The Subnational Political Economy of Power Plants:

Does local opposition drive up construction costs and lead time?

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Abstract

The construction of power plants often generates fierce local opposition. I hypothesize that local opposition has economic consequences for power plant construction if political institutions grant sufficient autonomy to subnational governments. In a cross-country analysis of a global sample of power plants, I test whether subnational autonomy predicts the cost and lead time of power plant construction, and whether such an effect is contingent on the type of power plant. In a cross-state analysis of American power plants, I test whether public opinion, state policy, and interest group activity predicts power plant construction costs and lead time. Globally, I find that the economics of coal, nuclear, and hydroelectric power plants are sensitive to political decentralization; decentralization, particularly in highly democratic nations, tends to drive up their costs and lead times. In the United States, I find that subnational political conditions are correlated with cost and lead time for nuclear but not coal power plants.

Keywords: power plants, construction, political economy, decentralization

JEL Codes: Q42, Q48, L94, P16, P18,

1 Introduction

The siting of controversial infrastructure is a standard problem in political economy. Typical outcomes of interest are where projects are built (Hamilton, 1993), whether they receive approval (Aldrich and Crook, 2008), or the conditions that generate social acceptance or opposition (Frey and Oberholzer-Gee, 1996). However, even when it fails to block a project, local opposition may still delay the project, induce regulators to place more stringent regulatory conditions on it, or incent the firm to modify the project in some way so as to placate the opposition. These mechanisms can have substantial economic consequences for the project, the industry of which it is a part, and the broader economy, as is most powerfully attested by the literature on land use regulation and residential construction (Hsieh and Moretti, 2019).

Power plants, the subject of this article, are a prominent example of controversial infrastructure that attracts local opposition. I provide the reader with a cursory exposition of the terminology and literature of energy economics in Section 2.

Prior literature on the political economy of power plants typically closely evaluates individual projects (Aldrich, 2010) or presents a historical narrative of a particular time and place (Wellock, 1998; Lesbirel, 1998). In contrast, I examine the constitutional framework that governs the political process that local opposition must participate in. Trivially, I theorize that democracy enables local opposition to cohere and effect greater economic consequences on power plant construction. More substantively, I theorize that political decentralization—conditional on democracy—places greater authority in the hands of politicians with stronger incentives to respond to local opposition and weaker incentives to consider national benefits arising from power plant development. I summarize the prior literature on decentralization and elaborate my theory of "the logic of local democratic control" in Section 3.

I assembled a database of 1,340 observations, the sources and data cleaning procedures for which are detailed in Section 4. Because of the large sample, it is beyond the scope of the present work to evaluate of individual project histories and quantitatively measure the strength of local opposition. Omitting a direct measure of local opposition presents some difficulty in producing convincing results. While the structure of political institutions is exogenous to power plant construction, a simple regression of construction cost on political institutions is vulnerable to omitted variable bias. For example, highly decentralized countries may also tend to have a higher cost of doing business in general, and that could be reflected in power plant construction costs for reasons that have nothing to do with local opposition to controversial infrastructure. In Section 5, I lay out two methodological approaches to overcoming this problem. I conduct two separate analyses, one of a global sample and a second that exploits cross-state variation within the United States.

In the cross-country analysis, the results of which are presented in Section 7, I interact political institutions with the type of power plant. If political institutions are an important enabling factor for local opposition, then they should have greater economic consequences for types of power plants more likely to generate local opposition. Otherwise, decentralization should exhibit comparable effects on the construction cost of all types of power plants. I find that decentralization increases the cost of coal, nuclear, and hydroelectric plants in democratic countries. In particular, the marginal effect of decentralization is higher and strengthens in the level of democracy for nuclear and hydroelectric plant, whereas it is comparatively modest and constant for coal plants.

By contrast, the marginal effect of decentralization on the costs of wind and solar farms is large and positive for imperfectly democratic countries, but it falls in the level of democracy, becoming negative in the most highly advanced democracies. This result does not have a clear theoretical interpretation, but it is evidence that decentralization matters and it affects different types of power plants differently.

Finally, the marginal effect of decentralization on the costs of oil-fired and gas-fired power plants is not statistically significant; indeed, it is estimated fairly precisely as zero. Given that gas-fired plants emit far less air pollution than coal plants, this result is consistent with the view that they attract less local opposition and consequently decentralization is not correlated with their costs.

In the cross-state analysis, the results of which are presented in Section 7, I focus on coal and nuclear power plants built in the United States which began construction between the 1960s and 1970s. I select the United States for standard reasons of data availability but also because its federal political structure is highly representative of the decentralization that I theorize plays a role in the effects documented in the global analysis. The era of this analysis corresponds to the emergence mass movement politics in opposition to nuclear power. Meanwhile comparatively less concern was paid to coal, with many leading environmental thinkers, organizations, and policy-makers expressing outright support for coal as preferable to nuclear power (Lovins, 1976; Hays, 1981; Wellock, 1998), at least as a "bridge fuel." Unsurprisingly, my analysis shows that state-level political variables associated with pro-environmental attitudes and policies are associated with higher construction costs for nuclear but not coal power plants.

In section 8, I conclude that these findings are suggestive evidence for the hypothesis that local opposition substantively impacts the economics power plant construction. Future research in this area would benefit from (1) larger samples, particularly of non-nuclear power plants, (2) higher quality data sources, and (3) direct measures of local opposition to power plants that are comparable across jurisdictions.

2 Theory and Prior Literature: Energy Economics

2.1 Capital Costs of Electricity Generation Technologies

The two most commonly studied outcomes in the literature on power plant construction are overnight capital cost (OCC) and lead time (LT) (Komanoff, 1981; Koomey and Hultman, 2007; Grubler, 2010; Sovacool et al., 2014; Rubin et al., 2015; Rangel and Lévêque, 2015; Berthélemy and Escobar Rangel, 2015; Lovering et al., 2016; Csereklyei et al., 2016; Rothwell, 2016; Portugal-Pereira et al., 2018).

