POLICY CHALLENGES OF NUCLEAR REACTOR CONSTRUCTION, COST ESCALATION AND CROWDING OUT ALTERNATIVES

LESSONS FROM THE U.S. AND FRANCE FOR THE EFFORT TO REVIVE THE U.S. INDUSTRY WITH LOAN GUARANTEES AND TAX SUBSIDIES

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Debate over the cost of building new nuclear reactors in the U.S. and abroad has returned to center stage in U.S. energy policy, as the effort to expand loans guarantees heats up in the wake of the failure to move climate change legislation forward. The French nuclear program is frequently given the spotlight because of its presumed success and because the state-owned French nuclear champion EDF has bought a large stake in a major U.S. utility and is seeking to build a new U.S. reactor with federal loan guarantees.

Missing from the current scene is information about the history and recent experience of French nuclear costs, detailed analyses of past U.S. costs or current cost projections, and a careful examination of the impact of the decision to promote nuclear reactor and central station construction on the development of alternatives.

This paper fills those gaps by analyzing these two major challenges of nuclear reactor construction -- cost escalation and crowding out alternatives -- with new data in multiple analytic approaches.

Type of Analysis	**Data:** **Cost Escalation**	**Crowding Out Alternatives**
Cross national comparisons	U.S. and France	Western European nations (& U.S.)
Qualitative Examination	U.S. & French history	Individual U.S. utility examples
Statistical analysis	Econometric production function	Correlation analysis of 10 variables

FINDINGS: COST ESCALATION

The report finds that the claim that standardization, learning, or large increases in the number of reactors under construction will lower costs is not supported in the data.

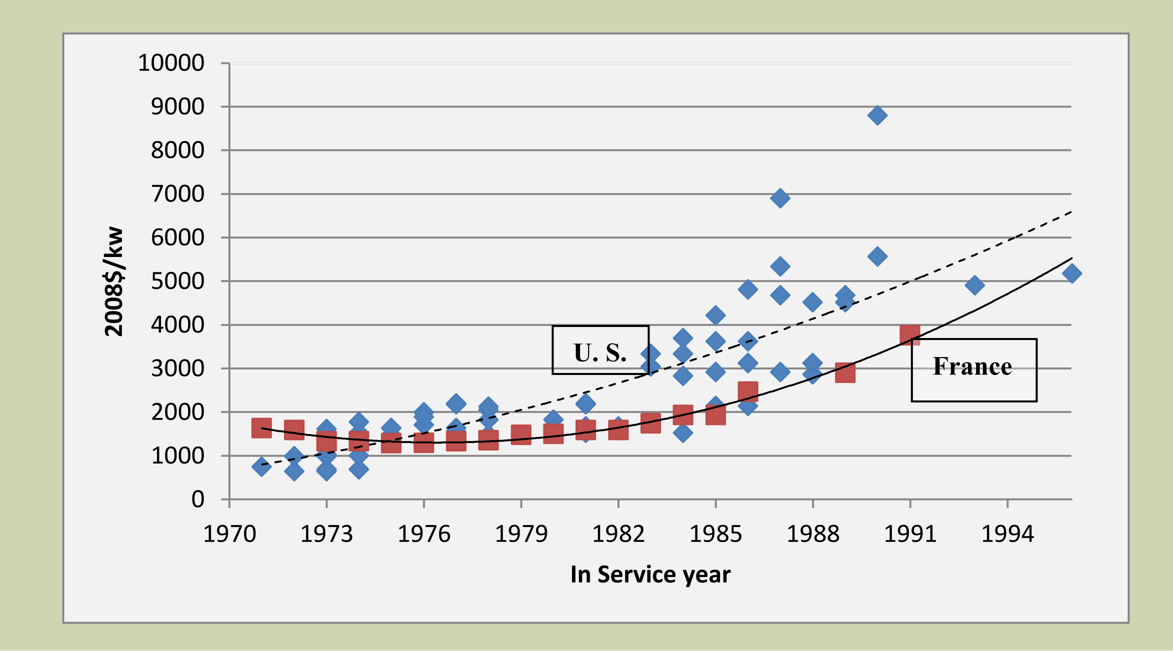
- The increasing complexity of nuclear reactors and the site-specific nature of deployment make standardization difficult, so cost reductions have not been achieved and are not likely in the future. More recent, more complex technologies are more costly to construct.
- Building larger reactors to achieve economies of scale causes construction times to increase, offsetting the cost savings of larger reactors.

Comparing Pressurized Water Reactors, which are the main technologies used in both nations, we find that both the U.S. and French nuclear industries experienced severe cost escalation (see Exhibit ES-1).

- Measured in 2008 dollars, U.S. and French overnight costs were similar in the early 1970s, about $1,000 per kW. In the U.S. they escalated to the range of $3,000 to $4,000 by the mid-1980s. The final reactors were generally in the $5,000 to $6,000 range.

- French costs increased to the range of $2,000-$3,000 in the mid-1980s and $3,000 to $5,000 in the 1990s.

EXHIBIT ES-1: OVERNIGHT COSTS OF PRESSURIZED WATER REACTORS (2008$)



Source: Cooper, 2009a, database, updated; Grubler, 209.

Cost projections in both nations have proven to be unreliable, particularly so in the U.S., where vendors compete to convince utilities to buy their designs. In France, the state-owned construction company builds reactors for the state-owned utility. In the U.S., as shown in Exhibit ES-2, cost projections by vendors have been lower than those of utilities, which have been lower than projections from independent analysts. In the past, the analysts' projections have been closer to the actual costs.

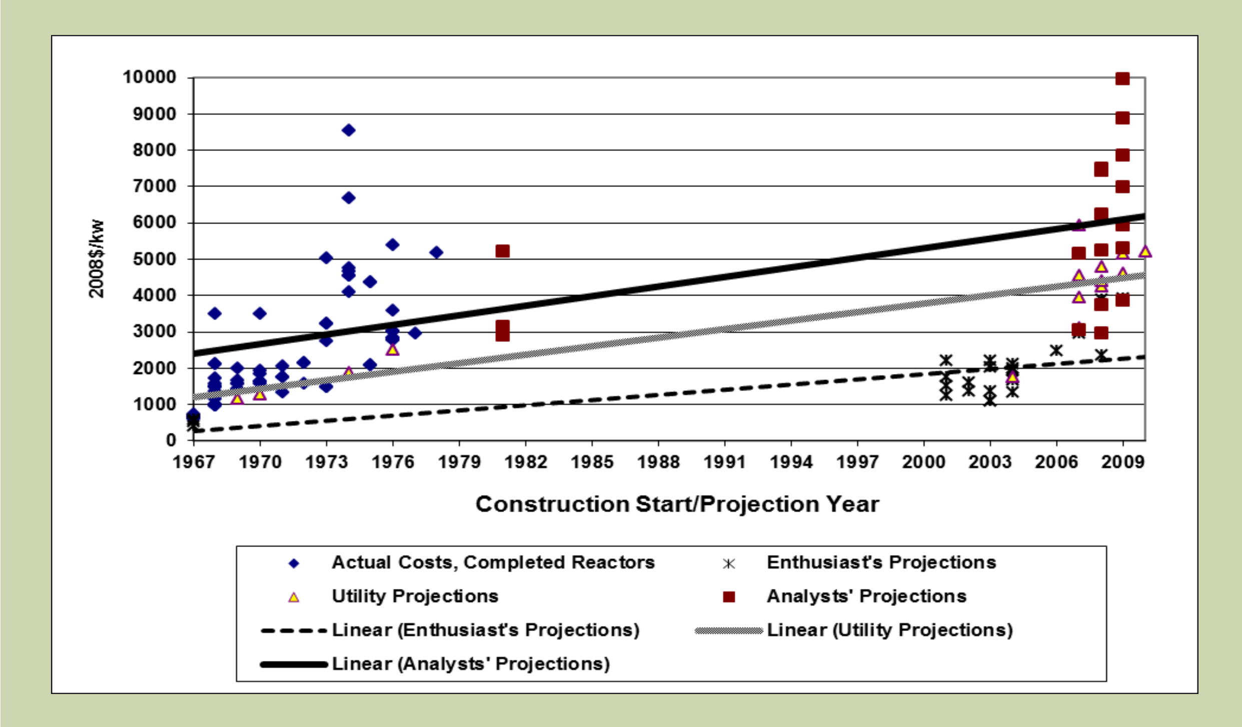
FINDINGS: CROWDING OUT ALTERNATIVES

The commitment to nuclear reactors in France and the U.S appears to have crowded out alternatives. The French track record on efficiency and renewables is extremely poor compared to similar European nations, as is that of the U.S.

States where utilities have not expressed an interest in getting licenses for new nuclear reactors have a better track record on efficiency and renewable and more aggressive plans for future development of efficiency and renewables, as shown in Exhibit ES-3. These states:

- had three times as much renewable energy and ten times as much non-hydro renewable energy in their 1990 generation mix and

EXHIBIT ES-2: INITIAL COST PROJECTIONS VASTLY UNDERESTIMATE ACTUAL COSTS



Source: Cooper, 2009, database.

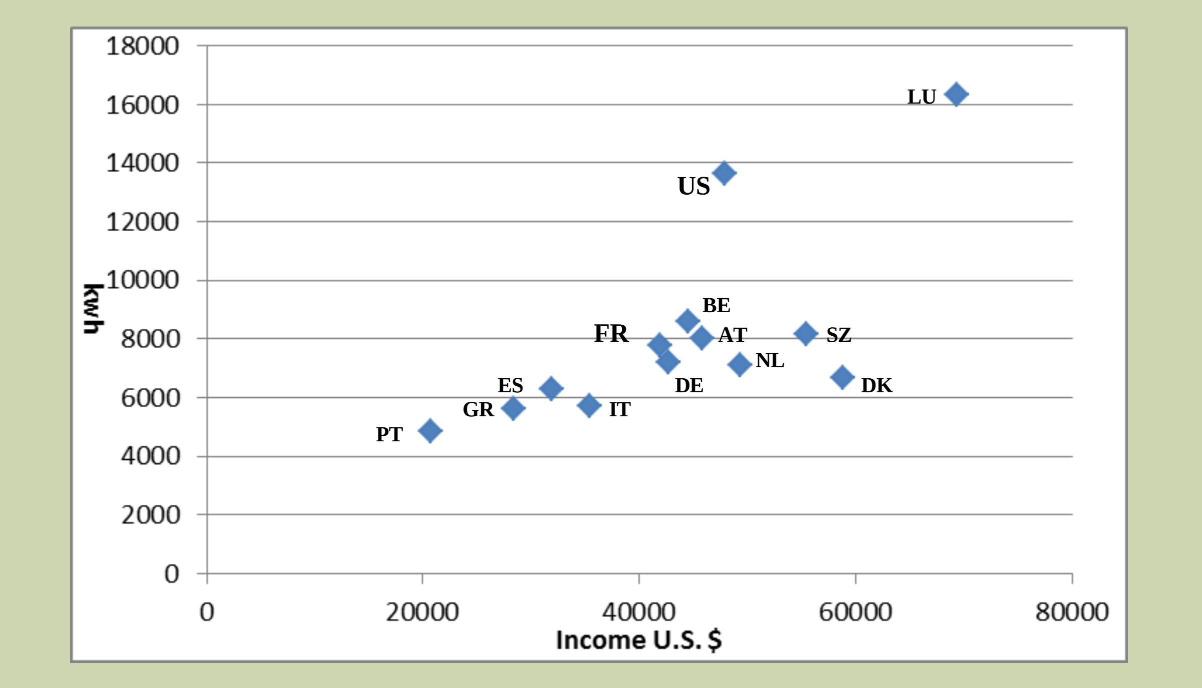
EXHIBIT ES-3: TESTING THE CROWDING OUT HYPOTHESIS IN THE U.S.

Category Means	**Renewable % of 1990 Generation**	**Non-hydro Renewables as % of 1990 Generation**	**RPS Goal (%) 2010**	**Efficiency Spend as % of 2006 Revenue'**	**Energy Saved % of total Energy**	**ACEEE Utility Efficiency Program Score 92 – '06**
Central Station Plans 2009						
None	**19.23**	**0.61**	**16.22**	**0.95**	**2.78**	**9.08**
Nuke or Coal	**7.48**	**0.02**	**11.26**	**0.46**	**1.13**	**5.21**
Nuke & Coal	**4.04**	**0.0**	**7.36**	**0.29**	**0.60**	**1.79**
Nuke License: State						
None	**15.09**	**0.40**	**14.33**	**0.82**	**2.29**	**7.72**
Pending	**6.66**	**0.03**	**9.58**	**0.25**	**0.58**	**3.38**
Nuke License Utility						
None				**0.47**	**2.42**	
Pending				**0.06**	**0.94**	
Correlation (Significance)						
Central station	**-.50**	**-..06**	**-.10**	**-.28**	**-.37**	**-.27**
as % of Total	**(.002)**	**(.696)**	**(.477)**	**(.012)**	**(.0070**	**(.052)**
1990 Generation						
Central Station	**-.29**	**-.19**	**-.29**	**-.34**	**-.39**	**-.42**
Plans	**(.039)**	**(.178)**	**(.037)**	**(.016)**	**(.051)**	**(.002)**
Nuclear License	**-.18**	**-.10**	**-.20**	**-.30**	**-.33**	**-.34**
Pending State Utility	**(.039)**	**(.491)**	**(.166)**	**(.033)**	**(.017)**	**(.009)**
				-.20	**-.13**	
				(.046)	**(.186)**	

- set RPS goals for the next decade that are 50 percent higher;
- spent three times as much on efficiency in 2006;
- saved over three times as much energy in the 1992-2006 period, and
- have much stronger utility efficiency programs in place.

The cost and availability of alternatives play equally important roles. In both nations, nuclear reactors are substantially more costly than the alternatives. The U.S. appears to have a much greater opportunity to develop alternatives not only because the cost disadvantage of nuclear in the U.S. is greater, but also because the portfolio of potential resources is much greater in the U.S. The U.S. consumes about 50 percent more electricity per dollar of gross domestic product per capita than France, which have the highest electricity consumption among comparable Western European nations (see Exhibit ES-4).

