individual utility and depends on its mitigation efforts or on divestiture of generation assets, 1.5 if just & reasonable stranded costs can be recoverable, and appropriate consumer safeguards related to stranded costs are implemented, 2 if there is an opportunity to recover prudently incurred stranded costs, 2.5 if in addition to prudently incurred stranded cost the utility can fully recover nuclear stranded costs and 3 if there is opportunity for full recovery of all stranded costs.

competition. The number of years that a state has to graduate to full retail competition may affect its R&D spending. Even if the deregulation order has been passed, each state has its own time frame by which it operates. Two states may have passed a deregulatory order but one may mandate that retail competition start twenty years from now and the other may mandate retail competition immediately. Presumably firms will behave differently in the two situations. Apriori, the effect on research spending is not clear. An IOU may invest more or less depending on its perception of uncertainty. We hypothesize that that greater the number of years left till the start of retail competition, the lower will be the R&D spending, due to greater uncertainty that is involved in a longer time horizon. A firm which has to embark on retail competition, say in two years, will not cut back its R&D by as much as such an action may have adverse consequences on its competitive advantage in the market.

So far 18 states have set concrete dates for the start and phasing in of full retail competition. For states that have not set a date, we assume that they have 20 years till retail competition begins (i.e., at any point of time, their expected start date is 20 years in the future). For the states with a specific start date, this variable takes the value: start-date of retail competition minus current year if and only if deregulation index is greater then zero. This variable is bounded below at zero and bounded above at 20[24]. For a summary of the mandated dates please refer to Table 1(c).

Passing a deregulatory order, or even mandating the date for the start of retail competition is not sufficient to engender effective competition in the market. For example, a state may be deregulated but lack of competitors, or customers eligible to switch to other companies may imply low levels of actual competition. When there is effective competition in a state, utilities would increase at least a section of their research spending that is directly related to gaining market share or increasing profits. To measure competition we use the percent of customers who are eligible to choose a provider. This is essential to the development of retail energy competition and its maturation because the greater the percentage of eligible customers, the greater the potential competition. This is particularly important as an explanatory variable for R&D as research expenditures are essentially forward looking and a firm that knows that its entire market will be open to competition a few years down the line, it may behave very differently from another whose market is fairly protected despite deregulation.

Section 3.3: Firm and Regulator Characteristics

Firm Characteristics

To measure the financial health of the firm we use the bond rating of utilities. A better bond rating also implies that a firm will have higher chances of borrowing money cheaply in the market. Thus availability of increased low cost resources may have a positive effect on R&D. The bond rating goes from AAA+, AAA, AAA-, AA+ to below C. This has been converted to an 18 point scale where AAA+ corresponds to 18 and below B- corresponds to zero[25].

For the power industry, the nature and type of firm would critically affect the amount of R&D investment. A hydro-electric plant, traditionally a low-technology operation, would invest less or nothing at all in research when compared to nuclear or fossil fuel plants. The share of fossil fuel in the generation mix, share of purchase to generation and resale share may all affect how firms respond to deregulation. In addition, firms have to be a critical minimum size to effectively undertake research. The yearly operating revenues (1996 dollars) of each company are used as a proxy for firm size. However, we are agnostic about the size elasticity of R&D –

[24] Sensitivity analysis shows that the choice of 20 years does not affect the results.

[25] Companies that have no long-term debt have no bonds. They have been coded to missing for now - until an acceptable solution is found for including them in the data set.

we have no apriori reason to suspect that this will be greater, equal to or less than one. The ratio of purchase to generation is used an indicator for the type of firm – to indicate whether its main operations lie in generation or elsewhere. We also include a dummy for steam plants as a proxy for firm type. All the generation and revenue data are from the "Financial Statistics of Major Investor Owned Utilities" published by the Energy Information Administration annually.

Regulator Nature

R&D investment decision by utilities is influenced by its internal profit motive, nature of its operations as well as implicit regulatory pressure. The external pressure is captured by the variable denoting the nature of the Public Utility Commission (PUC). A higher score for PUC nature implies that the regulators are more pro-active than those in other states and IOUs in such states may be pressured to invest more in research. This variable is constructed from the regulatory history of the state outlined in Anderson (1981, pp. 82-83). It traces out the status of electric rate structure reform in the fifty states and DC in 1977, which gives us a clear picture of the 'progressive' regulators. This reform was characterized by four indicators – generic rate hearings, FEA funded experiments, lifeline or inverted rates and time-of-day rates. We create an indicator variable using this information. A state is given 1 point for implementing each of the above reform mechanisms. So the highest point on the scale is 4 and the lowest 0[26]. For a detailed table of this variable please refer to Table 1(d).

Section 4: Empirical Results

The R&D model consists of data for 9 years and 190 IOUs. The panel is unbalanced due to missing data and mergers. In addition, 27 percent of total R&D expenditure is zero. As

[26] California is a 4 on this scale while Alabama is a 0.

discussed earlier, the decision to perform R&D is modeled as a two-stage process[27] estimated by an approximation of the Heckman procedure. In the first stage the firm decides whether it should engage in research and development or not[28]. The second level decision involves determining the optimal amount of R&D expenditure that would maximize the present discounted value of the firm's value function subject to various institutional and revenue constraints.