Overnight capital cost consists of all direct outlays on materials, manufactured components, construction equipment, labor, land, permitting, and other costs that would be registered as direct outlays during engineering of the design, permitting of the plant, procurement of equipment, and construction (Rothwell, 2016). These are what economists call accounting costs.[1] While not a complete measure of capital cost, OCC enables comparisons that are independent of financing parameters, which can vary due to macroeconomic conditions, government policies to subsidize the cost of capital, and other factors that do not reflect underlying techno-economic characteristic of the technology employed.

Lead time does not have a universal definition across studies and technologies, but it generally denotes the length of time between the dates of two major events involved in the construction of a power plant. Initiating events can include the decision to go forward with investment in the project, the granting of regulatory approval, or the commencement of construction activities. Terminating events can include the material completion of the plant or the start of commercial operation. For example, by convention in the nuclear industry, lead time is typically measured from the first day of pouring of concrete for the foundation of the plant (Rothwell, 2016).

Lead time factors into the total capital cost of a power plant because it represents the delay between the time when initial outlays in the plant are sunk and when the plant begins to generate revenue. The opportunity cost of funds used during construction rises with lead time, making it a relatively minor cost for power plants that can be deployed quickly (e.g. photovoltaic solar farms) and a major cost for power plants that require many years to construct (e.g. nuclear power plants).

By convention in the electric utility sector, capital costs are normalized by the rated size of its maximum power output in watts, kilowatts, or megawatts (Rothwell, 2016). This ensures a fair comparison between power plants of different scales; larger plants cost more

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[1] The designation "overnight" refers to the hypothetical case of a power plant constructed from start to finish over the course of a single night. Effectively no interest would accumulate during construction.

but also generate greater output.[2] Total OCC trivially rises in wattage, but OCC per watt may rise or fall in wattage, depending on economies or diseconomies of scale. Throughout this paper, when referring to “overnight capital cost” or OCC for brevity, I mean OCC per watt. In the analysis, I employ the natural log of overnight capital cost per kilowatt in 2010 PPP-adjusted 2010 dollars. For lead time, I employ the natural log of months of construction duration.

2.2 Learning-by-Doing

Learning-by-doing is a theory of endogenous technological change that ascribes cost reductions and quality improvements to the accumulation of practical experience with a production process (Arrow, 1962). The electricity generation sector has offered fertile ground for economists to study learning-by-doing, as certain technologies have consistently exhibited dramatic cost-declines over recent decades. A recent survey of the literature (Rubin et al., 2015) reports estimated learning rates[3] of 15% for natural gas combustion turbines, 12% for wind turbines, 23% for PV solar farms, and 11% for biomass generation.

Estimates of learning rates for nuclear power plants are far more sparse and subject to considerable debate (Lovering et al., 2016; Koomey et al., 2017). Values collected by Rubin et al. (2015) range from −38% (Grubler, 2010) to 5.8% (Kouvaritakis et al., 2000). Subsequent to the release of more authoritative data on the costs of France’s nuclear reactor fleet, work by Rangel and Lévêque (2015) showed that the cost estimates underlying the calculations of Grubler (2010) were too high for later reactors. The findings of Berthélemy and Escobar Rangel (2015) correspond to a learning rate of 10%,[4] conditional on the same design of plant being built by the same architect-engineer.

For lack of firm-level, country-level, or global data on cumulative experience with power plants of types other than nuclear, I do not directly analyze or control for the effect of experience in the present analyses. I instead approximate the effect of learning-by-doing with technology-specific time trends. However, learning-by-doing is of relevance to the current work because political variables may help explain why nuclear power plants have failed to achieve learning-by-doing in many countries, particularly highly developed Western nations.

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[2] However, this comparison is only fair when comparing plants of the same technology. Further analysis is required to fairly compare technologies that are capable of greater utilization rates or tend to operate at particular hours of the day (when the price of electricity may be higher or lower than average).

[3] The learning rate is the percentage reduction in cost arising from a doubling of cumulative construction (or other output, more generally).

[4] $1 - 2^{-.152} = 10\%$

3 Theory and Prior Literature: Political Economy of Decentralization

Decentralization has been “in vogue” as an economic development strategy promoted by major international institutions (e.g. World Bank and International Monetary Fund) since the closing decades of the 20th century, a recommendation which has been increasingly accepted by a variety of countries (Bardhan, 2002; Faguet and Pöschl, 2015; Martinez-Vazquez et al., 2017). The advice is motivated by a large and well-established literature that spans political economy, economic history, and development. Purported benefits of decentralization include greater public sector efficiency (Adam et al., 2008), greater accountability (Agrawal, 1999), lower corruption (Lessmann and Markwardt, 2010), and disciplining extractive behavior by governments through Tiebout competition (Weingast, 1995).

However, there may be limited applicability of the lessons from the broader literature on decentralization to the economics of controversial infrastructure such as power plants. The consequences of what might be considered “inefficient regulation”—preventing or halting the construction of power plants—are often intentional. The literature on decentralization primarily studies outcomes that are valence issues for voters, such as economic growth, public goods provision, and corruption. How does decentralization operate when the issue in question is a controversial project over which preferences differ? While the discussion below draws from the history of and literature on nuclear power—arguably the most salient of power plants in attracting local opposition—the causal mechanisms described can in principle operate on any type of power plant that prospective nearby residents find distasteful.

Cohen, McCubbins, and Rosenbluth (1995) compare the trajectory of nuclear power plant (NPP) deployment in the United States and Japan. They observe that the constitutional, political, and regulatory environments of the two nations differ in a variety of respects that explain why NPP construction was far more economically successful (as measured by lower cost, shorter lead time, absence of cancellations, and ongoing initiation of new construction) in Japan than in the United States. Most notably, local opposition to NPP construction was routinely “bought off” through a national scheme of transfer payments *à la* Coase, including to municipal governments as well as fishermen and farmers.