EXHIBIT ES-4: ANNUAL ELECTRICITY CONSUMPTION IN WESTERN EUROPE AND THE U.S.



Sources and notes: World Bank per capita electricity consumption and Gross National Income.
http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC
http://data.worldbank.org/indicator/NY.GNP.PCAP.CD

- The U.S. has renewable opportunities that are four times as great as Europe.
- Design problems and deteriorating economic prospects have resulted in a series of setbacks for nuclear construction plans and several utilities with large nuclear generation assets who had contemplated building new reactors have shelved those plans because of the deteriorating economics of nuclear power relative to the alternatives.

POLICY IMPLICATIONS

The two challenges of nuclear reactor construction studied in this paper are linked in a number of ways. Nuclear reactors are extremely large projects that tie up managerial and financial resources and are affected by cost escalation, which demands even greater attention. The reaction to cost escalation has been to pursue larger runs of larger plants in the hope that learning and economies of scale would lower costs. In this environment, alternatives are not only neglected, they become a threat because they may reduce the need for the larger central station units.

The policy implications of the paper are both narrow and broad.

Narrowly, the paper shows that following the French model would be a mistake since the French nuclear reactor program is far less of a success than is assumed, takes an organizational approach that is alien to the U.S., and reflects a very different endowment of resources.

Broadly the paper shows that it is highly unlikely that the problems of the nuclear industry will be solved by an infusion of federal loans guarantees and other subsidies to get the first plants in a new building cycle completed. If the industry is relaunched with massive subsidies, this analysis shows the greatest danger is not that the U.S. will import French technology, but that it will replicate the French model of nuclear socialism, since it is very likely that nuclear power will remain a ward of the state, as has been true throughout its history in France, a great burden on ratepayers, as has been the case throughout its history in the U.S., and it will retard the development of lower cost alternatives, as it has done in both the U.S. and France.

I. DRAWING INSIGHTS FROM THE HISTORICAL AND CROSS-NATIONAL EXPERIENCE OF THE NUCLEAR INDUSTRY

RESEARCH ISSUES ARISING FROM THE DEBATE OVER NUCLEAR REACTOR CONSTRUCTION

The history of the dramatic escalation of the construction cost of nuclear reactors in the U.S. has been well documented and the causes hotly debated. On average, the reactors completed in the U.S. cost about twice as much as their initial projections and the final reactors built during the "Great Bandwagon Market"[1]of the 1970s cost seven times as much as the initial reactors.[2] Proponents of nuclear power blame a large part of the cost escalation on public opposition to reactor construction and claim that the next generation of reactors will not suffer the cost overruns experienced by the last,[3] in part because public opposition has declined. They frequently point to the success of the French as proof that cost escalation can be controlled.[4] The fact that the French nuclear giant EDF has purchased a large stake in a major U.S. electric utility – Constellation Energy – and is seeking a license to build a new reactor at Calvert Cliffs Maryland has heightened interest in the French approach. Ironically, this interest comes a time when the severe difficulties that the French nuclear industry is having in building its new generation of nuclear reactors in France and Finland and in securing competitively bid contracts elsewhere is receiving a great deal of attention in the U.S. media.[5]

Given the current economics of nuclear reactor construction in both the U.S. and France, advocating for an expansion of nuclear power involves government involvement and subsidies.[6] Two questions arise. First, will large subsidies be a permanent part of a commitment to build large numbers of nuclear reactors? Second, how will a major commitment to nuclear reactor construction impact the prospects for development of alternatives? While concerns about climate change lead some to argue we must do everything to address the problem, the most aggressive advocates of nuclear reactor construction see the commitment to nuclear construction as competing with alternatives.[7]

Missing from the current scene is information about the history and recent experience of French nuclear costs, detailed analyses of past U.S. costs or current cost projections and a careful examination of the impact of the decision to promote nuclear reactor construction on the development of alternatives.

A clear understanding of what works and does not work in the U.S. and France and how major commitments to one technology affect others can shed important light on the prospects for construction of new nuclear reactors and alternatives.

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[1] Bupp and Derian, 1978.

[2] EIA, 1986.

[3] An early and thorough explanation of the underlying problems can be found in Bupp and Derian, 1978. Recent example of the extremely optimistic view can be found in MIT, 2003; University of Chicago 2004.

[4] Alexander, 2009

[5] In a two week period spanning the end of July and the beginning of August, a number of issues were reported on in major U.S. print media outlets including: Safety (New *York Times;* Brett, 2010), French industry structure (Time, Levin, 2010, *Wall Street Journal,* 2010); company (EDF) financial status (*New York Times,* Saltmarsh, 2010; *Bloomberg,* Patel), project viability (*Baltimore Sun,* Cho, 2010, *Dow Jones,* Peters, 2010);. Roussely, 2010, presents a critique of the French export efforts.

[6] Recent analyses by objective third parties make this clear. On France see Roussely, 2010. On the U.S. see Standard and Poor's, 2010.

[7] Alexander, 2010.

ANALYTIC APPROACH

This paper combines a new analysis of a detailed data set on the U.S. cost experience with recently published cost data on the French experience[8] and compares that history to current cost projections.[9] The historical accounts suggest that crowding out existed in the past, so contemporary and statistical data is marshaled to examine the crowding out issue more fully.[10] Thus, this paper fills the knowledge gaps affecting two major challenges of nuclear reactor construction -- cost escalation and the crowding out alternatives – by examining new data in multiple analytic approaches.

To put the issues in traditional research terms, the public policy claims in the contemporary debate can be transformed into research hypothesis as follows:

> H_{r1}= Nuclear construction costs decline over time as a result of learning, standardization, and increasing economies of scale
>
> H_{r2}= Nuclear reactor construction does not crowds out alternatives.

These hypotheses are examined at several levels.

Type of Analysis	**Cost Escalation**	**Crowding Out Alternatives**
Cross national comparisons	U.S. and France	Western European nations (& U.S.)
Qualitative Examination	U.S. & French history	Individual U.S. utility examples
Statistical analysis	Econometric production Function	Correlation analysis of 10 variables

FINDINGS AND IMPLICATIONS

The paper shows that the intensity of the debate over nuclear reactor construction is well justified. It finds that the cost escalation problem is endemic to nuclear technology. The inherent problems in nuclear reactor design and construction mean that the reduction in cost that nuclear advocates hope would result from "learning-by-doing" or increasing scale has not materialized in the past and is not likely to happen in the future. The historical and quantitative evidence supports the conclusion that commitments to nuclear reactors and central station facilities crowd out the alternatives.

Moreover, the paper shows that the two challenges of nuclear reactor construction studied in this paper are linked in a number of ways. Nuclear reactors are extremely large projects that tie up managerial and financial resources and cost escalation demands even greater attention. The reaction to cost escalation has been to pursue larger runs of larger plants in the hope that learning and economies of scale would lower costs. In this environment, alternatives are not only

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[8] Grubler, 2009, presents the quantitative cost analysis. Schneider, 2008, has discussed the industry from a qualitative perspective.

[9] Cooper, 2009a, presents a compilation of recent cost projections. The U.S. database is derived from Koomey and Hultman, 2007. The database used in this analysis has been updated to include half a dozen recent projections. Because long-term comparisons are being made, this analysis uses the producer price index for capital goods as a deflator, instead of the consumer price index.

[10] Qualitative cross national comparisons have been made of European nations (e.g. Froggatt and Schneider, 2010) and univariate analyses of performance on alternative technologies have been offered for both Europe (see Geller, et al., 2006; Olz, 2007; Suding, 2007. Olz, 2007; Ragwitz and Held, 2007) and the U.S. (see Chicetti, 2009 and ACEEE, 2009). This paper quantifies the measures and offers bivariate analysis that relates reliance on central station generation to the development of alternatives.

neglected, they become a threat because they may reduce the need for the larger central station units.

These finding have major implications for the ongoing debate over building new nuclear reactors in the U.S. At present, the cost of constructing new reactors is projected to result in a cost of electricity that is substantially higher than the alternatives, so high in fact that utilities cannot raise capital on Wall Street to fund these projects at a normal cost of capital.[11] To fill the gap, the nuclear industry is seeking subsidies from federal taxpayers, in the form of loan guarantees and tax credits, and from ratepayers, in the form of construction work in progress and guaranteed recovery of costs, while they hold out the hope/promise that costs will come down.[12] The empirical evidence reviewed in this paper suggests that the hope/promise is unlikely to be fulfilled. Nuclear construction costs will remain high and a large-scale building program will require continuous subsidies from taxpayers and ratepayers. Moreover, because the costs and demands for subsidies are so high, the crowding out effect is likely to be strong, as scarce financial resources are devoted to the high cost projects.

OUTLINE

The paper is organized as follows:

Section II discusses the cost trends in the U.S. and France, as well as the record of cost projection in the two nations. The cost experience was a major topic of public discussion in the 1980s in the U.S., as cost overruns created rate shock for consumers, which was a major contributor to the abandonment of about half of U.S. reactors that had been ordered to be abandoned or cancelled.[13] The cost experience in France was shrouded in the secrecy of a state-owned monopoly company, but has recently been examined in a study by Grubler. The problems that the French industry is having building the current generation of reactors has become front page news. Comparing the historical experiences of the two nations with detailed data and reviewing the current pattern of escalating cost projections provides important insights into the pattern of cost escalation in the industry. Section II concludes with an explanation for the trends in terms of general economic processes.

Section III examines the characteristics of nuclear reactors that account for the overall trend of cost escalation using a series of bivariate analyses for both France and the U.S. The French data is extracted from published graphs and tables, but access to the underlying data was not provided, so the comparison between the two nations is limited to this bivariate approach. However, section III concludes with a detailed, multivariate econometric model to assess which factors are the most important in the U.S. The multivariate regression model for the U.S. enables us to analyze the causes of cost escalation with greater precision and it confirms the findings of the bivariate analysis.

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[11] Cooper, 2009b reviews the current financial challenges facing nuclear reactor construction and identifies key Wall Street analyzes that elaborate on this issue including Moody's, 2008, 2009, Kee (NERA), 2009, Maloney (Towers Perrin), 2008, 2009, and Atherton (CITI), 2009.

[12] For example, the original MIT (2003) study started with a low overnight cost ($2,000/kW) and considered only lower costs. The update (MIT, 2009) used costs of $4,000/kW, which are still well below the costs projected by most other analysts.

[13] Cook, 1986; Komanoff, 1992.

Section IV presents qualitative and quantitative evidence on the tendency for nuclear reactors and central station facilities to crowd out alternative like efficiency and renewables. It shows that the cost of these alternatives is lower than nuclear reactor construction in both the U.S. and France and cites evidence that there are more opportunities to pursue these alternatives in the U.S.

Section V reviews the discrepancies in the U.S. between cost projections and cost performance from different sources. It offers observations on the contemporary experience in the startup of the U.S. “nuclear renaissance” and closes with some conclusions for policymakers on the implications of the cost escalation and crowding out of nuclear reactor construction.

II. NUCLEAR REACTOR COST ESCALATION

COST TRENDS

As shown in Exhibit II-1, the nuclear construction programs in both the U.S. and France exhibited a continuous escalation of costs from the outset. The estimated overnight costs cost numbers from the published French figures and U.S. data are shown in 2008 dollars and placed on two separate graphs.[14]

The French data looks smoother than the U.S. data because the cost estimates are year-by-year costs for all reactors put under construction in a given year.[15] Even if specific reactor costs were used, the French cost curve is likely to be smoother, because there was a single monopoly company in France in contrast to over a dozen companies in the U.S. In France, at present, one reactor is under construction. In the U.S., one reactor is under construction, but there have been a flurry of cost estimates since 2001. The current French project and the U.S. cost projections will be discussed below.

In France, from the low-cost point in the mid-1970s to the high-cost point in early 1990s, costs for new reactors have more than tripled. The cost escalation came in three spurts, from the mid-1970s to the end of the 1970s, from the mid-1980s to the end of the 1980s, and in the beginning of the 1990s.[16] French costs increased from a low of just under $1,000/kW to $1,500/kW by the end of the 1970s. The costs escalated to $2,000/kW by the end of the 1980s and $3,000/kW in the 1990s. The projected cost for the reactor currently under construction is in the range of $4,500 to $5,000/kW.

The U.S. cost increase was similar to the French in the first decade, from about $1,000/kW to $2,000/kW, with the average cost for the decade of about $1,250/kW. Cost escalation was faster in the U.S in the second decade, with the French going from $2,000/kW to $3,000/kW while the U.S. costs increased to an average of $3,600/kW, with a number of units much higher. As we shall see below, the current projected costs of reactors in the U.S. are literally all over the map, with the 2008-2009 cost estimates clustering in the $4,000 to $6,000/kW range, with estimates going as high as $10,000/kW.