Section 4.1: Basic Model

Stage 1: Selection Equation (Table 2(a))

Results for the first stage selection equation are shown in Table 2(a). The decision to conduct research depends crucially on the nature and structure of the firm and political factors as well. First, we find that resources of the firm have positive effect on R&D – the higher the operating revenues the more likely it is for a firm to conduct R&D, supporting the 'deep pocket' theory of R&D. Share of generation in total sales does not affect the R&D decision, while utilities that generate a larger portion of their power from hydro sources are less likely to invest in any research as this is low-tech and further efficiency improvement or cost decrease may not be feasible. Pending mergers make research investment unlikely, as firms want to reduce discretionary expenditures during states of uncertainty. In addition, the probability of IOUs investing in R&D is higher the more pro-active a PUC is in that state. To summarize, a company with a low hydro generation, high operating revenues, with no mergers in the horizon and located in a pro-active state has a higher probability of investing in R&D.

[27] In this case a tobit model would be inappropriate as it does not make a distinction between the two stages and treats all zeros as levels.

[28] In my panel there are 19 IOUs that switch between conducting and not conducting R&D between 1989-1997. For the rest the decision remains unchanged throughout this period.

Stage 2: Determinants of Positive Total R&D (Table 2(b) & (c))

Next we investigate the determinants of R&D levels. Table 2(b) and (c) provide the basic results for the second stage of the model. The dependent variable is the log of positive real total R&D (1996 dollars). To account for selection, we include a polynomial of the probability of selection from the first stage[29]. Other explanatory variables are divided into three main sub-groups - the market institution variables, firm characteristics and state and year variables. We observe that the issue of selection is important (the coefficients on all the terms of predicted probability of a positive outcome is significant at 5 percent) and that indeed a two-stage model is warranted instead of a tobit specification.

Before we estimate the full model outlined earlier, we first investigate whether the regime change after EPAct had a significant impact on R&D. Thus we estimate a simple difference-in-difference model in Table 2(b) given by the equation below[30].

$$\ln RD_{it} = \alpha + \beta D_{1993} + \phi Treated_i + \theta (D_{1993} * Treated_i) + \sum_{P=1}^{p} \gamma_P F_{it} + \delta Z_i + \sum_{T=1}^{t} \phi_T T + \lambda t + v_i + \varepsilon_{it}$$

In this model D_{1993} is the after EPAct dummy[31], the treated group are all IOUs in states that had shown some deregulatory activity[32] by 1996 and θ is the difference-in-difference coefficient. If deregulation and its associated changes were indeed responsible for the sharp decline in R&D spending by IOUs, we would expect θ to be negative and significant. From table 2(b) we find that θ is indeed negative and significant (-0.202) and IOUs in deregulated states experience a significant decline in R&D after 1992 when compared to their counterparts in other states.

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[29] This is an approximation for the Mill's ratio.

[30] F_{it} denotes firm specific characteristics like profit, Z_i comprises individual firm characteristics that vary between firms but not by year. '*t*' is a time trend and *T* are year dummies.

[31] EPAct was passed in 1992. Therefore, D_{1993}=1 if year>=1993

[32] The deregulatory index for these states was at least 1 by 1996, i.e. they had investigations ongoing or had orders and legislation pending.

However, this simple specification fails to capture the various facets of deregulation. After 1992 states differed not only in their pace of deregulation, but also in terms of effective competition, and other market institution variables. So we estimate a richer model in Table 2(c) to investigate the impact of these variables. This model is given by the error components model outlined earlier.

The five variables that capture the changes in the institutional environment are the deregulation index, the probability of deregulation, effective competition, the years till start of retail competition and stranded cost recovery levels. An increase in deregulation (by one stage) increases real total R&D by 0.32 percent. The non-linear nature of the specification implies that the effect of deregulation on R&D levels is dependent on the base level of R&D[33]. This implies that the higher the base level of research a firm is engaged in, the greater will be the effect of deregulation on its R&D budget. For example, consider two companies in 1997 - Texas Utilities Company with a real R&D expenditure of 12.8 million dollars and Maine Public Service Company, - with 0.006 million dollars and both at stage 1 of the deregulatory process in 1997. If deregulation increases by one stage, R&D increases by $4.03 million for Texas Utilities, whereas it increases by only $0.002 million for Maine Public Service Company. This is intuitively clear because a firm that performed very little research in the first place, will be less affected by changes in the regulatory structure that a firm with a large R&D budget. From Table 4(a)[34], we find that for the mean firm, R&D increases by 1.66 million dollars when deregulation progresses by 1 stage.

[33] The coefficient is the semi-elasticity and the marginal effect is given by: δ(RD)/δ(Dereg) = β-hat.RD, where RD is evaluated at the mean or median and β-hat= .315 from Table 2(c).