A case study in the role of federalism on the nuclear industry in the United States can be found in Wellock (1998). The author conducted interviews of major participants in the events culminating in 1978 in the ban on the construction of new NPPs in the state of California (excepting four reactors already under construction). The law creatively circumvents federal preemption of nuclear safety regulation by couching legislative intent in terms of economic concerns about the indefinite cost of storing spent nuclear fuel on site (Wellock, 1998, p.171). It is unlikely that much if any further NPP development would have occurred in California in the absence of the law, as new orders for NPPs throughout the United States had begun to decline and ceased by 1979 (Hultman and Koomey, 2013), and many NPPs under construction were abandoned due to budget and schedule overruns over the subsequent decade. However, it is noteworthy that San Diego Gas & Electric exerted considerable lobbying effort in Sacramento to seek a one-time exemption from the law.

The protests, lawsuits, legislation, and regulation documented by Wellock are suggestive of the causal mechanisms by which decentralization might lengthen power plant lead times. For example, Diablo Canyon Power Plant in California was the target of public protests throughout its construction during the 1970s and early 1980s, drawing record-breaking crowds, celebrities, and then-governor Jerry Brown. Seismic safety was among activists' leading concerns about the plant. In spite of federal preemption of nuclear safety regulation, state agencies such as the State Lands Commission and the Public Utilities Commission offered ample opportunities to intervene in the construction of the plant. Not coincidentally, commercial operation of Diablo Canyon was delayed by approximately a decade relative to initial projections.

Sovacool and Valentine (2010a,b) argue in case studies of China, India, South Korea, and Japan that "centralization of national energy policymaking and planning" is one of six key factors for successful NPP deployments. They note, for example, that "in South Korea, the Office of Atomic Energy was placed directly under the President and the nuclear program was structured as a monopoly under the Korea Electric Power Corporation." However, even South Korea–arguably the world leader in centralization, standardization, and successful learning-by-doing in the nuclear industry–offers examples of how decentralization can impede timely NPP construction:

> *Yonggwang*[5] *was one of the first of the state-owned utility (Korea Electric Power Co KEPCO) projects to attract serious local opposition. Political reform in South Korea has devolved some power from the centre. Local politicians in Yonggwang used their new strength to slow down construction.*
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> *Hanjung (Korea Heavy Industries and Construction) was due to begin construction in December 1995, but a delay was brought on by the cancellation of construction permits for the site by Yonggwang County, South Cholla Province.*[6]

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[5] Yonggwang NPP was renamed Hanbit NPP in 2013.

[6] "The Yonggwang Units at the South Korea Nuclear Power Plant." *Power Technology.* `https://www.power-technology.com/projects/yonggwang/`

3.1 The Logic of Local Democratic Control

Decentralization is one factor among many in the argument of Cohen et al. (1995). However, I theorize that it holds a greater significance in explaining the political economy of power plant construction. Subnational governments are commonly structured with a separation (or fusion) of powers similar to that of that national government. To the extent subnational autonomy permits, this implies the possibilities of vetoes held by the subnational legislature, the executive (if not fused with the legislature), the bureaucracy (if insulated from political control), and the judiciary. This means that a regional jurisdiction with strong institutional capacity and autonomy from the central government potentially offers many venues in which opponents of a plant may intervene in its construction.

Furthmore, I draw on the framework of Mancur Olson's seminal work, *The Logic of Collective Action* (1965). The standard problem considered by Olson posits some policy with concentrated benefits to a small group and diffuse costs to the rest of society. Lobbying the government to advocate for or against the policy requires overcoming a collective action problem, as no one individual can meaningfully influence the outcome. Olson argues that this situation inherently favors small groups for whom overcoming the collective action problem is comparatively easy and for whom the benefits to an individual participant are quite large.

To analyze the political economy of power plant construction, I modify Olson's problem in three ways. First, I give a spatial dimension to group identity and interest, as defined by proximity to the proposed plant. For example, those who live within the range of a hypothetical evacuation or exclusion zone in the event of a catastrophic nuclear accident are the small group; those who live further away and yet would still benefit from the plant in some way are the rest of society.

Next, I invert the distribution of costs and benefits. The small group now faces a geographically concentrated risk while the rest of society stands to gain diffuse benefits. Of course, there is also the geographically concentrated benefit in the form of increased local economic activity. However, given that many types of power plants are typically sited in rural areas to minimize the population impacted, it is not uncommon for residents to regard this benefit as a cost—increased development ruining the character of a small community, such as at Bodega Bay, California (Wellock, 1998). Local advocacy for power plants on the basis of their local economic benefits typically does not emerge until the plant begins operating, its workers settle into the community, and the economic impact is observed.

The primary diffuse benefit consists of the electricity produced by the plant, which can be transmitted by the electricity grid to households and firms hundreds of miles away. The electricity may not be particularly valuable if substitute sources of electricity can be had at little, zero, or negative additional cost. However, other diffuse benefits include avoided externalities, [7] lessening of national dependence on expensive energy imports,[8] downstream flood control and water management provided by hydroelectric dams, and interregional technological spillovers through learning-by-doing.

In a final modification of Olson's original framework, I observe that democratic subnational government is a ready-made solution to the collective action problem faced by local residents who do not want a certain power plant "in their backyard." Elected politicians are strongly incentivized to care about the interests of constituents in their jurisdiction and may take on the cause of opposing power plant construction as an electoral strategy. Even when the issue does not immediately arouse the attention and action of subnationtal politicians, the subnational government offers a more convenient forum with lower transaction costs in which local opponents of a nearby NPP can mobilize and effectuate policy. A subnational government with sufficient autonomy and institutional capacity can directly intervene to regulate construction without ever needing to lobby or influence the national government.

I call this modified framework "the logic of local democratic control." It can be applied to a variety of political economy problems of a spatial nature, such as municipal zoning laws causing regional housing shortages, routing disputes over high-speed rail lines, and opposition to the provision of infrastructure and services to aid the mentally ill and homeless. In the case of power plant construction, I argue it can explain the patterns we see in the data through three possible mechanisms:

Mechanism 1: Regulatory Delays

Political authorities impose conditions that cause construction to be temporarily halted or to proceed more slowly than would otherwise occur.