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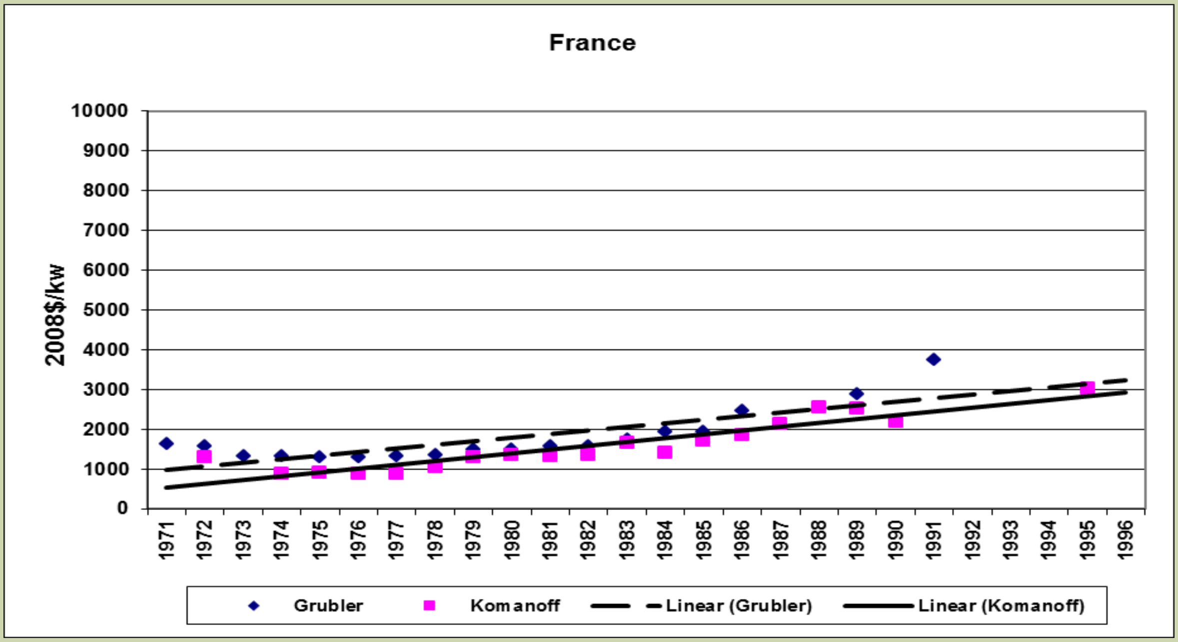
[14] Wikipedia defines overnight costs as follows: "**Overnight cost** is the cost of a construction project if no interest was incurred during construction, as if the project was completed "overnight." An alternate definition is: the present value cost that would have to be paid as a lump sum up front to completely pay for a construction project." http://en.wikipedia.org/wiki/Overnight_cost

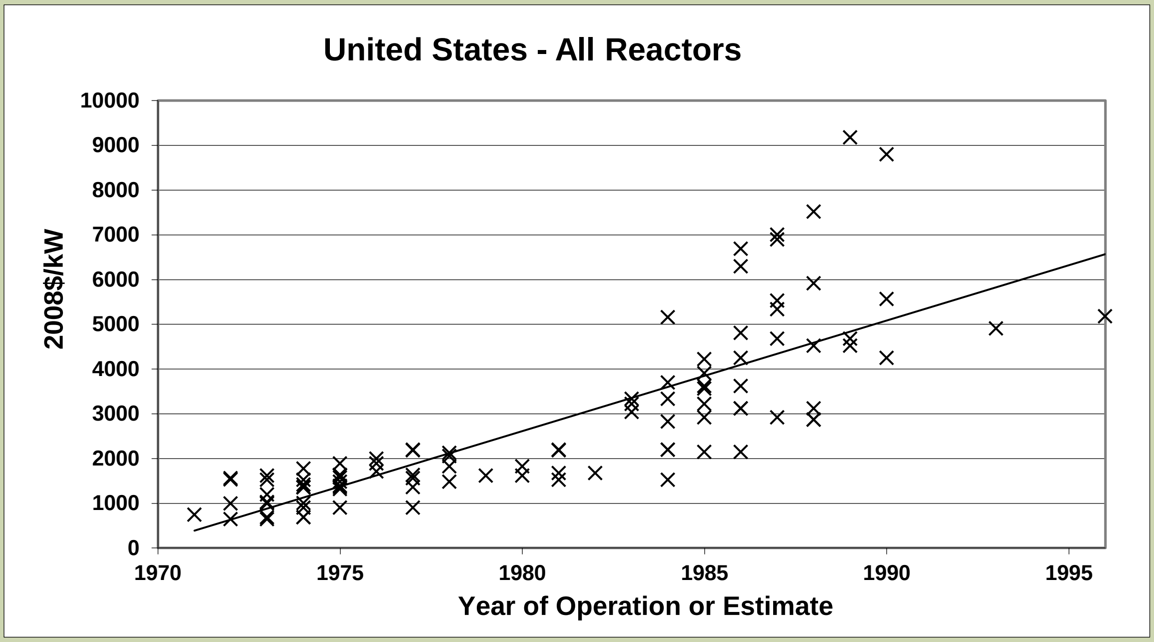
[15] Grubler, 2009. Two papers have been published based on the data (Komanoff, 2010), is the second). One presents the original range of estimates per year. The other presents point estimates for each year.

[16] Grubler, pp. 25-26, One French reference (though discussions of cost are extremely rare in this period) put the escalation of real investment per kW at 50% or 4.4%/year during 1974-1984 (as reported by Crowley and Kaminski, 1985). "Yet these trends did not cause alarm, as other countries were suffering even worse escalation—as in Germany and especially the US, with 10-15% real cost escalation per year. Between 1974 and 1984, specific real investment costs increased from some 4,200 to 7,000 FF98/kW (gross capacity), or by some 5% per annum. Between 1984 and 1990, costs escalated from some 7,000 to 10,000 FF98/kW, or by some 6% per annum. For the last reactors, the "entirely French design" N4 series, the inferred construction costs are about another 45 percent higher (14,500 FF98/kW "best guess" model estimate). …We conclude, therefore, that the **last N4 PWR reactors built were some 3.5 times more expensive, in constant Francs per kW, than the early 900-MW units** that started the French PWR program."

EXHIBIT II-1: FRENCH AND U.S. NUCLEAR REACTOR OVERNIGHT COSTS (2008$)



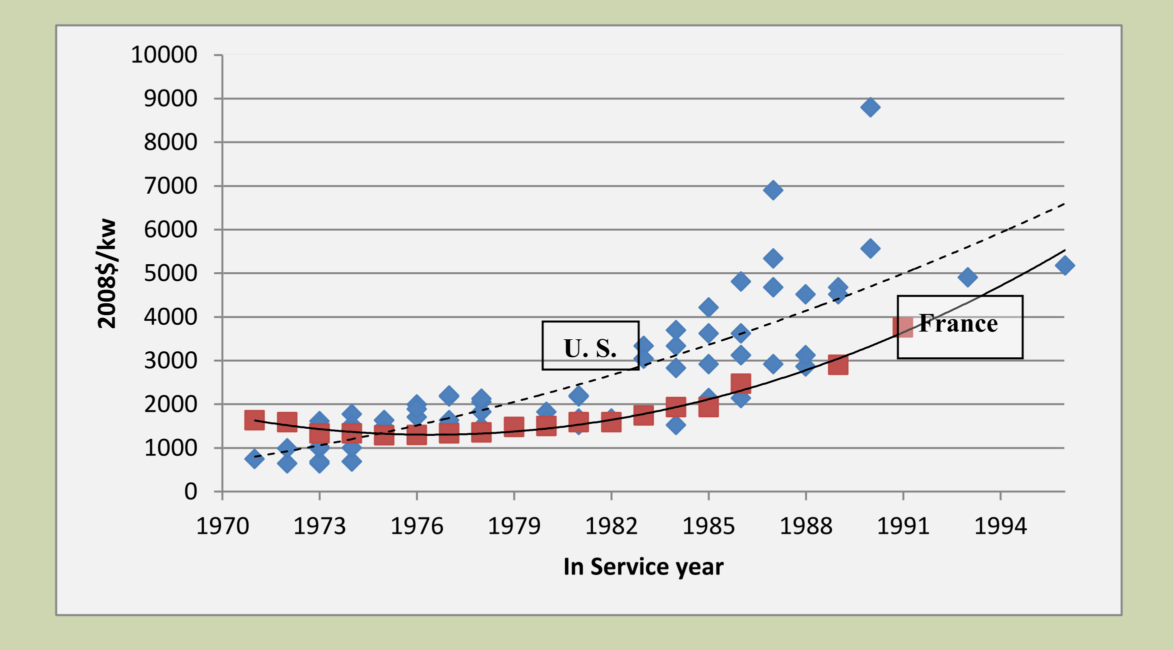
Grubler, 2009, Figure 8; Komanoff, 2010, Figure 1.



Cooper, 2009a, database updated

Exhibit II-2 begins to explain some of the differences between the French and U.S. experiences. It shows the U.S. costs for pressurized water reactors (PWR) and suggests that part of the large difference in cost escalation between the two countries can be explained by the homogeneity of technology in France. About two-thirds of the U.S. reactors used PWR technology, while all the French reactors used this technology (in fact the French PWR industry was launched with a licensed U.S. design, American Pressurized Water Reactor). The French tried to "Frenchify" this design over time and Grubler attributes the worst of the cost escalation to this endeavor. However, it remained basically a PWR design. The PWR technology was the dominant technology in the U.S. as well. There are 69 pressurized water reactors in the U. S. database, compared to the 54 in the French database.

EXHIBIT II-2: OVERNIGHT COSTS OF PRESSURIZED WATER REACTORS (2008$)



Source: Cooper, 2009a, database, updated; Grubler, 209.

The cost escalation trends in the two countries are closer when a single technology is examined. As noted above, by the end of the 1980s, French reactors were consistently in the range of $2,000/kW to $3,000/kW. In the U.S., costs for PWRs increased from $1,200/kW in the 1970s to $3,100/kW in the 1980s. Three-quarters of the U.S. PWR reactors cost less than $3,000/kW. Most of the reactors in the U.S. were in the $4,000/kW to $6,000/kW range by the 1980s. Thus, the U.S. PWRs were closer in cost to the French PWRs than the BWR reactors. Virtually all of the currently proposed reactors in the U.S. for which there are site-specific projections are PWRs of one form or another. All of the generic costs estimates in recent years have been for PWR technologies. Therefore, the remainder of the side-by-side analyses in this section will focus on the PWR subset. We control for technology in the econometric analysis by including a technology variable in the overall regression and performing regressions in the subset of PWRs only.

Exhibit II-2 suggests a second factor that should be incorporated into the analysis. Cost escalation was greater for the reactors built later. The TMI accident occurred in 1979 and caused a probing review of safety, which increased the construction period of the reactors that had not been completed. To account for this and ensure that the analysis of the causes of cost escalation does not confuse the effects of TMI with other factors, we incorporate TMI into the analysis in two ways that are similar to the manner in which we handle technology. We include it as a control variable in the analysis of the full data set and we conduct the analysis separately in subsets of the reactors completed.

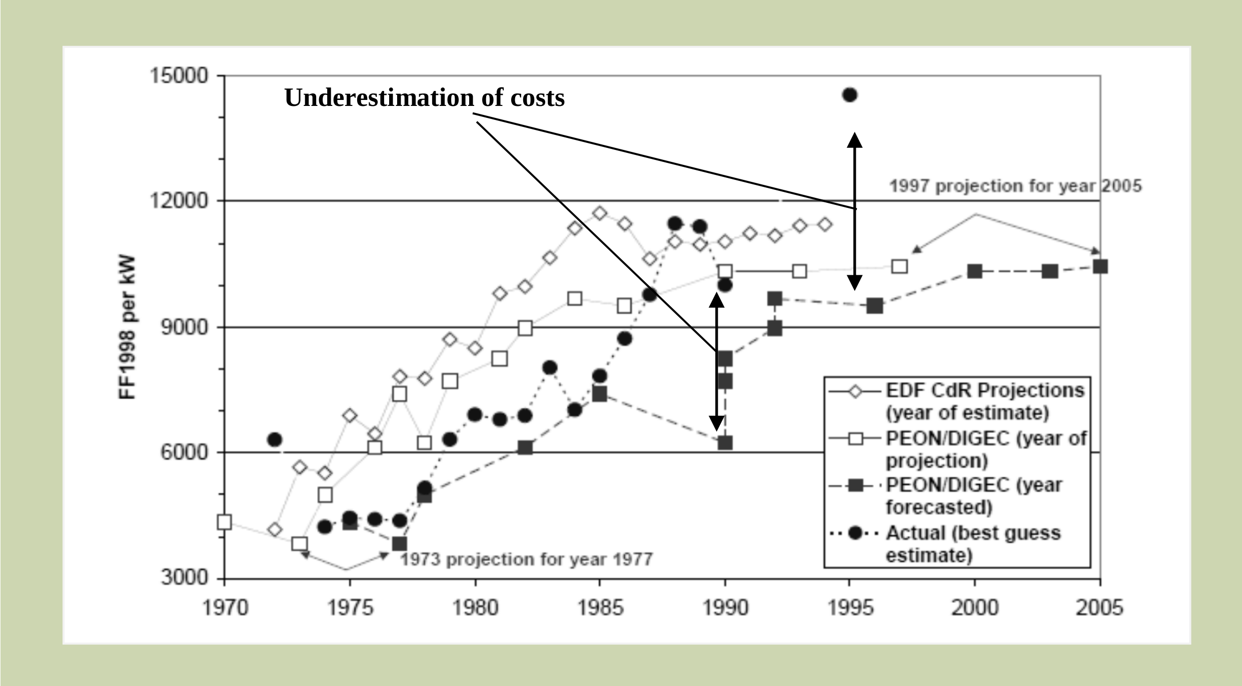
COST PROJECTIONS

The Historical Experience

In an industry that was undergoing rapid cost escalation, we should not be surprised to find that cost projection was a problem, particularly in the U.S. where reactors had to be "marketed" to individual utilities. From the beginning of the industry in the U.S., cost projections have crept up slowly, while the actual cost of construction skyrocketed. The timing of the problem was different in France, but the underlying cause was the same.

Exhibit II-3 shows Grubler's comparison of cost projections and actual costs in France. The solid circles in the Exhibit reflect the actual costs. The solid squares reflect the projected costs. Beginning in the mid-1980s the actual costs began to exceed the projected costs. The projections adjusted, but never caught up.

EXHIBIT II-3: FRENCH COST PROJECTIONS



Grubler, Figure 11

Grubler sees a certain strategic motivation behind the underestimation of costs, even in the French system, where the reactors were being deployed subject to a central plan, rather than being "marketed" to individual utilities.