[34] For Table 4(a) and (b), we do not calculate the elasticities because for most the market institution variables, a one percent increase does not have an economic meaning.

The probability of deregulation has a negative coefficient implying that firms that have a greater expectation of deregulation decrease their R&D budget. A possible explanation is the unwillingness of firms to invest in research till some of the uncertainties involved in the deregulation process are resolved and a final market structure emerges. When the probability of deregulation increases by one percent[35], R&D expenditures decrease by half a percent or 2.6 million dollars. Performing the same analysis as before, R&D expenditure for Texas Utilities decreases by 6.32 million, while that of Maine Public Service decreases by 0.003 million.

The percentage of customers eligible for retail competition measures the "effective competition" in the state. In line with earlier predictions, increased competition implies an increase in R&D expenditures and a one percent increase raises R&D spending by 0.004 percent or $21,000 (evaluated at mean R&D). Another related variable is the number of years till start date of retail competition. Suppose two firms are in the same stage of deregulation - but one has 10 years till retail competition starts and the other has 1 year, a positive coefficient implies that R&D declines as the retail competition date becomes closer, whereas a negative coefficient implies that firms increase research spending as the date draws near. In the basic model, the coefficient is positive but not significant, suggesting that this may not be an important factor in deciding R&D levels. In addition, the level of stranded cost recovery is not significant. Our basic models points to the varied impact of different institutional forces on a firm's R&D expenditure. To study the magnitude of total effect we refer to Table 4(a). We find that when all the market institution variables change by one unit, R&D decreases by 0.92 million dollars or 0 .17 percent.

The next set of variables relate to the financial health of the company and firm characteristics. A better the bond rating induces more R&D since a firm with higher bond rating

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[35] This probability lies between 0 and 1 and a one unit change is 0.1, which is equivalent to one percent. The effective retail competition is measured by the percentage of customers and lies between 0 and 100.

has a better chance of borrowing money cheaply in the market and this may increase R&D. The size and type of the firm also influence R&D expenditures. The effect of size on R&D (as measured by the operating income) is different pre and post 1992. Before deregulation, the elasticity of R&D expenditure with respect to size is 0.964, implying that a one percent increase in the size of a company increases R&D by almost one percent. However after 1992 this elasticity declines to 0.735, implying that size becomes less important as a determinant of research after restructuring. The share of industrial sales in total generation positively affects R&D pre and post deregulation and a one percent increase leads to a 0.67 percent increase in spending[36].

The share of purchased power is not a significant factor in explaining R&D in the regulated regime. However, post-deregulation it has a significant negative impact, with a one percent increase in this ratio leading to a 0.17 percent[37] decline in research spending. Thus when IOUs mostly purchase power rather than generate, they have less incentive to conduct R&D, especially in a market environment where they have to keep a close watch on their bottom line. The share of fossil fuel in the generation mix does not affect research spending. Last, we find that a more pro-active PUC induces greater R&D expenditures, as expected from earlier discussions. The model also includes a time trend that is negative and significant and year dummies to control for macroeconomic shocks.

Section 4.2: Alternative Specifications

In Table 3(a) we provide some sensitivity analysis for our basic model. Model 1 estimates the same specification as the basic model, with resale share added. This variable denotes the sales for resale of a utility, i.e. the amount of power sold in the wholesale market.

[36] Elasticity = $\delta \ln(RD)/\delta \ln(Share) = \beta$-hat. (Share evaluate at mean). β-hat=1.285 and Mean Share = 0.519
[37] Post-Deregulation: β-hat=-0.546 and Mean Share = 0.312

Since the whole sale market was well under way to deregulation by 1993, this variable should be an important factor and we would expect utilities with a higher share of wholesale to invest more in R&D due to higher competitive pressures. We find that pre-1992, this variable does not affect spending, whereas post-1992, there is a significant positive impact on research spending. Except for a couple of variables all results remain unchanged. The percentage of eligible customers is now insignificant and the share of industrial customers is insignificant before 1992 and positive and significant post-1992. The latter may be because the resale share and the share of industrial customers may be picking up the same effect and are highly collinear.

Model 2 adds a state fuel composition to the above specification. This dummy takes the value 1 if the share of gas and coal in electricity generation is greater than other fuels. This captures the generation technology in the state as this may influence research spending by companies. A greater use of fossil fuel in a state may imply a greater research spending to appease the environmental lobbies, as discussed earlier in the political economy discussion. We find that this is not validated and states with a higher coal and gas fuel share conduct less research. We also included separate dummies for coal, gas and hydro and again the coal and gas dummies are negative and significant (the results are not presented). The result is especially strong for the coal states. This may suggest that all else equal, states with a higher share of coal in their generation mix are those with less active regulators and hence the R&D push is not there. The last column of Table 3(a) estimates the basic model with state fixed effects to capture state-level unobservables. We find that their inclusion does not fundamentally change any of the earlier results, especially on the institutional variables, except making the start date variable significant.