Mechanism 2: Conservatism in Design

Political authorities require firms to adopt certain design characteristics in the interests of safety, environmental protection, or other public concerns. These design characteristics are inherently more costly than those that firms would have otherwise chosen.

Mechanism 3: Resetting of the Learning Curve

Political authorities require firms to adopt a more radically revised design as opposed to a gradual evolution of an existing design. This forces firms to abandon gains from continuing with an established learning curve and begin exploring a new learning curve.

Fuel Source	Mean OCC (2010$/kW)	N	Mean LT (months)	N
Biomass	$1,797	3	22	1
Coal	$1,414	211	57	159
Geothermal	$3,031	4	–	0
Hydroelectric	$2,824	191	117	29
Natural Gas	$1,339	138	36	3
Nuclear	$2,765	489	91	623
Oil	$1,820	19	60	1
Solar	$7,988	39	27	23
Waste	$8,916	2	–	0
Wind	$2,404	79	12	18

Table 1: Summary statistics for overnight capital cost (OCC) and lead time (LT). The columns titled N report the number of observations for which each type of data are available.

4 Data

Tables 1 and 2 present summary statistics on the economic outcome and technological specifications of power plants included in the database assembled for my analysis. The subsections that follow discuss the data sources and data cleaning.

4.1 Nuclear Power Plants

Portugal-Pereira, Ferreira, Cunha, Szklo, Schaeffer, and Araújo (2018) assembled a database of overnight capital costs for 522 nuclear power plants, which is approximately 80% of the global population. They draw on the earlier work of Koomey and Hultman (2007), Berthélemy and Escobar Rangel (2015), and Lovering et al. (2016) while expanding data coverage to nations not included in those previous studies. For lead time and all other characteristics of nuclear power plants, I rely on Benson (2019), to which the reader is referred for an in-depth discussion of the data sources, data cleaning, and methodology. The data from Benson (2019) is comprehensive of the global population of every commercial nuclear power plant ever built as of 2018.

Unfortunately, comparable datasets do not exist for other types of power plants. Therefore, the present work relies on samples of convenience drawn from prior literature or other publicly available data sources.

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[7] Assuming the substitute sources of electricity are polluting. Historically, this has been the case (Kharecha and Hansen, 2013).

[8] Even for nations building nuclear power plants, importing uranium is much cheaper per unit of final electricity generated than fossil fuels.

Prime Mover	N	Fuel/Technology	N
Steam Turbine	906	Nuclear	623
		Coal	236
		Other Fossil	7
		Solar Thermal	31
		Other Renewable	9
Gas Turbine	24	Natural Gas	24
Combined Cycle (steam turbine + gas turbine)	114	Gas	112
		Coal	1
		Solar Thermal	1
Internal Combustion Engine	17	Oil	11
		Diesel	4
		Natural Gas	2
Not Thermo-Electric	279	Onshore Wind	63
		Offshore Wind	16
		Impounded Hydro	87
		Run-of-River Hydro	41
		Pumped Storage Hydro	16
		Solar PV	7

Table 2: Summary of technological characteristics of power plants in the sample.

4.2 Coal Power Plants

Komanoff (1981) assembled a database of nuclear and coal power plants built in the United States. Because I rely on more recent and comprehensive sources for the overnight capital cost and other data relating to nuclear power plants, I only draw on Komanoff (1981) for his data on coal power plants. The sample consists of 116 plants, built between the mid-1960s and late 1970s. This corresponds reasonably well to the period when most nuclear power plant in the United States began construction. However, due to extreme delays in the nuclear sector, many plants only finished construction in the 1980's or even early 1990's. Komanoff's dataset only includes coal plants that finished construction prior to 1978. This introduces obvious concerns about selection bias that I address in Section 5.

In Benson (2019), I observe that South Korean nuclear power plants are global leaders in achieving short lead times, with remarkably little variance. With this in mind, I sought out data on lead time for South Korean coal power plants as a point of comparison. I draw on data supplied by Lee, Lee, and Alleman (2018) for 18 South Korean coal-fired generating units, built between the mid-1990s and the present. I further supplement this sample with eight observations of South Korean coal-fired units using data provided by Power-Technology.com, a website which provides news and analysis on the energy sector. The resulting South Korean coal power plant dataset the nameplate net generating capacity in megawatts, the dates of commencing and finishing construction, the type of coal burned, the method of steam condenser cooling, whether the plant's steam cycle is classified as super-critical or ultra-super-critical, and whether SO_2 control equipment was installed during construction (rather than added later).

4.3 Other Types of Power Plants

To broaden the set of technologies represented in this study, I draw on two further sources.

Sovacool, Gilbert, and Nugent (2014) assemble a database of 401 construction projects in the electric utility sector. Of these, fifty are transmission lines, which I exclude from my sample due to their non-comparability to power plants, which are the topic of this paper. Another 180 observations provided by Sovacool et al. (2014) are of nuclear power plants; I exclude the data provided by Sovacool et al. (2014) and preferentially rely on Portugal-Pereira et al. (2018), whose cost data benefit from more recent scholarship. I exclude six multinational hydroelectric dams because of the ambiguity in attributing multiple countries' political institutions and economic conditions to a single project.