> The projections also bear witness to the economic expectations of the actors. Declining trends indicate the cost-reducing expectations (though never realized) of upscaling to the 1300-MW reactor series, and also, by the mid-1980s, the unfounded hopes of cost savings from the N4 reactor design [the final design in the building cycle that ended in the 1990s]. It is particularly noteworthy that while cost projections in the 1970s and 1980s reflected cost escalation trends well from actual experience (albeit with a delay), they no longer did so in the 1990s, when the substantial cost overruns and difficulties of the N4 reactor design must have been apparent to all insiders, yet were not visible in the cost projections. Apparently, the projections no longer served their original purpose—to communicate the benefits of the nuclear program within France's technocratic elite—but were rather instrumentalized—so as not to add insult to injury—to communicate an economic success story whilst distracting from the difficulties encountered with the problem N4 reactors. Ever since, the cost projections have further lost their credibility and usefulness in public discourse and decision-making.[17]

This characterization of cost projections suggests a mix of motivations, genuine uncertainty, and also manipulation of cost data for political reasons. Other analysts have come to a similar conclusion in the U.S. (that cost estimates were politicized) for both the nuclear construction boom of the 1970s and the recent round of cost projections offered by nuclear advocates.[18]

> At the beginning of 1970, none of the plants ordered during the Great Bandwagon Market was yet operating in the United States.
>
> This meant that virtually all of the economic information about the status of light water reactors in the early 1970s was based upon expectation rather than actual experience. The distinction between cost records and cost estimation may seem obvious, but apparently it eluded many in government and industry for years…
>
> In the first half of this crucial 10-year period, the buyers of nuclear power plants had to accept, more or less on faith, the seller's claims about the economic performance of their product. Meanwhile, each additional buyer was cited by the reactor manufacturers as proof of the soundness of their product…The rush to nuclear power had become a self-sustaining process...
>
> There were few, if any, credible challenges to this natural conclusion. Indeed, quite the contrary. Government officials regularly cited the nuclear industry's analyses of light water plants as proof of the success of their own research and development policies. The industry, in turn, cited those same government statements as official confirmation. The result was a circular flow of mutually

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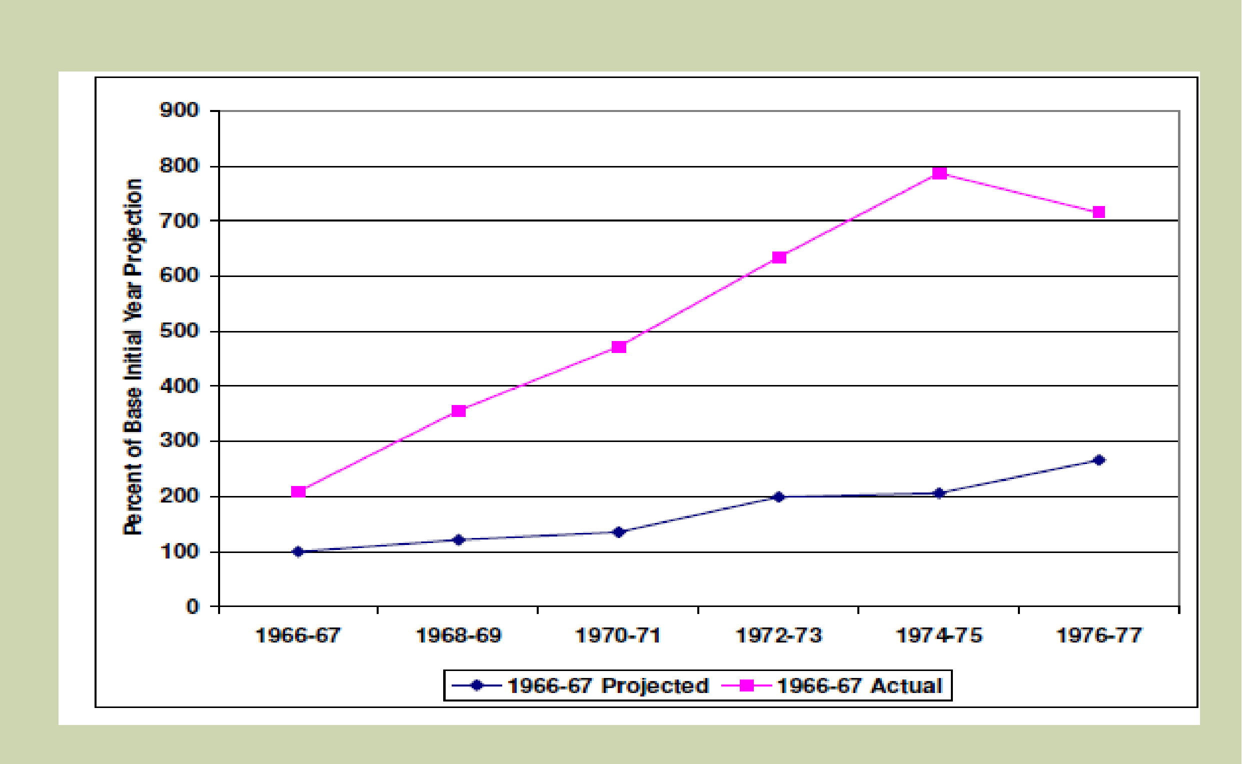
[17] Grubler, p. 30.
[18] Cooper, 2009a, Chapter IV.

> reinforcing assertion that apparently intoxicated both parties and inhibited normal commercial skepticism about advertisements which purported to be analyses. As intoxication with promises about light water reactors grew during the late 1960s and cross-national and even ideological boundaries, the distinction between promotional prospectus and critical evaluation become progressively more obscure.
>
> From the available cost records about changing light water reactor capital costs, it is possible to show that on average, plants that entered operation in 1975 were about three times more costly in constant dollars than the early commercial plants competed five years earlier.[19]

As shown in Exhibit II-4, U.S. cost projection was farther off the mark sooner than the French. This reflected both that vendors were trying to convince utilities to buy their products (creating a tendency to low-ball cost projections) and that costs were escalating more rapidly in the U.S. Thus, the gap between hype and reality was larger and grew faster.

EXHIBIT II-4: U.S. UNDERESTIMATION OF COST



Cooper, 2009, based on EIA, 1986.

The Contemporary Experience

The construction of nuclear reactors in the U.S. ended in the mid-1990s. Over 90 percent

---

[19] Bupp and Derian, 1978, pp.71… 72…74…75…76…78…79.

of the reactors in France were also completed by that time. Construction of one new reactor commenced in France in 2007. Interestingly, one of the most prominent indices of the cost of construction of central station generation facilities – the IHS-CERA index – tells a story about cost escalation in recent years that is remarkably similar to the historical experience, as shown in ExhibitII-5.

Since 2000, the IHS-CERA Power Capital Cost Index, which is used to indicate changes in the cost of power plant construction that includes nuclear reactors, has escalated much more rapidly than the index without nuclear in both the U.S. and Europe. However, the disparity is much greater in the U.S., where nuclear cost estimates have increased by 113 percent, compared to 77 percent in Europe. Grubler gives an estimate for France and described it as follows:

> Using the N4 [the final design in the building cycle that ended in the 1990s] costs as a precursor model of the subsequent EPR design, one might speculate on updating its costs to current conditions. Converting the N4 14,700 FF98/kW into 2007 money and considering a cost escalation factor of 1.5 based on the Handy-Whitman (Whitman, Requard & Assocs, 2008) construction cost index (which has reflected French cost escalation well over the period 1975-1990) yields a conservative estimate of at least 3,000 Euro (2007) or 4,500 US$2007 per kW under current conditions for a N4/EPR design reactor under favorable (French) construction conditions. This lower-bound estimate is still higher than the recent MIT update (Deutch *et al.,* 2009) of nuclear construction costs of some 4,000 US$/kW, suggesting that the MIT estimates are once again optimistic… In the meantime, climate policy analysts may well be advised to consider nuclear construction costs to the tune of 5,000 US$/kW (i.e. a number close to solar PVs) in scenarios and sensitivity analyses. Even this may prove conservative, since some utility and financial-analyst estimates of nuclear construction cost published in the US in 2008 approach 8000$/kW (US$ 2007 including interest during construction).[20]

Grubler's estimate of $5,000/kW (US$2007) for the current French EPR projects is close to the estimates U.S. utilities are using for non-French technologies. As shown in Exhibit II-6, this is still considerably below the estimates of the costs in the U.S. for the French EPR technology, which are in the range of $6,000/kW[21] to $7,500/kW.[22] Given the cost projection track record of the industry and its actual construction record in both countries, even these estimates are likely to be far too low.

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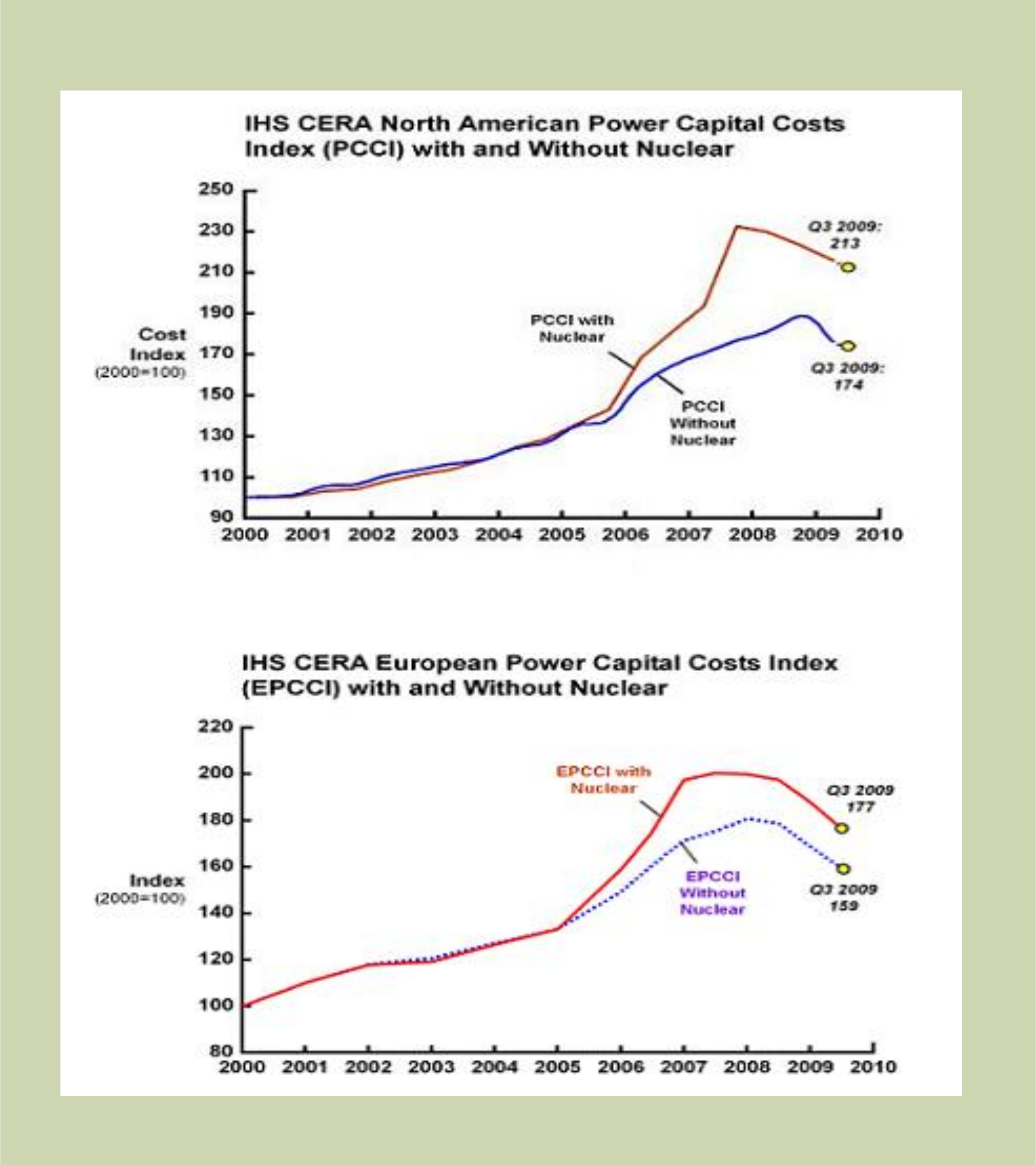
[20] Grubler, p. 26.

[21] The current estimate for the proposed 1,600 MW EPR reactor at the Calvert Cliffs site in Maryland is at $7 to $10 billion, which does not include financing costs, Buurma, 2010.