Next, instead of taking 1992 to be the watershed year and observing pre and post 1992 effects, we introduce three different interactions in Table 3(b). The first model comprises interactions of variables of interest with date of retail competition in each state, to directly capture the effect of retail competition on firm characteristics and R&D. The second includes interactions of firm characteristics with the deregulation index, to study how these variables affect R&D as deregulation progresses. The last model creates a deregulation dummy that takes the value 1 when the deregulation index is 1 or greater.

From model 1 in Table 3(b), we find several differences from the basic model in Table 2(c). First, the competition variable is not significant. Second, the regulator nature is not significant as the retail dates may already capture some of this effect, i.e. states with more pro-active regulators would start retail competition faster than others. Third, none of the interaction terms are significant suggesting that the retail competition date does not have any significant impact of how these firm level variables behave. Fourth, size has the same effect before and after the retail competition date. The results from model 2, with interactions with the deregulation index, are very similar to the model 1, except that the regulator nature is positive and significant. When the interactions are done with the deregulation dummy (model 3), results are once again very similar to the basic model. The main difference is that the share of industrial sales has a much stronger effect than the basic model. This suggests that as deregulation progresses, utilities with a greater share of the wholesale market will increase R&D spending to gain an edge over competitors. But in all three specifications, a majority of the market and institutional variables behave as before, suggesting that our choice of 1992 as the break-point is indeed justified.

Section 5: Conclusion

In the recent years there has been a great deal of concern among industry analysts and the Department of Energy, about the apparent decline in R&D expenditure by the IOUs. The California Public Utility Commission has instituted a new public interest energy research program on the presumption that deregulation will adversely affect R&D. Our research points in a different direction. We find that although the process deregulation has adversely affected R&D investment by IOUs, it may be a transition phenomenon. Various facets of the institutional environment affect R&D expenditures in different ways. Greater deregulation and competition has a positive effect on R&D whereas a higher probability of deregulation adversely affects research spending. The start date for retail competition and level and policies for stranded cost recovery do affect spending.

Combining the contradictory trends we conclude that once full deregulation takes place and the market becomes truly competitive, R&D expenditures may be less adversely affected than what is postulated by recent trends. It may be the uncertainty associated with the process that is adversely affecting research expenditures. With the start of effective competition, firms will very likely invest in research that gives them a competitive edge. We find that given a stage of deregulation, a firm invests more in R&D when there is effective competition in the market. Thus we hold that once the dust settles, and the companies are more confident about the nature of the emerging market structure, R&D expenditures will recover, at least for certain types of research.

The nature of the firm has differential effects in the pre and post-deregulation periods. The size elasticity of R&D is near unity pre-1992 and slightly lower post-1992 suggesting that size affects R&D less after deregulation. Also, R&D expenditures are more elastic to changes in the share of industrial sales post-1992. A utility that purchases a greater part of the power it sells invests little in research post-deregulation. In addition firms located in states with pro-active regulators and those with higher bond ratings invest more in research activities.

These findings suggest that when the uncertainty is resolved and full deregulation goes into effect, and there is effective competition in the market, R&D spending may increase from its current low level. One factor to remember is that, most likely, we will not observe the R&D expenditures of the past. If we assume that the regulators were maximizing social welfare when setting the level of R&D cost pass through, then R&D under the regulatory regime would be optimal. With competition, 'public interest' research, the benefits of which cannot be captured by any single firm, may decline - leading to expenditure levels below the regulated one.

However, common belief is that a portion of R&D was performed by the firm in accordance with the regulator's wishes. If we are willing to assume that Public Utility Commissions were not omniscient and their R&D decisions may not have maximized social welfare, then this decline may not decrease social welfare. Further analysis needs to be conducted on the decline and changing composition of R&D after 1992. This paper is a step towards understanding the dynamics of R&D spending when firms transition from a regulated to a market environment

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Appendix Tables

Table 1(a): Summary Statistics

First Stage: ***Sample: All Firms, 1989 – 1997(1110 obs.)***				
	Mean	**SD**	**Min**	**Max**
Dependent Variable: Decision to conduct R&D	-	-	0	1
Regressors:				
Real Operating Revenues	1.22e+09	1.49e+09	4652657	8.44e+09
Share of Generation in Total Sales	0.783	0.284	0.074	3.707
Share of Hydro Electric Power in Generation	0.121	0.286	0	1
Pending Merger	-	-	0	1
PUC Nature	1.578	1.219	0	4
Second Stage: ***Sample: Firms with Positive R&D only, 1989 – 1997 (881 obs.)***				
	Mean	**SD**	**Min**	**Max**
Dependent Variable:				
Real Total R&D Expenditure (1996 dollars)	5264682	8989887	291.1	81900000
Log (Real Total R&D Expenditure – 1996 dollars)	14.419	1.798	5.674	18.222
Regressors:				
Deregulation Index	0.261	0.702	0	3
Probability of Deregulation	0.244	0.336	0	1
Start Date of Retail Competition	18.427	4.999	1	20
% Customers Eligible for Retail Competition	17.123	36.702	0	100
Stranded Cost Recovery	0.401	0.886	0	3
Bond Rating	10.396	2.568	0	17
Log (Real Operating Revenues)	20.629	1.020	17.857	22.857
Share of Industrial Sales in Total Elec. Generation	0.520	0.131	0	0.799
Share of Purchased Power	0.277	0.238	0	1
Share of Fossil Fuel Generation	0.776	0.245	0	1
Resale Share	0.192	0.180	0	1
PUC Nature	1.603	1.222	0	4