Sovacool et al. (2014) categorize power plants as wind, hydro, solar, nuclear, and thermal. However, there are meaningful differences in technology and fuel within the categories of "solar" and "thermal" (i.e. fossil-fired); these differences are strongly associated with differing capital costs. I reviewed their appendices and collected further specifying information about plants of these categories. For solar farms, I identify whether the farm installed photovoltaic or solar thermal technology. For fossil-fired thermal power plants, I identify the fuel used (coal, natural gas, oil) and the type of prime mover (steam turbine, gas combustion turbine, combined-cycle, or internal combustion engine). This level of specificity enables comparability with the other datasets I draw upon. However, in two cases, their appendices provided insufficient information to independently verify the existence of two thermal power plants listed in their dataset, precluding the possibility of ascertaining their fuel type and prime mover. Therefore, I exclude these two plants.[9]

Of the 164 observations retained from Sovacool et al. (2014), 55 are hydroelectric, 32 are solar thermal, 7 are solar PV, 35 are wind, 25 are coal-fired, 4 are natural gas-fired, 4 are diesel-fueled, and 1 is biomass-fired. Variables include name of the power plant, the country in which it is located, nameplate net electric capacity in megawatts, year of initial operation,

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[9] "Argenne [sic]" (United States, 960 MW) and "Jamaia [sic] Energy Sector" (Jamaica, 90 MW). Variations on these terms with alternate (correct) spellings were entered into Internet search engines and other databases of power plants. No results were found that were consistent with the data provided by (Sovacool et al., 2014).

lead time in months, and overnight capital cost in 2012USD per kW, which I deflate to 2010USD.

The Global Energy Observatory (GEO)[10] is a crowd-sourced website with geo-located data on power plants, transmission lines, coal mines, LNG terminals, and other energy infrastructure. While the crowd-sourced nature of this data raises questions about its accuracy, the site requires users to register with the site before making changes and all changes are subject to moderation by the site's creators, Dr. Rajan Gupta and Harihar Shankar, researchers at Los Alamos National Laboratory.

While GEO includes 10,082 power plant observations, its coverage of capital cost is relatively sparse, with capital cost reported for only 568 observations. One issue confounds the cross-comparability of GEO data on capital cost with data from other sources. The GEO codebook[11] instructs users to report total capital cost. Although the codebook is not explicit on this point, this is likely intended to be inclusive of accumulated financing expenses during construction. Overnight capital cost, which is the standard metric for comparison of power plants built under differing financing arrangements, excludes these costs. To control for this, I include fixed effects for the data source in all regressions that combine multiple datasets.

For observations whose capital cost is reported in currencies other than US dollars, I convert to US dollars using PPP-adjusted exchange rates from the World Bank [12] (which provides global coverage from 1990 to the present) and the OECD[13] (which provides coverage of OECD countries and other major economies beginning in 1960). I then use the US GDP deflator to adjust all costs to 2010 US dollars.[14]

Other data from GEO include the name of the power plant, the country and subnational jurisdiction in which it is located, the plant's latitude and longitude, nameplate net electric capacity in megawatts, fuel type, and other plant characteristics such as prime mover (if applicable), secondary fuel (if any), and certain features of renewable energy generation (e.g. run-of-river, impounded reservoir, pumped storage; on-shore vs. off-shore wind). GEO provides a year in which capital cost was reported (which I use as the relevant year for currency conversion and inflation adjustment)[15], but it does not report construction lead time.

GEO provides capital cost for two nuclear power plants. I drop one, Units 1 & 2 Kudankulam NPP in India (which are reported jointly as a single observation), because it is

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[10] `http://globalenergyobservatory.org/`

[11] `http://www.globalenergyobservatory.org/docs/GlossaryGeoPower.php#Common`

[12] `https://data.worldbank.org/indicator/pa.nus.ppp` Accessed May 9th, 2019.

[13] `https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm` Accessed May 9th, 2019.

[14] `https://fred.stlouisfed.org/series/GDPDEF` Accessed May 9th, 2019.

[15] For 127 observations, capital cost is reported without a corresponding year. I drop these observations.

already represented in Portugal-Pereira et al. (2018). I drop the other, the China Experimental Fast Reactor (CEFR), which is not a commercial nuclear power plant and is excluded from Benson (2019).

GEO duplicates Sovacool et al. (2014) in one instance[16]; I preferentially retain the overnight capital costs reported by Sovacool et al. (2014), although they quantitatively differ very little.

The resulting cleaned and processed GEO dataset consists of 407 observations, of which 136 are hydroelectric, 134 are natural gas, 70 are coal, 44 are wind, 15 are oil, 4 are waste, and 4 are geothermal.

4.4 Country-Level Data

For the cross-country analysis, I collected and matched to each power plant variables describing country-level characteristics as of the year construction began, or—where not available—the year of the "current dollar year" for which overnight capital cost was reported. These include democracy-autocracy score from the Polity IV project (Marshall et al., 2018), GDP per capita from the Maddison Project (Bolt et al., 2018), and the Regional Authority Index (RAI) (Hooghe et al., 2016),

The Regional Authority Index (RAI) (Hooghe et al., 2016) is a quantitative measure of political decentralization at the subnational level. Drawing on the constitutions and political histories of individual countries, the RAI systematically scores each country on the basis of a variety of aspects, such as the role of subnational governments in approving constitutional change, whether the central government holds a veto over subnational decisions, and the autonomy of subnational jurisdictions in setting their tax base and rates. These scores are summed to generate indices along two dimensions of decentralization: self-rule ("the authority exercised by a regional government over those who live in the region") and shared rule ("the authority exercised by a regional government or its representatives in the country as a whole"). These two indices are then summed to generate a single, generalized measure of decentralization, which they call the Regional Authority Index (RAI). For the theoretical reasons elaborated in section 3, I rely solely on the self-rule index, as it better captures the mechanisms by which local opponents of a power plant may intervene in its construction.

Summary statistics on country characteristics are presented in Table 3. Polity ranges from -10, denoting total autocracy, to +10, denoting a strong democracy. Positive values of the RAI self-rule sub-index indicate higher levels of regional autonomy. GDP per capita is in 2010 PPP-adjusted US dollars.

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[16] The John. W. Turk Jr. Coal Plant in the United States

Variable	Min.	Mean	Median	Max.	Std. Dev.	N
Polity	-10	5.4	8	10	6.5	1,339
RAI Self-Rule	0	15.1	19	24.1	7.2	802
GDP per capita	$688	$18,155	$17,575	$152,349	$12,886	1,338

Table 3: Summary statistics of country characteristics. See text for definitions.