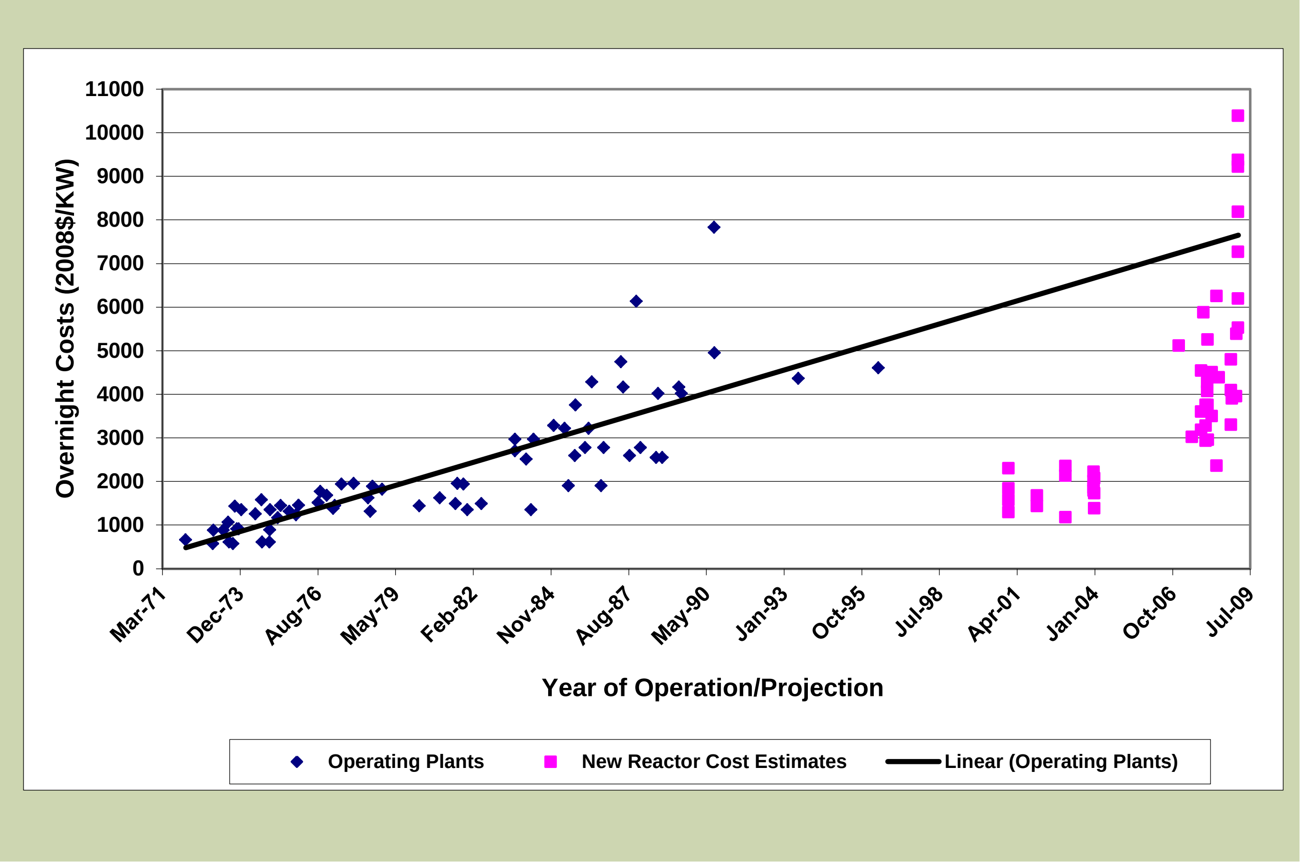
[22] The current estimate for the proposed 1,600 MW EPR reactor at the Bell Bend site in Pennsylvania is at $13-15 billion, which includes financing costs, PPL, 2009.

Exhibit II-5: Recent Cost Escalation In the U.S. Exceeds Europe



CERA, 2009

EXHIBIT II-6: PRESSURIZED WATER REACTORS IN U.S.: ACTUAL OVERNIGHT COST COMPARED TO RECENT PROJECTION OF FUTURE OVERNIGHT COSTS



Sources: Koomey and Hultman, 2007, Data Appendix; University of Chicago 2004, p. S-2, p. S-8; University of Chicago estimate, MIT,2003, p. 42; Tennessee Valley Authority, 2005, p. I-7; Klein, p. 14; Keystone Center, 2007, p.42; Kaplan, 2008 Appendix B for utility estimates, p. 39; Harding, 2007, p. 71; Lovins and Sheikh, 2008b, p. 2; Congressional Budget Office, 2008, p. 13; Lazard, 2008, p. 2; Lazard, 2009, p. 2; Moody's, 2008, p. 15; Standard &Poor's, 2008, p. 11; Severance, 2009, pp. 35-36; Schlissel and Biewald, 2008, p. 2; Energy Information Administration, 2009, p. 89; Harding, 2009; PPL, 2009; Deutch, et al., 2009, p. 6. See Bibliography for full citations.

THE PERSISTENT PATTERN OF DESIGN FLAWS, DELAY, COST ESCALATION, AND FINANCIAL DIFFICULTIES

A decade and half after the start of the commercial deployment of nuclear reactors in the U.S. and France, and well before the accident at Three Mile Island in the U.S., two individuals who had been close observers of nuclear technology in both countries offered an insightful explanation of the economic forces underlying the cost escalation problem. These authors, Bupp and Derian, locate the problem as early as the late 1960s, when it had already become apparent that the cost reduction the industry hoped would flow from learning processes had not come to pass.

> By the end of the 1960s, there was considerable evidence that the 1964-1965 cost estimates for light water plants had been very optimistic. The manufacturers themselves were prepared to admit this. But at the same time they contended that the causes of the first cost overruns were fully understood and were being dealt with. They were entirely confident that the combination of "learning effects" and engineering improvements in key reactor performance parameters (e.g. fuel life) could be relied upon to compensate for the unexpectedly high costs they were encountering. Economies of scale were also seen as a powerful tool for lowering the cost of electricity from nuclear power plants…
>
> Costs normally stabilize and often begin to decline fairly soon after a product's introduction… the reactor manufacturers repeatedly assured their customers that this kind of cost stabilization was bound to occur with nuclear power plants. But cost stabilization did not occur with light water reactors… The learning that usually lowers initial costs has not generally occurred in the nuclear power business. Contrary to the industry's own oft-repeated claim that reactor costs were "soon going to stabilize" and that "learning by doing" would produce cost decreases, just the opposite happened. Even more important, cost estimates did not become more accurate with time.[23]

Writing over three decades later, Grubler concludes that this analysis applies equally to the French situation, but takes it one step further. Faced with the failure of cost control and the prospect of cost escalation, the industry attempted to solve the problem by shifting designs and increasing scale. The result is a "negative learning" process. Things not only do not get better, they get worse. A negative learning process occurs when the enterprise encounters problems with one technology at one scale, but ignores the obvious lessons and assumes that shifting to another technology and larger scale will solve the problem. This short circuits potential gains from standardization and reintroduces learning and first-of-a kind costs.[24] The cycle of cost escalation is repeated.

> The French nuclear case has also demonstrated the limits of the learning paradigm: the assumption that costs invariably decrease with accumulated technology deployment. The French example serves as a useful reminder of the limits of the generalizability of simplistic learning/experience curve models. Not only do nuclear reactors across all countries with significant programs invariably exhibit negative learning, i.e., cost increase rather than decline, but the pattern is also quite variable, defying approximations by simple learning-curve models…
>
> In symmetry to the often evoked "learning-by-doing" phenomenon, there appears not only to be "forgetting by not doing" (Rosegger, 1991) but also *"forgetting by doing,"* suggesting that technology learning possibilities are not only structured

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[23] Bupp and Derian, 1978, pp. 72…79.

[24] As Grubler, p. 27, put it in the French case: "This cost escalation is far above what would be expected just from longer construction times." The reasons for this cost escalation await further detailed research, but have been already alluded to above: loss of the cost-dampening effects from standardization, partly due to upscaling to 1300 MW, but especially in the "frenchifying" of the tested Westinghouse design (as evidenced in the differences between the P4 and the N4 reactor series); a certain "stretching" in the construction schedules after 1981 to maintain human and industrial knowledge capital during the significant scale-back of the expansion program as a result of built overcapacity; and above all, the unsuccessful attempt to introduce a radically new, entirely French design towards the end of the program that did not allow any learning spillovers in design or construction."

> by the actors and institutional settings involved, but are also fundamental characteristics of technologies themselves.
>
> In the case of nuclear, a theoretical framework explaining this negative learning was discussed by Lovins (1986:17-21) who referred to the underlying model as Bupp-Derian-Komanoff-Taylor hypothesis. In essence, the model suggests that with increasing application ("doing"), the complexity of the technology inevitably increases leading to inherent cost escalation trends that limit or reverse "learning" (cost reduction) possibilities. In other words, technology scale-up can lead to an inevitable increase in *systems complexity* (in the case of nuclear, full fuel cycle management, load-following operation mode, and increasing safety standards as operation experience [and unanticipated problems] are accumulating) that translates into real-cost escalation, or "negative learning" in the terminology of learning/experience curve models.[25]

An analysis of the historical experience identifies specific characteristics of nuclear reactor construction that cause these endemic problems. Nuclear reactors are mega-projects that suffer inherent cost escalation.[26] In extremely large, complex projects that are dependent on sequential and complementary activities, delays tend to cascade into long-term interruptions. There are also specific characteristics of the technology and the construction process that pose endemic problems for nuclear reactor development and construction and make them prone to these problems: reactor design is complex and site-specific, which makes them difficult to standardize. The complexity makes it difficult to scale up from smaller-scale demonstrations. The U.S. experience was described as follows in 1978:

> After more than a decade of experience with large light water nuclear power plants, important engineering and design changes were still being made. This is contrary to experience with other complex industrial products…
>
> For 15 years many of those most closely identified with reactor commercialization have stubbornly refused to face up to the sheer technical complexity of the job that remained *after* the first prototype nuclear plants had been built in the mid-late 1950s. Both industry and government refused to recognize that construction and successful operation of these prototypes – though it represented a very considerable technical achievement – was *the beginning and not the near completion* of a demanding undertaking… It became painfully evident that the problems associated with building and operating 1,000 to 1,200 MW nuclear plants bore disappointingly slight resemblance to those associated with 100 to 200 MW plants.[27]

The French had the same experience, as suggested by Grubler:

> First, while the nuclear industry is often quick to point at public opposition and regulatory uncertainty as reasons for real cost escalation, it may be more productive to start asking whether these trends are not intrinsic to the very nature of the

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[25] Grubler, p. 34.

[26] Flybierg, Bruzelius and Rothengatter, 2003; Merrow, Phillips and Myers, 1981.

[27] Bupp and Derian, pp. 154…155…156.

> technology itself: large-scale, indivisible (lumpy), and requiring a formidable ability to manage complexity in both construction and operation. These intrinsic characteristics of the technology limit essentially all classical mechanisms of cost improvements—standardization, large series, and a large number of quasi-identical experiences that can lead to technological learning and ultimate cost reductions—except one: increases in unit size, i.e., economies of scale. In the history of steam electricity generation, these indeed led initially to substantial cost reductions, but after the late 1960s that option has failed invariably due to the corresponding increases in technological complexity.[28]

Another aspect of the negative learning process entails excess capacity. The hope that learning and scale economies will bring costs down requires the industry to commit to large runs of large reactor construction, but the size of the projects and their cost leads to problems and threats of excess capacity. The solution to the rising cost of units creates a new systemic problem of excess capacity.

> With the previous nuclear expansions completed, construction of the last remaining… reactors was "stretched out," and doubts started to creep in. First was the disappointing experience on the construction sites of the four N4 reactors—especially the two Chooz units that took 12 years between construction start and first criticality, plus another 3-4 years until commercial operation (IAEA, PRIS, 2009). Design flaws also took sudden center-stage in the media (e.g., MacLachlan, 1991). A design flaw co-located hot and cold pipes in the primary circuit, leading to enormous thermal stresses and a spectacular leak in 1998 and thus requiring redesign. Digitizing the control system also turned out to be a veritable N4 nightmare, among other problems.
>
> The French nuclear industry needed to consolidate whilst maintaining its ambition for technological innovation, in particular to develop a successor to the N4 reactor—the European Pressurized Water Reactor, EPR.[29]

The endemic problems that afflict nuclear reactors take on particular importance in an industry in which the supply chain is stretched thin.[30] These one-of-a-kind, specialized products have few suppliers. In some cases, there is only one potential supplier for critical parts. Any interruption or delay in delivery cannot be easily accommodated and ripples through the supply chain and the implementation of the project. Any increase in demand or disruption in supply sends prices skyrocketing.

CONCLUSION

Understanding the institutional context is particularly important when using cross-national comparisons to inform decision-making. Blindly applying conclusions about the French industry to the U.S. industry, either positively or negatively, can be misleading. While both nations have capitalist economies, the French nuclear program is a majority state-owned

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[28] Grubler, p. 32.
[29] Grubler, p. 13.
[30] Harding, 2007, Keystone2007.

monopoly, while the U.S. program is made up of privately owned companies, some regulated, some not regulated. It is only by rigorous, side-by-side analysis of the nuclear programs in both countries that one can have confidence in drawing conclusions about similarities and differences between the two or take lessons about the performance of the industry in either nation.

In pointing to the French as a role model for the U.S., it is important to note key difficulties that the unique French model encountered. The 'success' of the French industry was based on an imported design and though they wanted to develop a homegrown design, they were not successful economically.[31]The shift to larger scale and "frenchified" technology proved problematic. The more "frenchified" the design became, the more technical difficulties and the higher the cost that were encountered.[32] The EPR, which is the reactor that the French industry is struggling with in Finland and Flamanville, as well as the one several utilities in the U.S. have considered deploying, lies in this line of development.[33]

In summary, the French success, such as it was, lasted less than a decade and a half, never achieved the hoped-for dynamic economies, encountered mounting problems as it tried to scale up and become independent, resulted in large excess capacity, distorted energy policy, and has failed to achieve success in either captive or non-captive markets with the contemporary large, homegrown technology.

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[31] "As it turned out later, the decision to develop and build the N4 reactor was the most problematic of the entire French PWR program: the new reactor faced numerous technical difficulties, substantial delays, and by French standards prohibitive costs overruns. Not a single N4 reactor was exported. All in all, France exported 9 reactors to 4 countries— all of the original 900-MW first-generation Westinghouse license type" (Grubler, 2009, p. 11). A small number of EPR reactors have been sold abroad.

[32] "Conversely, the gradual erosion of ÉDF's determination to standardize (caving in to proposals of numerous design changes in the wake of the "frenchifying" of the Westinghouse design, and above all to the new N4 reactor design pushed by the CEA), as well as the abrupt slowdown of the expansion program after 1981, paved the way towards a gradual demise of the French success model, as borne out in lengthened construction times and ever higher cost escalation towards the end of the program" (Grubler, 2009, p. 17).