Table 1(b): Deregulation Status in 1997

Deregulation Status, 1997 (Formulated Index)	No. of States	States
0 = No Activity	7	Alaska, Colorado, Delaware, Florida, Kentucky, Ohio, South Dakota
1 = Investigations Ongoing or Orders and Legislation Pending	30	Alabama, Arkansas, Arizona, Connecticut, Georgia, Hawaii, Idaho, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, North Carolina, North Dakota, New Jersey, Nebraska, New Mexico, Oregon, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wisconsin, Wyoming
2 = Order Issued For Retail Competition	2	Maryland, Vermont
3 = Legislation Enacted to Implement Retail Access	11	California, Illinois, Maine, Massachusetts, Montana, Nevada, New Hampshire, New York, Oklahoma, Pennsylvania, Rhode Island

TABLE 1(C): DATES OF EFFECTIVE RETAIL COMPETITION

State	Restructuring Act that introduced competition	Date when the Act was enacted	Date when large or a portion of residential customers would get retail access	Date when all customers would get retail access
Arizona	HB 2663	5/98	1/1/99	1/2001.
California	AB 1890	9/96	-	3/1998
Connecticut	RB 5005	4/98	1/2000	7/2000
Illinois	HB 362	12/97	10/99	5/2002
Maine	LD 1804	5/97	-	3/2000
Maryland	-	12/97	7/2000	7/2000
Massachusetts	-	11/97	-	3/1998
Michigan	-	6/97	3/98	1/2000
Montana	SB 390	4/97	7/98	7/2000.
Nevada	AB 366	7/97	-	12/1999
New Hampshire	HB 1392	5/96	-	7/1998
New Jersey	-	4/97	10/98	7/2000
New York	-	5/96	1/98	-
Oklahoma	SB 500	4/97	-	7/2000
Pennsylvania	HB 1509, HB 2286	12/96, 3/98	1/99	1/2001, 1/99
Rhode Island	-	8/96	7/97	7/98
Vermont	-	12/96	1/98	12/1998
Virginia	HB 1172	4/98	1/2002	1/2004

TABLE 1(D): STATUS OF ELECTRIC RATE STRUCTURE REFORM, 1977

State	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID
Generic Rt. Hearings			*		*	*	*		*	*		*	
FEA-Funded Experi.			*	*	*		*						
Lifeline/Inverted Rt.			*		*				*	*			*
Time-of-Day Rates				*	*		*			*	*		
State	IL	IN	IA	KS	KY	LA	ME	MD	MA	MI	MN	MT	NE
Generic Rt. Hearings	*							*	*				
FEA-Funded Experi.										*			
Lifeline/Inverted Rt.										*			
Time-of-Day Rates	*	*							*	*		*	
State	NV	NH	NJ	NM	NY	NC	ND	OH	OK	OR	PA	RI	SC
Generic Rt. Hearings		*			*	*					*		
FEA-Funded Experi.			*		*	*		*	*			*	
Lifeline/Inverted Rt.											*		
Time-of-Day Rates	*	*	*	*	*	*	*	*			*	*	
State	SD	TN	TX	UT	VT	VA	WA	WV	WI	WY			
Generic Rt. Hearings						*			*				
FEA-Funded Experi.					*		*		*				
Lifeline/Inverted Rt.													
Time-of-Day Rates	*				*	*		*	*				

Source: Anderson, Douglas D. - "Regulatory Politics and Electric Utilities", *Auburn House Publishing Company; Boston, Massachusetts, 1981*

TABLE 2(A): STAGE 1 - SELECTION EQUATION

Dependent Variable is a Binary Index Function for Total R&D Expenditure

(Standard Errors in Parenthesis)

Variable	Coefficient
Constant	-0.388 (0.364)
Real Operating Revenues	0.000000003 (0.0000000004) **
Share of Generation in Total Sales	0.184 (0.425)
Share of Hydro Electric Power in Generation	-2.421 (0.536) **
Pending Merger	-1.070 (0.341) **
PUC Nature	0.773 (0.185) **
Log Likelihood	-172.075
Log σ^2_u	2.178
Number of Observations	1168

Note: This selection equation has been estimated by a random effects panel probit model. Range: 1989-1997 and 161 utilities. '**' denotes significance at 5 percent and '*' denotes significance at 10 percent.