4.5 American State-Level Data

While a decentralized constitutional structure is a necessary precondition for sub-national governments to exert meaningful influence on power plant construction, decentralization is not sufficient if nearby residents have no objection to the power plant. Therefore, I rely on data which measures or is a proxy of public and elite attitudes toward nuclear power and environmental protection generally at the subnational level. Because of the large number of observations in the United States, I rely on the the Correlates of State Policy Project (Jordan and Grossmann, 2016), a massive database that collates quantitative data on state politics, policies, and economies from a wide variety of published sources.[17] The variables used in the analysis are summarized in Table 4.

Variable	Min.	Mean	Median	Max.	Std. Dev.	N
Liberalism of state policy	-2.06	0.00	0.05	2.27	0.88	248
Liberalism of citizen ideology	6.3	42.2	46.6	80.6	19.1	239
Percent of respondents to a 1973 survey who say the government is spending ... on protecting the environment						
"too little"	47.7%	62.3%	63.0%	74.0%	5.9%	248
"too much"	4.2%	8.2%	8.0%	13.4%	2.2%	248
Count of registered interest groups in the state						
Pro-environmental	0	7.6	5	29	6.9	223
Utility or energy-related	0	14.8	13	34	7.2	223
State-level economic characteristics						
Per capita personal income (*inflation-adjusted, 2010 dollars*)	$17,040	$23,411	$23,840	$30,865	$2,420	239
Percent of adults with HS diploma	64.3%	74.6%	75.4%	85.1%	5.0%	248
Prevailing wage law in effect	0	.79	1	1	.41	248

Table 4: Summary statistics for variables used in the cross-state analysis of US coal and nuclear power plants. Source: (Jordan and Grossmann, 2016)

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[17] Hat tip to Sargis Karavardanyan for introducing me to this resource and to its creators for collating the data of so many prior studies.

5 Methodology

In the present analyses, I focus on testing the hypothesized mechanisms (1) "regulatory delays" and (2) "conservatism in design." If otherwise identical plants cost more or take longer to build in otherwise economically comparable jurisdictions which vary solely in their political characteristics, I attribute the effect to either cost / delays directly imposed by regulators or firm behavior in response to a less favorable regulatory environment. Mechanism (3) ("resetting the learning curve") should be tested in future research.

5.1 Cross-Country Model

The cross-country model is estimated with the following regression:

$$\begin{aligned} ln(Y_i) = \alpha &+ \beta_{1f} Polity_{ct} + \beta_{2f} RAI_{ct} + \beta_{3f} Polity_{ct} \times RAI_{ct} + \gamma_1 ln(GDP_c) \\ &+ \gamma_{2f} ln(MW_i) + \gamma_{3f}\mathbb{I}\{cogen_i\} + \gamma_{4f}\mathbb{I}\{dualfuel_i\} + \gamma_{5p} + \gamma_{6s} \\ &+ \gamma_7 ROT_i \mathbb{I}\{nuclear_i\} + \gamma_8 CCL_i \mathbb{I}\{nuclear_i\} + \gamma_{9d} + \gamma_{10} suspended_i \\ &+ \gamma_{11}\mathbb{I}\{pair_i\} + \gamma_{12f} t + \varepsilon_{ic} \end{aligned} \tag{1}$$

where i is an index of observations (power plants), f is an index of fuel sources (e.g. coal, nuclear, wind), c is an index of countries, p is an index of prime movers, s is an index of categorical technical specifications (e.g. onshore vs. offshore wind), d is an index of data sources, and t is an index of years. Plant i is matched with year t based on the year construction began or, if that datum is not available, the year associated with the reported construction cost in GEO. Standard errors are clustered by country.

Y_i is the outcome of interest for plant i, either overnight capital cost (OCC) in 2010USD per kW, or lead time in months. $Polity_{ct}$ is the Polity score of country c in year t. RAI_{ct} is the self-rule subindex of the RAI of country c in year t. MW_i is the rated net electric capacity of plant i in megawatts. $\mathbb{I}\{cogen_i\}$ is an indicator variable that takes on the value 1 if plant i is designed for cogeneration (co-production of electricity and useful heat). $\mathbb{I}\{dualfuel_i\}$ is an indicator variable that takes on the value 1 if the plant i is designed to run on multiple types of fuel. $\mathbb{I}\{nuclear_i\}$ is an indicator variable that takes on the value 1 if the plant i is a nuclear power plant. ROT_i is the reactor outlet temperature in degrees centigrade of a nuclear reactor. CCL_i is the count of primary coolant loops of a nuclear reactor. $Suspended_i$ is the number of years construction was suspended before being later resumed. $\mathbb{I}\{pair_i\}$ is an indicator variable that takes on a value of 1 if plant i was the second in a pair (or third of a triplet) of identical plants built together at the same site.

5.2 Cross-State Model

The cross-state model is estimated with the following regression:

$$\begin{aligned} ln(Y_i) = \alpha &+ \beta_{1f}T_{st} + \beta_{2f}AT_{st}\gamma_{1f}ln(Pers.Inc._{st}) + \gamma_{2f}HS_{st} + \gamma_{3f}\mathbb{I}\{PW_{st}\} \\ &+ \gamma_{4f}ln(MW_i) + \gamma_5\mathbb{I}\{SO_{2i}\} + \gamma_{6f}StartDate_i \\ &+ \mathbb{I}\{nuclear_i\}\Big[\gamma_7 ROT_i + \gamma_8 ACPD_i + \gamma_9 RPV_i + \gamma_{10m} + \gamma_{11CC}\Big] + \varepsilon_{is} \end{aligned} \tag{2}$$

where i is an index of observations (power plants), f is an index of fuel sources (coal and nuclear), s is an index of states, m is an index of nuclear reactor manufacturers, and t is an index of years. Plant i is matched with year t based on the year construction began. Where the data on the treatment variable do not provide sufficient temporal coverage of the years in the sample, a representative year is selected and used for all observations. This year is reported where applicable. $StartDate_i$ is the calendar date on which construction of plant i began. Standard errors are clustered by state.