[33] "When the first EPR, the AREVA/Siemens Olkiluoto-3 project, went at least three years behind schedule and 50% over budget, AREVA could and did blame this on its foreign partners, but no such explanation was plausible for the identical Flamanville-3 EPR built by and for French institutions in France. When after a year's construction the project was a year late and 20% over budget, doubts arose about whether AREVA's last order before Olkiluoto-3, in 1992, was so long ago that critical design and construction skills may have atrophied." (Grubler, 2009, p. 14)

III. A COMPARISON OF COST ESCALATION IN THE U.S. AND FRANCE

This section examines the cost escalation of U.S. nuclear reactor construction using a database on 100 reactors, which includes almost all the reactors built after a small number of initial, turnkey reactors. This section addresses both the pattern of cost escalation and the economic processes that the industry hoped would lead to declining costs. It is based on a series of side-by-side comparisons of bivariate relationships in France and the U.S. and then presents a multivariate regression model for the U.S in order to provide more precise insight into the dynamics of cost escalation.

INCREASING LENGTH OF CONSTRUCTION PERIOD

The primary driver of costs in both the U.S and France was the increasing length of construction period.[34] Capital costs mount and compound in the early construction period as they linger on the books before the reactor is used and useful and can be depreciated. The key to cost reduction would have been to reduce the length of time it took to construct new reactors. The experience in both countries was the opposite – i.e. construction periods in both countries increased substantially over time (see Exhibit III-1). The French construction periods were relatively stable at between five and six years in the period between 1970 and 1985 and then doubled in the second half of the 1980s, for the reasons discussed in Chapter II, including a shift in design, the scaling up of the reactors, and the need to stretch out projects as excess capacity became apparent.

In the U.S., construction periods consistently increased from the 1970s to the 1990s. Exhibit III-1 identifies reactors completed before 1980 and those completed after. The first few reactors took about the same amount of time as the French and then there was a steady three-fold increase. The later reactors had a higher rate of construction period increase in the U.S., but the problem clearly existed prior to the TMI accident.[35]The U.S. and French data strongly indicates that TMI was not the sole cause of the problem.

As noted above, the cost escalation problems persist for the French, who have two reactors under construction in the West France and in Finland. Three French EPRs have been proposed in the U.S., and their cost projections have been increasing rapidly. Grubler notes the estimate of the construction period for the Flamanville-3 reactor now under construction in France was extremely optimistic.[36] The reactor is now experiencing substantial delays.[37] The Olkiluoto reactor, with the same design as the Flamanville reactor in Finland is also experiencing significant delays.[38]

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[34] Bupp and Dernier, 1978, Mooz, 1979; and Komanoff, 1981.

[35] Bupp and Dernier, 1978, Mooz, 1978, 1979, Komanoff, 1981, all relied on cost data that antedate TMI. Faber, 1991, showed that the negative impact of nuclear reactor construction on utility financial situation also antedated TMI. (see also Hearth, Melicher and Gurley, 1990)

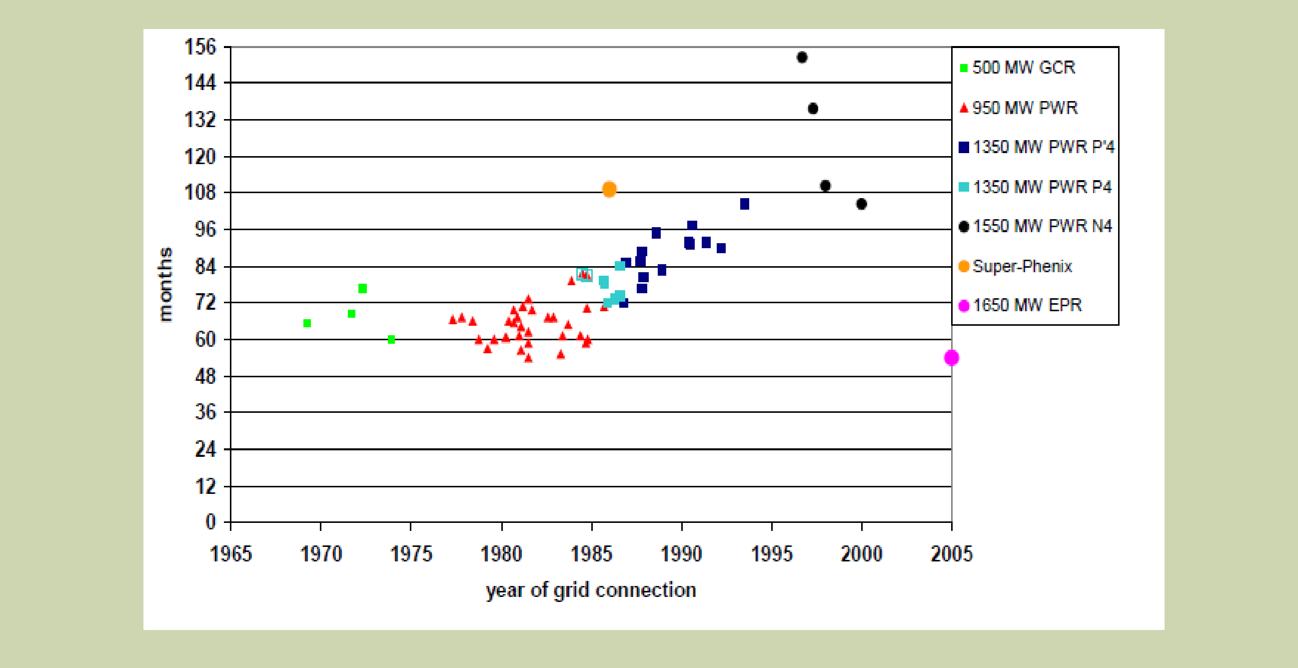
[36] Grubler, 2009, p. 14.

[37] Thomas, 2010, pp. 30-31.

[38] Thomas, 2010, pp. 28-30.

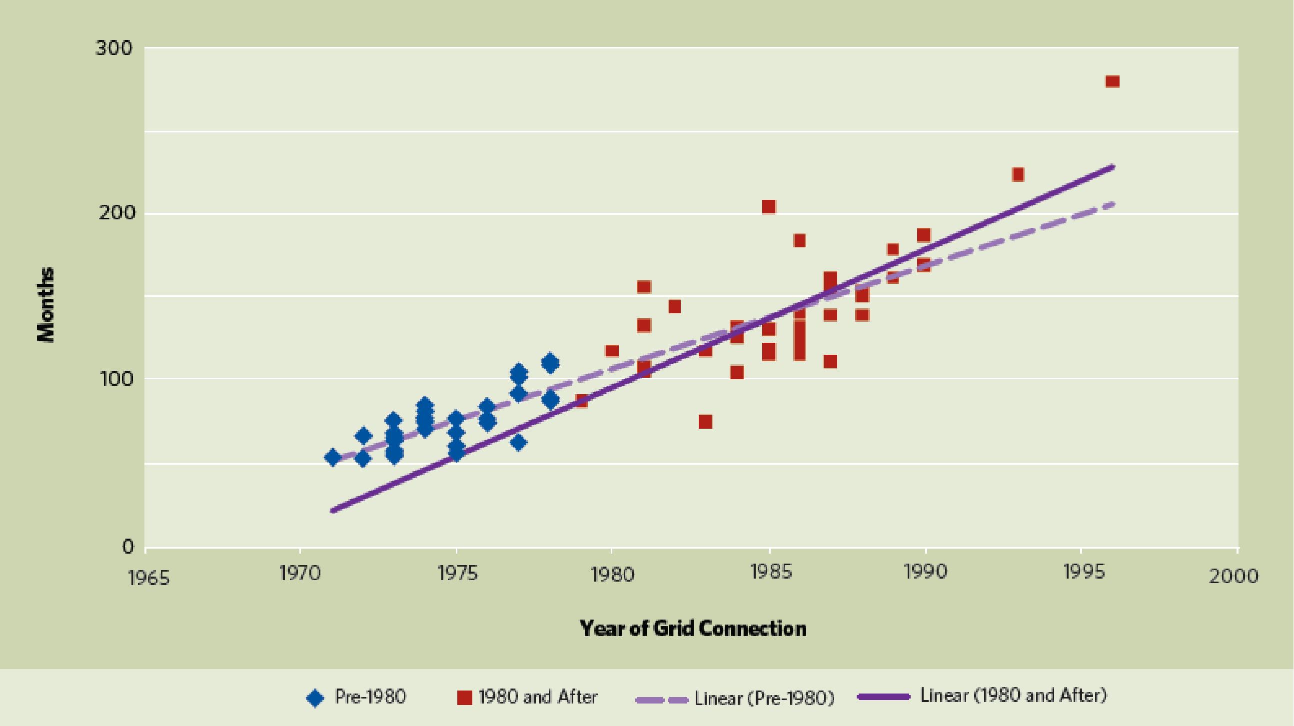
EXHIBIT III-1: CONSTRUCTION PERIODS, PRESSURIZED WATER REACTORS

FRANCE



Grubler, 2009, Figure 3

U.S.



Cooper, 2009, database.

The projected construction periods for the new reactors proposed in the U.S. are also optimistic. The original projections made by advocates of nuclear reactors and the utilities proposing them are in the four to six year range, with an occasional estimate as low as 3.5 years and as high as 7 years.[39] These seem as optimistic as the French projections, relative to the experience in each of the countries. *Moody's* used a ten year construction spend model,[40] with most of the expenditures in a seven year period.

LACK OF A LEARNING CURVE

Grubler tests the hypothesis that the builder would learn and, thereby, experience declining cost by plotting construction costs against the gross amount of reactor capacity built. There is no downward trend, as one would expect if learning were lowering costs (see Exhibit III-2). On the contrary, he finds a slight upward trend to 35 Gigawatts and then a sharp increase in costs. The U.S. exhibits a similar pattern.

Since the build-up of completed reactors is correlated with the lengthening of the construction period, this may be affecting the cost-capacity relationship. In France, all the reactors are built by one company, so the build-up of complete reactors is both the industry and the company experience curve. In the U.S., there are multiple companies so we should distinguish the industry experience curve from the company curve. Exhibit III-3 does so and finds that, for every utility and every range of experience, there was a cost escalation with experience, rather than a reduction. However, there is a distinction between the companies. Bechtel built a large number and had lower costs, but even for Bechtel, there was a steady, moderate increase in costs. Two other constructors had low and moderately rising costs that paralleled Bechtel (Duke and UE&C) [41]– although they built far fewer reactors. The other builders had much higher costs that rose faster.

INCREASING UNIT CAPACITY

Another characteristic that is playing a role in the current U.S. proposals and was also in play in France involves the size of the reactors. The experience of rising construction costs drove the French to seek large reactors;[42] hoping unit economies of scale would offset the upward trend. "But as it turned out later, the expectations of significant economies of scale proved unfounded: any cost reductions from larger components were more than offset by more complex construction sites, longer construction times, and the need to fix the inevitable technical problems arising from significant design changes."[43]

There has been a long-term trend to larger units and the current proposals in the U.S. and

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[39] Cooper, 2009a, p. xx.

[40] Moody's, 2008.

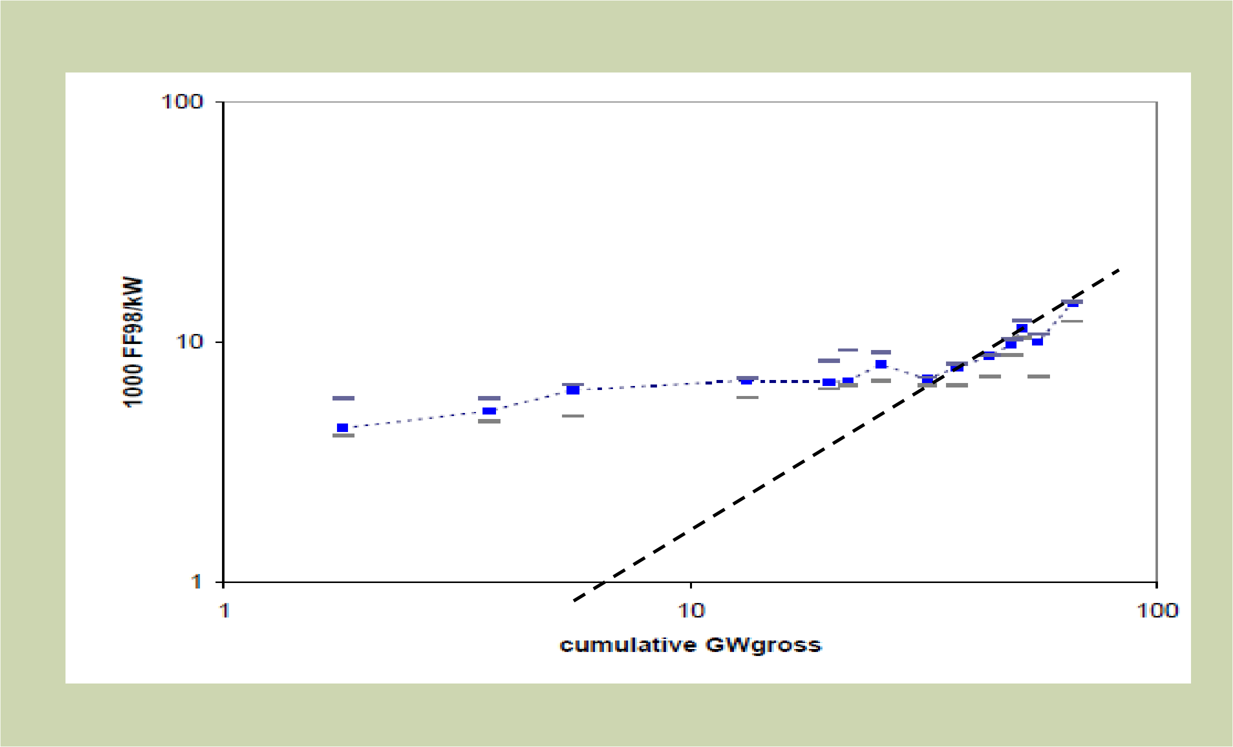
[41] Grubler suggests that utilities building reactors may overcome some principal agent problems by unifying the interest of the utility and the builder and thereby achieve lower cost.