TABLE 2(B): STAGE 2 - LEVELS EQUATION (DIFFERENCE-IN-DIFFERENCE MODEL)

Dependent Variable is Log (Positive Total R&D Expenditure)

(Standard Errors in Parenthesis)

Variable	Coefficient	Variable	Coefficient
Control for Selection Bias		**Firm Characteristics**	
Predicted Prob. of Positive Outcome	13.54 (4.745) **	Bond Rating	0.157 (0.036) **
Predicted Prob. of Positive Outcome Squared	-21.50 (8.029) **	Log(Real Operating Rev.)	0.873 (0.104) **
Predicted Prob. of Positive Outcome Cubed	11.29 (4.297) **	Share of Fossil Fuel Generation	-0.057 (0.300)
Difference-in-Difference Specification		Share of Industrial Sales in Total Electricity Generation	1.735 (0.547) **
Deregulation Dummy	-0.269 (0.014) **	Share of Purchased Power	-0.639 (0.264) **
Dummy for IOUs in Deregulated States	0.061 (0.204)	**Regression Diagnostics**	
Deregulation Dummy* Dummy for IOUs in Deregulated States	-0.202 (0.114) *	σ_u	0.920
Year Controls		σ_e	0.779
Year	-0.005 (0.001) **	Fraction of Variance Due to U_i	0.582
Year Fixed Effects	Yes	R-Square	0.532
		No. of Observations	886

Note: The estimation technique is a random effects panel data model. Unbalanced panel. Range: 1989-1997. '**' denotes significance at 5 percent and '*' denotes significance at 10 percent. The deregulation dummy takes the value 1 for year>=1993. The treatment group is IOUs in deregulated states. If a state

TABLE 2(C): STAGE 2 - LEVELS EQUATION (BASIC MODEL)

Dependent Variable is Log (Positive Total R&D Expenditure)

(Standard Errors in Parenthesis)

Variable	BASIC MODEL
Control for Selection Bias	
Predicted Prob. of Positive Outcome	15.06 (4.836) **
Predicted Prob. of Positive Outcome Squared	-22.46 (8.176) **
Predicted Prob. of Positive Outcome Cubed	11.15 (4.392) **
Market Institution Variables	
Deregulation Index	0.315 (0.104) **
Probability of Deregulation	-0.494 (0.278) **
% Customers Eligible for Retail Comp.	0.004 (0.002) *
Years Till Start of Retail Competition	0.017 (0.013)
Stranded Cost Recovery	-0.056 (0.062)
Firm Characteristics	
Bond Rating	0.149 (0.034) **
Log(Real Operating Rev.)	0.964 (0.105) **
Share of Industrial Sales in Total Electricity Generation	1.285 (0.580) **
Share of Purchased Power	-0.406 (0.310)
Share of Fossil Fuel Generation	0.098 (0.304)
Pro-Active State and Year Controls	
PUC Nature	0.132 (0.082) *
Year	-0.006 (0.001) **
Year Fixed Effects	Yes
Post-Deregulation Interactions	
Log(Real Operating Revenues) *Post 1992 Dummy	-0.129 (0.062) **
Share of Ind. Sales in Total Elec. Gen. * Post 1992 Dummy	0.545 (0.443)
Share of Purchased Power * Post 1992 Dummy	-0.546 (0.289) *
Regression Diagnostics	
σ_u	0.856
σ_e	0.777
Fraction of Variance Due to U_i	0.549
R-Square	0.541
No. of Observations	881

Note: The estimation technique is a random effects panel data model. Unbalanced panel. Range: 1989-1997. The interaction terms denote how important each effect is post 1992. Pre-1992 - marginal effects are the coefficients of the explanatory variables. Post-1992: the marginal effects are: coefficient of variable + coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same marginal effect pre and post 1992. '**' denotes significance at 5 percent and '*' denotes significance at 10 percent.

TABLE 3(A): SENSITIVITY ANALYSIS FOR THE BASIC MODEL

Dependent Variable is Log (Positive Total R&D Expenditure)

(Standard Errors in Parenthesis)