Y_i is the outcome of interest for plant i, either overnight capital cost (OCC) in 2010USD per kW, or lead time in months. T_{st} is the treatment of interest (multiple are tested) for state s as of year t. AT_{st} is an ancillary treatment included in some but not all regressions to help improve the precision of the estimated treatment effect. MW_i is the rated net electric capacity of plant i in megawatts. $\mathbb{I}\{SO_{2i}\}$ is an indicator variable that takes on the value 1 if the plant was built with SO_2 control equipment,[18] rather than installed later. $\mathbb{I}\{nuclear_i\}$ is an indicator variable that takes on the value 1 if the plant i is a nuclear power plant. ROT_i is the reactor outlet temperature in degrees centigrade of a nuclear reactor. $ACPD_i$ is the average core power density a nuclear reactor in kW per deciliter. RPV is the height of the reactor pressure vessel in meters.

Because General Electric exclusively manufactures boiling water reactors (BWRs) while the other three major firms exclusively manufacture pressurized water reactors (PWR), γ_{10m} effectively also controls for whether a nuclear power plant is a BWR or PWR.

γ_{11CC} is an trinary indicator variable regarding the era of plant construction relative to the decision in Calvert Cliffs' Coordinating Committee, Inc. v. United States Atomic Energy Commission (1971). This was an important event in the history of the US nuclear industry because a federal appeals court held that Atomic Energy Commission had to revise its licensing procedures to comply with the recently-passed National Environmental Policy Act (NEPA). This led to a backlog of licensing delays for plants that were under construction at the time. γ_{11CC} takes on three possible values: (1) "finished construction prior to the Calvert

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[18] Only applicable to coal-fired plants.

Cliffs decision", (2) "under construction during the Calvert Cliffs decision", and (3) "began construction after the Calvert Cliffs' decision." However, there is potential endogeneity in which nuclear power plants are assigned which value of this variable. Consider two otherwise identical plants which began construction in 1965. If one plant finished construction in 1970 and the other plant finished in 1973, it is not necessarily true that the difference can be attributed to the Calvert Cliffs' decision. The reason for this is that unobserved heterogeneity–by definition–explains why the second plant received the treatment (regulatory delay created by the decision).

To account for this, I construct dummy variables representing four eras of construction, to which each nuclear plant is assigned based purely on when it began construction. The eras are (1) prior to 1964, representing small "prototype" plants, (2) between 1964 and 1968, the era when plants were most likely to finish before the Calvert Cliffs decision, (3) between 1968 and 1972, when plants were likely to be impacted by the decision, and (4) 1972 and beyond, plants that began construction after the decision.[19] I use these dummy variables to instrument for γ_{11CC}. I argue that these dummies meet the exclusion criterion because I am separately controlling for a continuous time trend for the nuclear industry.

6 Results: Cross-Country Analysis

The results of the cross-country analysis are presented in Table 5. They are consistent with my hypothesis that certain types of plant exhibit higher costs and longer lead times as a function of a country's political institutions. In particular, the costs and lead time of coal, nuclear, and hydroelectric plants increase in decentralization. These plants are common targets of local opposition. In certain cases, this effect is only exhibited in highly democratic countries; in other cases, the marginal effect of decentralization is not a function of democracy. Furthermore, even a marginal effect of .02 is quite economically significant, as it implies a one-standard-deviation increase in decentralization (7.15 units of RAI self-rule) is associated with 14.3% increase in the outcome of interest.

The most puzzling interaction between democracy and decentralization concerns solar and wind farms. These types of plants are pooled together due to the paucity of solar observations in the data and because they are broadly viewed similarly. They are, at times, the subject of local opposition due to the intensive land use required and visual impacts in rural settings. However, they enjoy very large support from the public and policymakers at large for being "clean" and "renewable." The results in table 5 imply that decentralization

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[19] All but one of the plants in this final category were under construction when the Three Mile Island accident occurred in 1979, making this category effectively an indicator for that event.

Fuel Source	marginal effect of decentralization on log overnight capital cost, given a Polity score of... 6	8	10	significance of democracy × decentralization interaction	N
Coal	0.042 (0.032)	0.035 (0.020)	0.028* (0.011)	$t = -0.52$	154
Oil & Gas	-0.029 (0.020)	-0.017 (0.012)	-0.005 (0.007)	$t = 1.27$	77
Nuclear	-0.001 (0.006)	0.020 (0.011)	0.041* (0.018)	$t = 2.81$	251
Hydroelectric	0.010 (0.016)	0.032* (0.015)	0.054** (0.018)	$t = 2.86$	79
Solar & Wind	0.140*** (0.028)	0.061*** (0.013)	-0.018* (0.007)	$t = -5.07$	99

Fuel Source	marginal effect of decentralization on log lead time, given a Polity score of... 6	8	10	significance of democracy × decentralization interaction	N
Coal	0.096 (0.049)	0.149** (0.046)	0.203*** (0.042)	$t = 14.13$	152
Oil & Gas	*too few observations*			—	2
Nuclear	0.021*** (0.006)	0.023*** (0.005)	0.025*** (0.007)	$t = 0.60$	356
Hydroelectric	0.045*** (0.012)	0.051*** (0.010)	0.056*** (0.013)	$t = 0.79$	14
Solar & Wind	*dropped during estimation due to multicollinearity*			—	37

Table 5: Estimated marginal effects of a one-unit increase decentralization on power plant construction overnight capital cost and lead time, for selected levels of democracy best represented in the data. Decentralization is measured by the self-rule subindex of the Regional Authority Index, which takes ranges from observed values of 0 to 24.1. Democracy is measured by Polity score, which ranges from -10 for maximal autocracy to +10 for maximal democracy. Coefficients on control variables are omitted for brevity.

raises the costs of solar and wind farms in imperfectly democratic countries while it slightly lowers costs in fully developed democracies. The interaction effect is highly significant. Such a finding is not explained by my theory. It appears unlikely that this result is being driven by chance as a consequence of only a few countries being included in sample, as these 99 observations are based in 17 different countries, with the most represented country (Spain) contributing 21 observations. Other major countries this result is based on include Canada (n=15), Australia (n=13), United States (n=10), Denmark (n=9), and Estonia (n=8). Validating this result in a larger dataset merits future research.