[42] Grubler, p. 16, "The reason for this increase in reactor unit scale was primarily economic: significant economies of scale were sought and expected to encounter increasing tendencies for cost escalation. With the completion of the first reactors, the earlier optimistic assumptions about construction duration and investment costs faced a harsh reality check. The first reactor completed, at Fessenheim, took two years longer to build than originally projected, accruing additional interest during construction that further added to other cost escalation factors. As more experience was accumulated, the cost projections of the PEON Commission, as well as the internal ones of ÉDF, started to rise as well, adding urgency to the economic rationale for the move to the 1.3 GW PWR design."

[43] Grubler, p. 11.

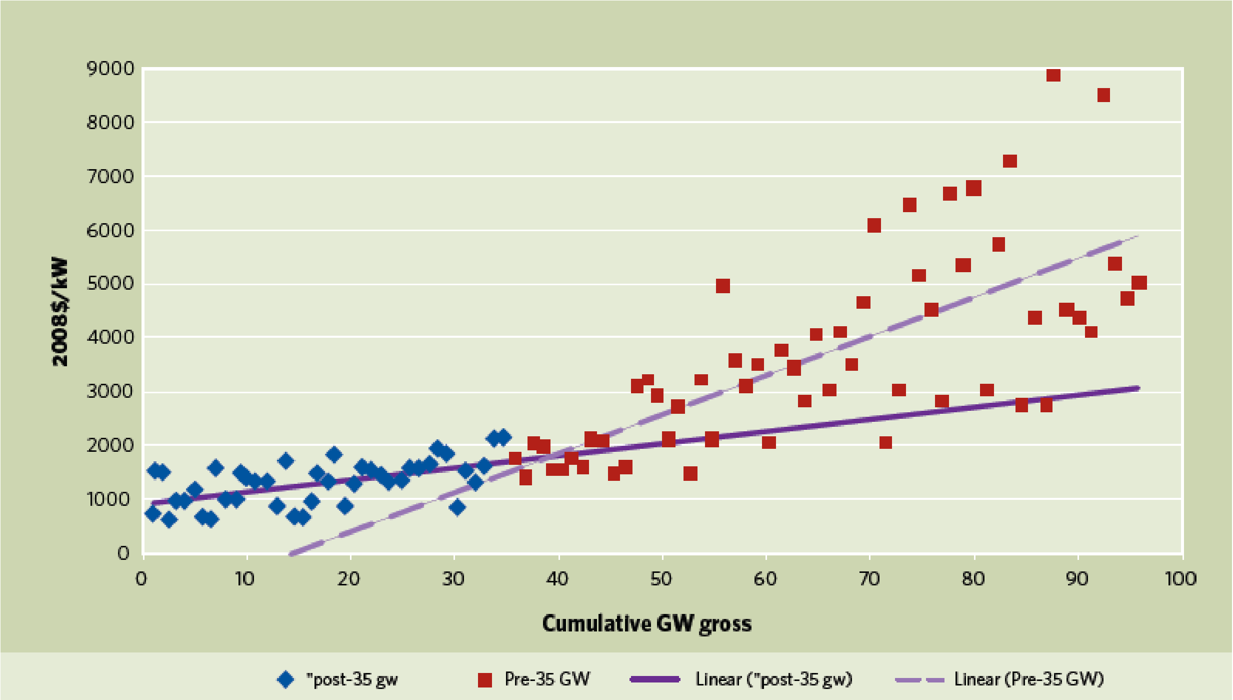
EXHIBIT III-2: FRENCH AND U.S. LEARNING CURVES: PRESSURIZED WATER REACTORS

France



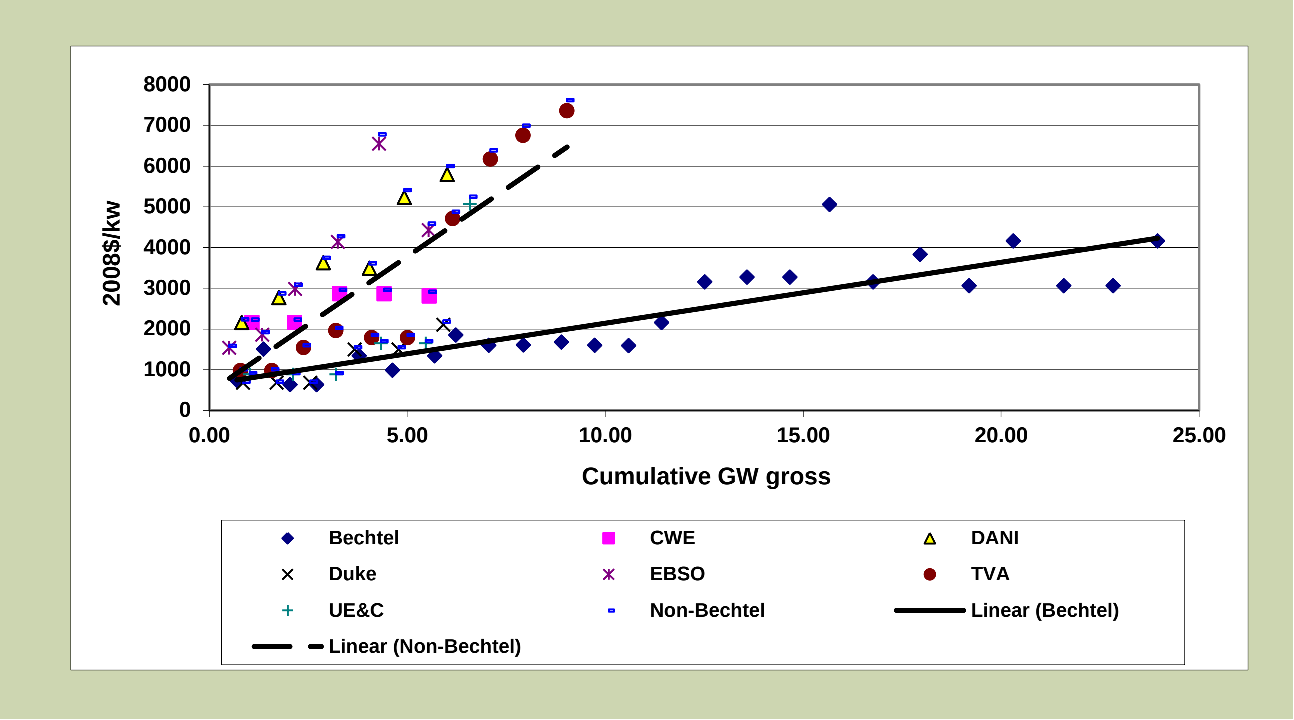
Grubler, 2009, Figure 9

United States



Cooper, 2009, database

EXHIBIT III-3: U. S. COMPANY LEARNING CURVES



Cooper, database, 2009

ongoing French projects are much larger than the early reactors. Since we do not have the underlying French data, Exhibit III-4 shows this at the technology level, with the average size plotted against the median year in which the units were under construction. For the U.S. data, we plot the size against the construction start date. Capacity increased dramatically across time in both cases. Since costs were rising as well, there is a correlation between size and cost, which may be a function of the co-linearity between start date, capacity, and cost.

The economies of scale that might drive prices down are not sufficient to offset other factors. The inherent technology characteristics of nuclear power (large-scale, complex, and with lumpy investments) introduce a significant economic risk of cost overruns in the build-up process. Anticipated economic gains from standardization and ever larger unit scales not only have failed to materialize, but the corresponding increasing complexity in design and in construction operations have reversed the anticipated learning effects to their contrary: cost escalation.[44]

MULTI-UNIT SITES

In the U.S., the nuclear industry is claiming that building two reactors at a given site dramatically lowers the cost (by about 25 percent), as long as the two units are constructed

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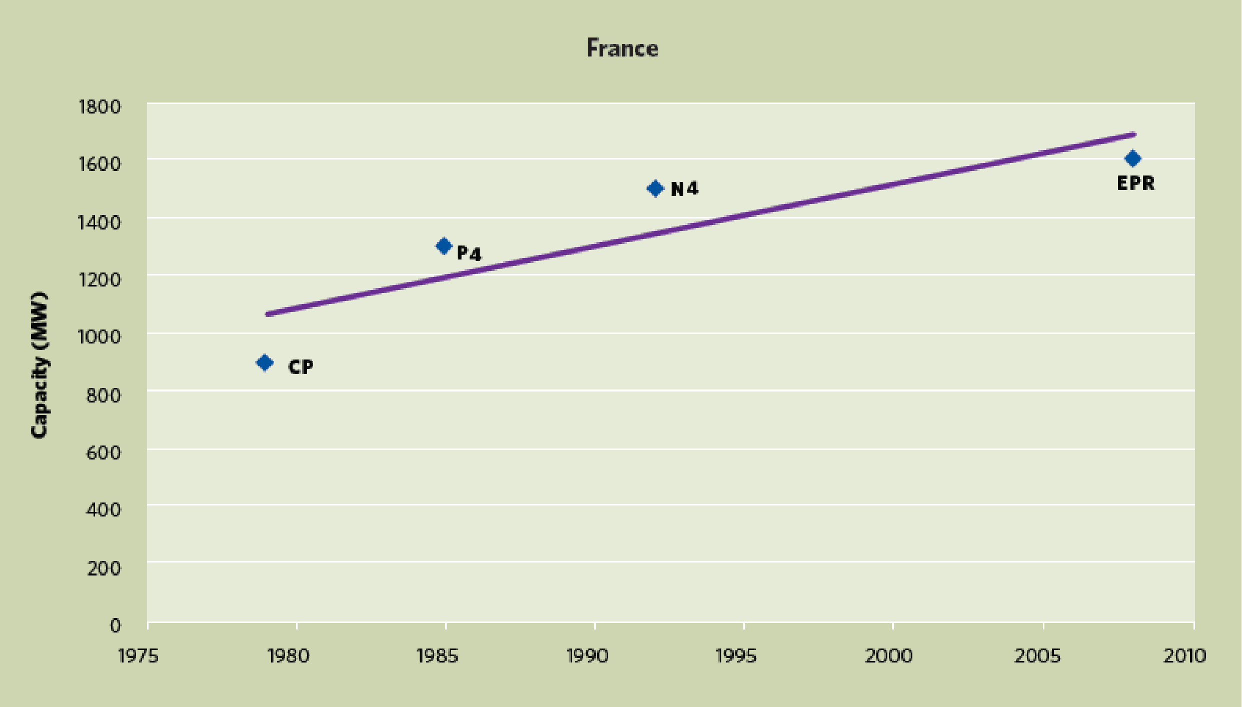
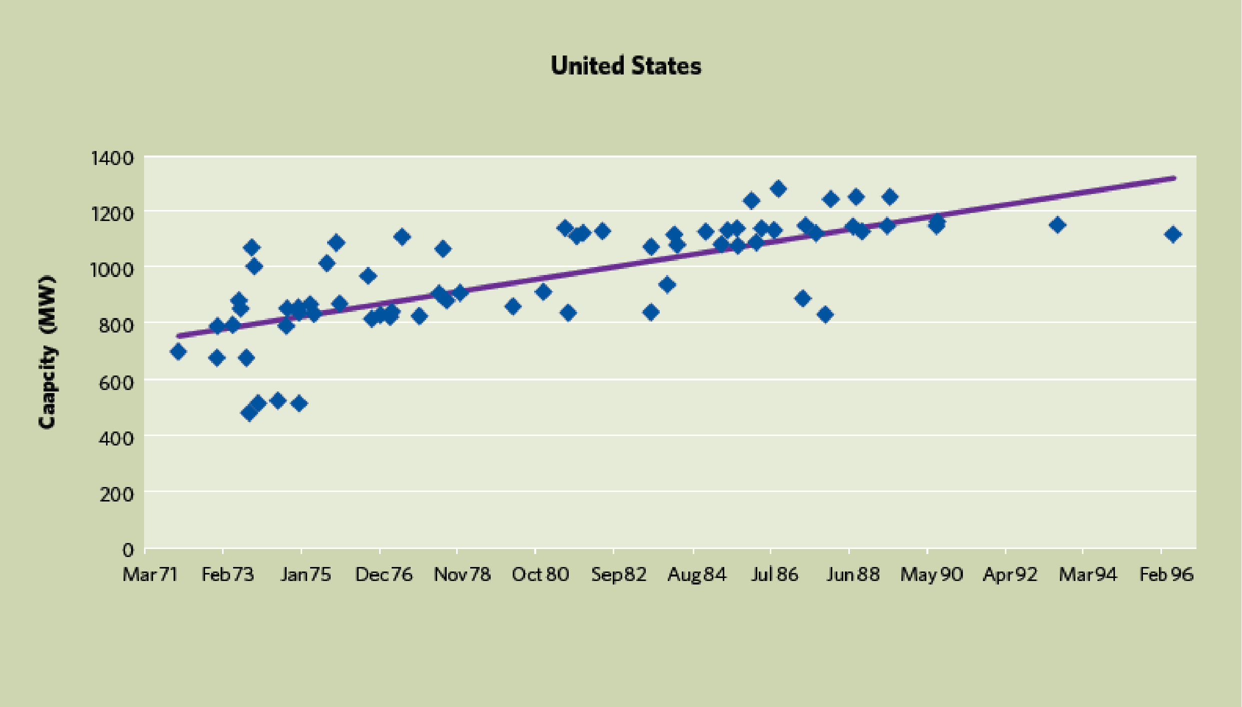
[44] Grubler, p. iii.