Variable	Model 1 With Resale Share	Model 2 State Fuel Composition	Model 3 State Fixed Effects
Predicted Prob. of Positive Outcome	14.96 (4.827) **	14.68 (4.818) **	12.22 (4.916) **
Predicted Prob. of Positive Outcome Squared	-22.44 (8.160) **	-21.85 (8.147) **	-18.37 (8.293) **
Predicted Prob. of Positive Outcome Cubed	11.23 (4.383) **	10.81 (4.377) **	9.232 (4.443) **
Deregulation Index	0.311 (0.104) **	0.304 (0.103) **	0.342 (0.106) **
Probability of Deregulation	-0.495 (0.278) **	-0.509 (0.277) *	-0.576 (0.290) **
% of Customers Eligible for Retail Comp.	0.003 (0.002)	0.004 (0.002) *	0.004 (0.002) *
Years Till Start of Retail Competition	0.017 (0.013)	0.015 (0.013)	0.021 (0.013) *
Stranded Cost Recovery	-0.056 (0.062)	-0.032 (0.062)	-0.037 (0.064)
Bond Rating	0.151 (0.034) **	0.153 (0.034) **	0.150 (0.038) **
Log(Real Operating Revenues)	0.957 (0.104) **	0.970 (0.104) **	1.067 (0.105) **
Share of Ind. Sales in Total Elec. Gen.	0.981 (1.102)	1.101 (1.101)	1.852 (0.574) **
Share of Purchased Power	-0.424 (0.311)	-0.495 (0.311) *	-0.349 (0.333)
Share of Fossil Fuel Generation	0.097 (0.303)	0.167 (0.305)	0.425 (0.304)
Resale Share	-0.294 (0.759)	-0.257 (0.757)	-
State Fuel Composition Dummy	-	-0.262 (0.120) **	-
PUC Nature	0.134 (0.082) *	0.134 (0.082) *	-
Year	-0.006 (0.001) **	-0.006 (0.001) **	-0.007 (0.001) **
Year Fixed Effects	Yes	Yes	Yes
State Fixed Effects	No	No	Yes
Log(Real Operating Revenues)*Post 1992 Dummy	-0.119 (0.062) **	-0.119 (0.062) **	-0.112 (0.063) *
Share of Ind. Sales in Total Elec. Gen. * Post 1992 Dummy	2.019 (0.832) **	2.004 (0.830) **	0.498 (0.447)
Share of Purchased Power * Post 1992 Dummy	-0.453 (0.294)	-0.472 (0.294) *	-0.592 (0.295) **
Resale Share* Post 1992 Dummy	1.295 (0.621) **	1.308 (0.620) **	-
σ_u	0.851	0.849	0.601
σ_e	0.776	0.774	0.778
Fraction of Variance Due to U_i	0.546	0.545	0.375
R-Square	0.545	0.550	0.702
No. of Observations	881	881	881

Note: The estimation technique is a random effects panel data model. The panel is unbalanced with minimum observations per group=1 and max=8. Range: 1989-1997. Pre-1992 - the marginal effects are the coefficients of the explanatory variables. Post-1992: the marginal effects are the coefficient of variable + coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same marginal effect pre and post 1992. '**' denotes significance at 5 percent and '*' denotes significance at 10 percent.

TABLE 3(B):INVESTIGATING INTERACTIONS – JOINT EFFECT OF RETAIL COMPETITION / DEREGULATION AND FIRM CHARACTERISTICS ON R&D EXPENDITURES

Dependent Variable is Log (Positive Total R&D Expenditure)

(Standard Errors in Parenthesis)

Variable	Model 1 Interaction with Retail Competition Date	Model 2 Interaction with Deregulation Index	Model 3 Interaction with Deregulation Dummy
Constant	15.48 (4.760) **	13.79 (4.843) **	14.87 (4.750) **
Predicted Probability of Positive Outcome	-23.20 (8.097) **	-20.42 (8.235) **	-22.66 (8.076) **
Predicted Probability of Positive Outcome Squared	11.45 (4.354) **	10.01 (4.430) **	11.32 (4.344) **
Deregulation Index	0.347 (0.104) **	1.671 (0.849) **	0.320 (0.104) **
Probability of Deregulation (1)	-0.587 (0.276) **	-0.662 (0.276) **	-0.562 (0.275) **
Percent of Customers Eligible for Retail Competition	0.003 (0.002)	0.004 (0.002) *	0.003 (0.002)
Years Till Start of Retail Competition	0.019 (0.013)	0.013 (0.013)	0.018 (0.013)
Stranded Cost Recovery	-0.086 (0.063)	-0.066 (0.062)	-0.072 (0.062)
Bond Rating	0.154 (0.033) **	0.147 (0.034) **	0.152 (0.034) **
Log(Real Operating Revenues)	0.885 (0.099) **	0.945 (0.103) **	0.817 (0.110) **
Share of Industrial Sales in Total Elec. Gen.	2.039 (0.728) **	1.549 (0.548) **	5.558 (2.115) **
Share of Purchased Power	-0.588 (0.338) *	-0.577 (0.267) **	-0.759 (0.642)
Share of Fossil Fuel Generation	0.140 (0.299)	0.172 (0.304)	0.147 (0.306)
PUC Nature	0.088 (0.088)	0.154 (0.082) *	0.164 (0.083) **
Year	-0.005 (0.001) **	-0.006 (0.001) **	-0.006 (0.001) **
Year Fixed Effects	Yes	Yes	Yes
Log(Real Operating Revenues) *(Retail/Dereg/Dummy)	0.042 (0.027)	-0.056 (0.040)	0.099 (0.054) *
Share of Ind. Sales in Total Elec. Gen. * (Retail/Dereg/Dummy)	-0.812 (1.039)	-0.060 (0.381)	-4.223 (2.170) **
Share of Purchased Power * (Retail/Dereg/Dummy)	-0.392 (0.488)	-0.385 (0.174) **	0.056 (0.088)
σ_u	0.812	0.859	0.861
σ_e	0.777	0.778	0.777
Fraction of Variance Due to U_i	0.522	0.549	0.551
R-Square	0.539	0.538	0.547
No. of Observations	881	881	881

Note: The estimation technique is a random effects panel data model. The panel is unbalanced with minimum observations per group=1 and max=8. Range: 1989-1997. Pre-1992 - the marginal effects are the coefficients of the explanatory variables. Post-1992: the marginal effects are the coefficient of variable + coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same marginal effect pre and post 1992. '**' denotes significance at 5 percent and '*' denotes significance at 10 percent.