An alternative explanation for what sets coal, hydroelectric, and nuclear power plants apart from other types of power plants is "megaproject syndrome." Plants which employ steam turbines tend to be quite large and complex, and hydroelectric dams consistently suffer from unexpected shocks to cost and schedule due to unique geologic conditions uncovered during construction. By contrast, gas turbines, solar PV panels, and wind turbines tend to achieve economies of serial production through assembly line manufacture. It may be that decentralization is spuriously associated with conditions that exercerbate "megaproject syndrome."

This result could also be consistent with the possibility of omitted variables that are correlated with both decentralization and productivity in the construction of megaprojects. However, the lack of an effect of decentralization on nuclear power plants under this specification–the model estimates an effect that is relatively quite close to zero–points against this possibility.

7 Results: Cross-State Analysis

Results of the cross-state analysis for US coal and nuclear power plants are summarized in Table 6. A full regression output is provided in the appendix, in Table 7. In general, although not all treatment variables exhibit meaningful predictive effects, the results are broadly consistent with the hypothesis that nuclear power plant costs are far more responsive than coal plants to the political environment of the state in which they are built.

In unreported regressions, I find that the absence of a treatment effect on coal plants is not explained by dropping the variable for SO_2 control equipment. One might have guessed that this is the mechanism through which liberal state politics would impact coal power plant costs. For most states, national regulation by the EPA is the primary determinant of whether a coal plant adopts pollution abatement equipment.

In unreported regressions, I find that controlling for a states' CPI relative to the national average CPI does not add any explanatory power to the model, although it does cause many

Treatment Variable (*Unit of Measure*)	Marginal Effect of the Treatment Coal ln OCC	 Coal ln LT	 Nuclear ln OCC	 Nuclear ln LT
State policy liberalism (*1 S.D. on dimensionless index*)	0.032 (0.106)	0.039 (0.032)	0.187*** (0.060)	0.074* (0.036)
Citizen ideological liberalism (*1 point on 100 point scale*)	-0.002 (0.004)	0.001 (0.001)	0.008** (0.003)	0.003 (0.002)
Pro-environmental public attitude (*percentage point of survey respondents)*	0.018 (0.024)	0.002 (0.014)	0.055* (0.023)	0.013 (0.040)
Registered environmental interest groups (*count*)	0.002 (0.011)	-0.001 (0.003)	0.009 (0.014)	0.005 (0.007)

Table 6: Coefficients of interest from separate regressions of various treatments on power plant construction outcomes in the United States. Pro-environmental public attitude is based on respondents to a 1973 survey who agreed with the statement "The government is spending too little on the environment." The regression with interest groups also controls for the count of registered utility and energy-related industry groups.

treatment effects to become marginally significant. This is unsurprising given the strong correlation between liberal politics, big cities with restrictive land use policies, and the cost of living. Furthermore, this modification to the model barely quantitatively alters the magnitude of the points estimates of the treatment effects. Finally, an alternate explanation for my results based on the general cost-of-doing-business cannot explain why many treatment variable affect nuclear power plants but not coal power plants. I posit that this is because of the heightened political opposition to nuclear power plants relative to coal power plants during this era.

8 Conclusion

This paper estimated the effect of decentralization and subnational politics on capital cost and lead time in power plant construction. I relied upon a global sample of power plants to evaluate whether the results in Benson (2019) were unique to nuclear power plants or applied more generally. I find that coal, hydroelectric, and nuclear power plants exhibit increasing costs and lead times as a function of decentralization. Within the United States, I show that the economics of nuclear power plant construction are associated with state-level political variables, whereas coal plants built during the same era are not.

Some skepticism of these results is merited for lack of a direct measure of local opposition to individual plants. Quantitative research of this type would be worth pursing in the future.

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		Coal		Nuclear	
Explanatory Variable / Control	Unit of Measure	ln OCC	ln LT	ln OCC	ln LT
State Policy Liberalism	one standard deviation on a dimensionless index	0.032 (0.106)	0.039 (0.032)	0.187** (0.060)	0.074* (0.036)
Average State Income	log of personal income per capita	-1.378* (0.536)	-0.204 (0.222)	0.382 (0.595)	0.082 (0.342)
Prevailing Wage Law	Binary Indicator = 1 if state had a prevailing wage law	0.140 (0.122)	0.055 (0.056)	0.160 (0.097)	.109 (0.073)
High School Education	percentage point of population with a high school diploma as of 1975	0.011 (0.006)	0.002 (0.003)	-0.027* (0.012)	-0.027*** (-0.008)
Nameplate Net Electric Capacity	log of megawatts	-0.142** (0.052)	0.180*** (0.041)	-0.248 (0.227)	0.620*** (0.157)
Sulfur Dioxide Control Equipment	Binary Indicator = 1 if plant was built with SO_2 control equipment	0.359*** (0.094)	0.030 (0.043)		
Reactor Outlet Temperature	degree centigrade			0.003 (0.013)	0.007 (0.008)
Height of the Reactor Pressure Vessel	meter			-0.168* (0.074)	-0.106* (0.042)
Average Core Power Density	kW per liter			0.002 (0.004)	0.002 (0.003)
Time Trend	day construction began	Yes	Yes	Yes	Yes
Calvert Cliffs decision (instrumented)	indicator variables, see text	N/A	N/A	Yes	Yes
Reactor Supplier Fixed Effects	indicator variables	N/A	N/A	Yes	Yes
R^2		39.3%	60.4%	39.3%	60.4%
N		116	116	111	112

Table 7: Regression of overnight capital cost (OCC, in \$/kW) and lead time (LT, in months) of coal and nuclear power plants built in the United States on state-level characteristics and design specifications. Unless otherwise stated, state-level characteristics are as of the year construction began. Standard errors clustered by state.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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