TABLE 4(A):SEMI-ELASTICITIES AND MARGINAL EFFECTS USING MEAN REAL R&D

Mean R&D = 5.265		Deregulation Index	Probability of Deregulation	% of Customers Eligible for Retail Comp.	Years Till Start of Retail Comp.	Stranded Cost Recovery	Change in R&D
	Mean	**0.261**	**0.244**	**17.12**	**18.43**	**0.401**	
	Coeff. (dlnRD/dx)	**0.315**	**-0.494**	**0.004**	0.017	-0.056	**-0.175(%)**
	mfx (dRD/dx)	1.658475	-2.60091	0.02106			**-0.921 ($)**
Table 3(a) - Column 1	Coeff. (dlnRD/dx)	**0.311**	**-0.495**	0.003	0.017	-0.056	**-0.184(%)**
	mfx (dRD/dx)	1.637415	-2.606175	0.015795			**-0.953 ($)**
Table 3(a) - Column 2	Coeff. (dlnRD/dx)	**0.304**	**-0.509**	**0.004**	0.015	-0.032	**-0.201(%)**
	mfx (dRD/dx)	1.60056	-2.679885	0.02106			**-1.058 ($)**
Table 3(a) - Column 3	Coeff. (dlnRD/dx)	**0.342**	**-0.576**	**0.004**	**0.021**	-0.037	**-0.209(%)**
	mfx (dRD/dx)	1.80063	-3.03264	0.02106	0.110565		**-1.211 ($)**

TABLE 4(B): SEMI-ELASTICITIES AND MARGINAL EFFECTS USING MEDIAN REAL R&D

Median R&D = 2.371		Deregulation Index	Probability of Deregulation	% of Customers Eligible for Retail Comp.	Years Till Start of Retail Comp.	Stranded Cost Recovery	Change in R&D($)
	Mean	**0.261**	**0.244**	**17.12**	**18.43**	**0.401**	
Table 2(c)	Coeff. (dlnRD/dx))	**0.315**	**-0.494**	**0.004**	0.017	-0.056	
	mfx (dRD/dx)	0.746865	-1.171274	0.009484			**-0.415**
Table 3(a) - Column 1	Coeff. (dlnRD/dx))	**0.311**	**-0.495**	0.003	0.017	-0.056	
	mfx (dRD/dx)	0.737381	-1.173645	0.007113			**-0.429**
Table 3(a) - Column 2	Coeff. (dlnRD/dx)	**0.304**	**-0.509**	**0.004**	0.015	-0.032	
	mfx (dRD/dx)	0.720784	-1.206839	0.009484			**-0.477**
Table 3(a) - Column 3	Coeff. (dlnRD/dx))	**0.342**	**-0.576**	**0.004**	**0.021**	-0.037	
	mfx (dRD/dx)	0.810882	-1.365696	0.009484	0.049791		**-0.545**

Note: The bold numbers imply that the coefficients are significant at lest at the 10 percent level. The dollars are in millions.

APPENDIX FIGURES

FIGURE 1(A)

TOTAL R&D EXPENDITURE BY IOUS FROM 1989-1997

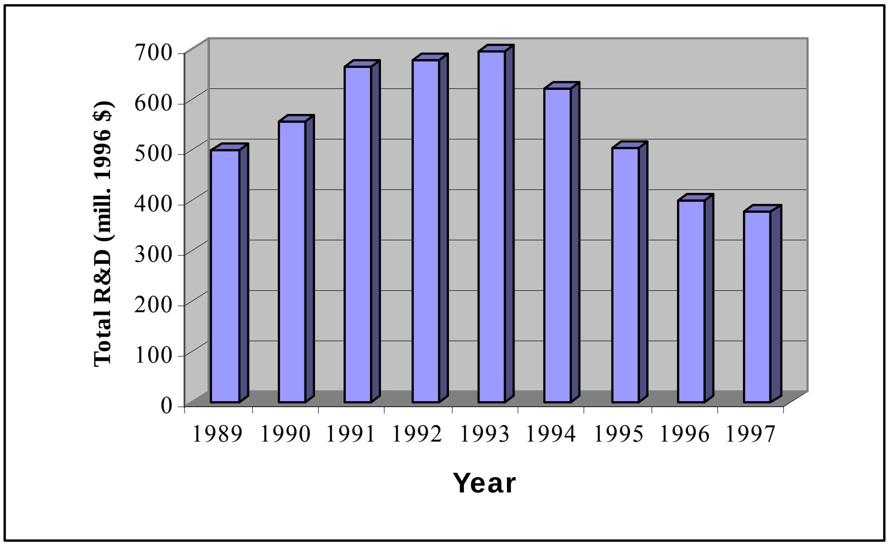

FIGURE 1(B)

CHANGING IOU R&D IN FIVE REPRESENTATIVE STATES