EXHIBIT III-4: FRENCH AND U.S. REACTOR CAPACITY: PRESSURIZED WATER REACTORS



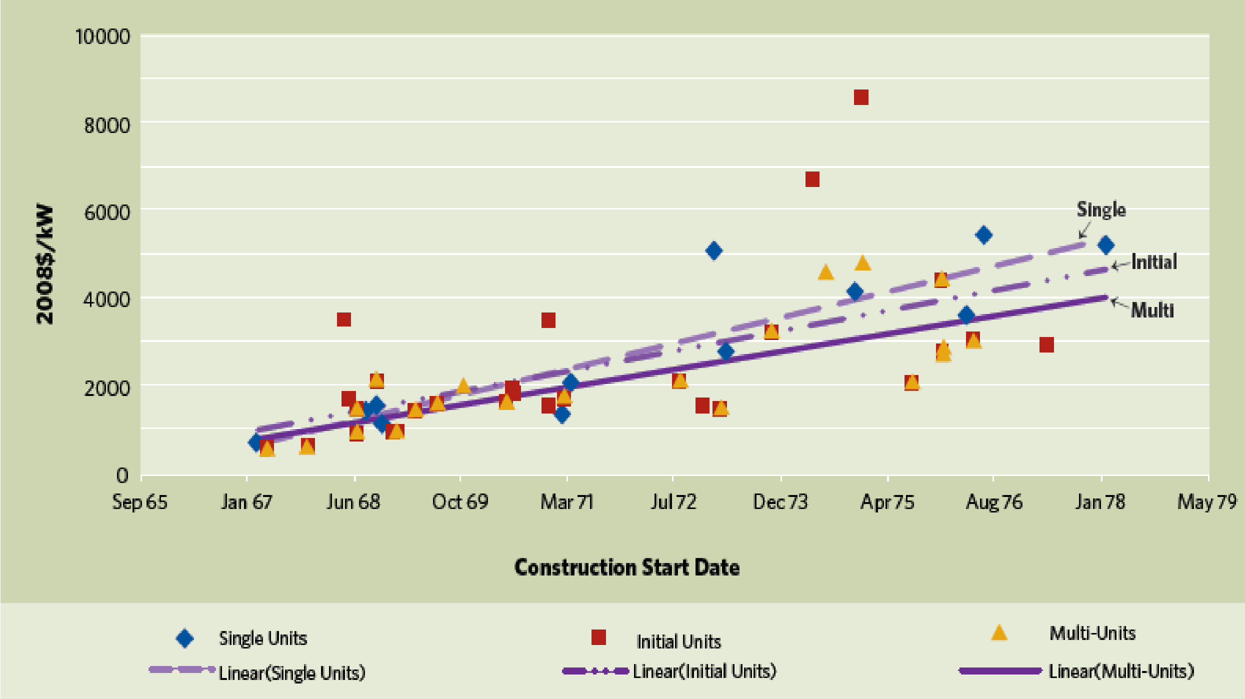
Grubler, 2009. Table



Cooper, 2009, database.

within a year or two.[45] Historical data shows a clear relationship between multi-unit sites and costs in the U.S., with second and third units costing substantially less (see Exhibit III-5). However, this has the impact of making the reactor projects very large and raises concerns about excess capacity, especially given the economic slowdown and dramatic change in household wealth resulting from the financial meltdown.[46]

EXHIBIT III-5: COST IMPACT OF MULTI-UNIT CONSTRUCTION



Cooper, 2009, database

For these pressurized water reactors, there was little difference in the cost of single and initial reactors, with an average cost of approximately $2,350/kW. The multi-unit reactors were substantially less costly, at an average of $2,000/kW. Including the boiling water reactors in the analysis shows a larger difference. The average cost of stand-alone units (i.e. units constructed at a site in which a second unit was not commenced within two years) was just under $3,000/kW. The initial unit of a multi-unit site cost just under $2,200/kW. The subsequent units of a multi-unit site cost just under $2,000/kW.[47] Note, however, that there was cost escalation for all three categories: single unit, initial unit and multi-unit.

We do not have data to make a direct comparison between the French and U.S. industries in this regard. We do note that the French have a much higher concentration of reactors at each site, averaging almost three per site, whereas in the U.S. over the course of the history of the industry, the average number was 1.5 reactors per site.

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[45] Cooper, 2009d.

[46] Cooper, 2009d.

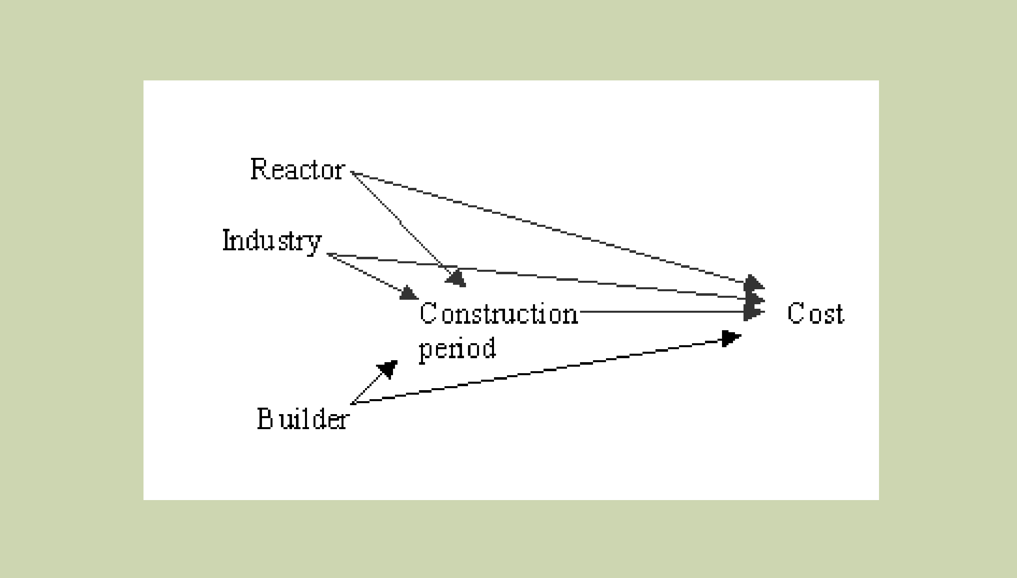
[47] In the French data, Komanoff finds that the number of reactors under construction in a given year lowers the cost. Without access to the data, we cannot examine this finding, but it may be that, given the pattern of French construction, the clustering of multiple site units may be causing this effect.

A MULTIVARIATE MODEL FOR THE U.S. PRODUCTION FUNCTION

Variables

The above discussion suggests three sets of characteristics that affect nuclear reactor building cost – the reactors, the industry, and the builder, as summarized in Exhibit III-6. The construction period is a key intervening variable.

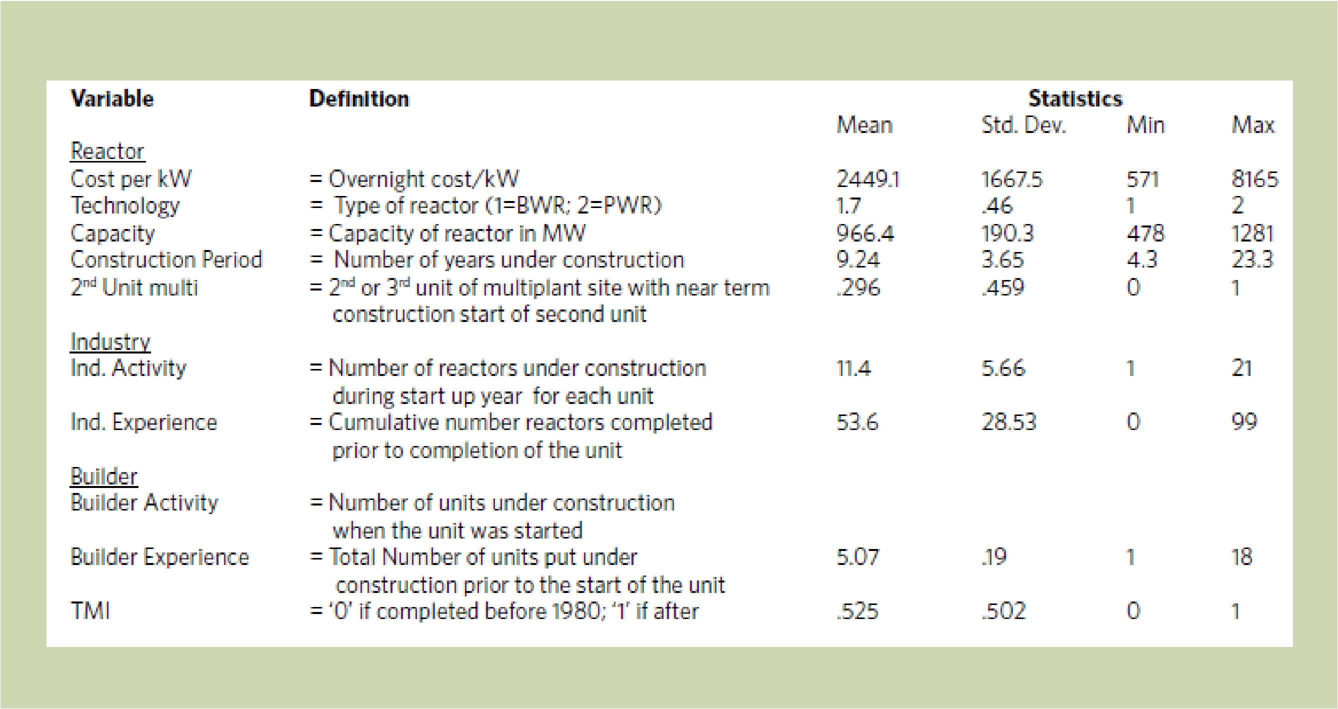
EXHIBIT III-6: FACTORS THAT AFFECT REACTOR CONSTRUCTION COSTS



To combine these variables into a multivariate approach, a data set was built with the variables as defined in Exhibit III-7. The variables have been operationalized along the lines used in the bivariate analysis. The analysis of the reactor economics focuses on the following factors:

- The primary dependent variable on which the analysis focuses is the overnight cost – the cost per kW for construction, without finance or owner costs stated in 2008$.
- The Construction Period is included as an intervening variable because it is such a strong predictor of construction costs. It is included as a direct cause of construction cost. The indirect effect of other variables on construction cost is also examined through their effect on the construction period.
- Technology is included in two ways: as a variable in the overall econometric model to assess its impact on the other factors in the model and as a subset of observation within which the model is estimated. The effect of TMI is handled in a similar fashion.
- Reactor Capacity is included, as well as whether the reactor was a second or third unit at a multi-unit site started in a time frame that was expected to yield cost savings.

EXHIBIT III-7: VARIABLES IN THE U.S. DATA SET



Variable	Definition	Statistics			
		Mean	Std. Dev.	Min	Max
Reactor					
Cost per kW	= Overnight cost/kW	2449.1	1667.5	571	8165
Technology	= Type of reactor (1=BWR; 2=PWR)	1.7	.46	1	2
Capacity	= Capacity of reactor in MW	966.4	190.3	478	1281
Construction Period	= Number of years under construction	9.24	3.65	4.3	23.3
2nd Unit multi	= 2nd or 3rd unit of multiplant site with near term construction start of second unit	.296	.459	0	1
Industry					
Ind. Activity	= Number of reactors under construction during start up year for each unit	11.4	5.66	1	21
Ind. Experience	= Cumulative number reactors completed prior to completion of the unit	53.6	28.53	0	99
Builder					
Builder Activity	= Number of units under construction when the unit was started				
Builder Experience	= Total Number of units put under construction prior to the start of the unit	5.07	.19	1	18
TMI	= '0' if completed before 1980; '1' if after	.525	.502	0	1

For the industry, two variables are included:

- Industry Activity: the number of reactors under construction in the industry in the year in which a given reactor was put under construction.
- Industry Experience: in the year a given reactor is put into construction, the number of units completed or put under construction prior to that year since the beginning of the building cycle.

For the builder, two variables are included that parallel the industry variables:

- Builder Activity: the number of reactors under construction by the builder in the year in which a given reactor was put under construction.
- Builder Experience: in the year a given reactor is put into construction, the number of units completed or put under construction prior to that year by the builder since the beginning of the building cycle.

The dependent variable is the log of the overnight cost (log linear models), which can be interpreted as the percentage change in cost per unit of change in the independent variable.

RESULTS

The analytic strategy is to isolate the impact of industry, builder and project characteristics by including different sets of variables, as well as conducting the analysis in separate subsets of reactors. Exhibit III-8 presents the results in the form of bivariate and multivariate regression coefficients. The results shown in Exhibit III-8 are for a log linear model, where the causal factors (independent variables) are the characteristics of the reactors, the industry and the builder.[48] The log linear approach is intuitive,[49] particularly with a number of categorical variables.[50] Because the earlier discussion also focused on Pressurized Water Reactor as a separate technology, the results for this subset of the reactors are presented separately.[51] Given the important role that the construction period plays in the determination of cost, the indirect effects of each of the factors on the final cost are also considered through their indirect effect on construction period.

The Beta coefficients are shown for both bivariate and multivariate models in Exhibit III-8. Betas are standardized coefficients that measure a one-unit change in each of the variables, so they help to assess the relative importance of each of the variables.

Exhibit III-9 shows the effects of each independent variable on overnight costs expressed as the percentage change in overnight costs associated with a one-unit change in the independent variable. The results show that there is little support for the learning and scaling up hypothesis at the industry level. The evidence is mixed at the builder and reactor levels.

The variables included in the model explain almost nine-tenths of the cost of the reactors and about two-thirds of the construction period. This is true for all reactors, as well as the subset of pressurized water reactors. The amount of variance in cost explained by the variables in the split sample before and after TMI is similarly high, but the amount of variance explained in the construction period before and after TMI is lower because TMI accounts for a large part of the variance as a covariate in this approach.

Pressurized water reactors had almost 13 percent lower costs than boiling water reactors with larger effects after TMI.

Larger units had lower costs, with each additional unit of capacity lowering the cost by 0.07 percent; however, note that larger capacity units took longer to build. Therefore, approximately three-quarters of the cost savings due to the size of the unit were offset by increases in the construction period. This is consistent with the findings discussed in Chapter II about why increasing the size of the units did not have the anticipated cost-reducing benefits.

The length of the construction period had a major impact on cost, with each year of construction increasing cost by 11 percent.

Second units at multi-unit sites had substantially lower costs, by 25 percent.

---

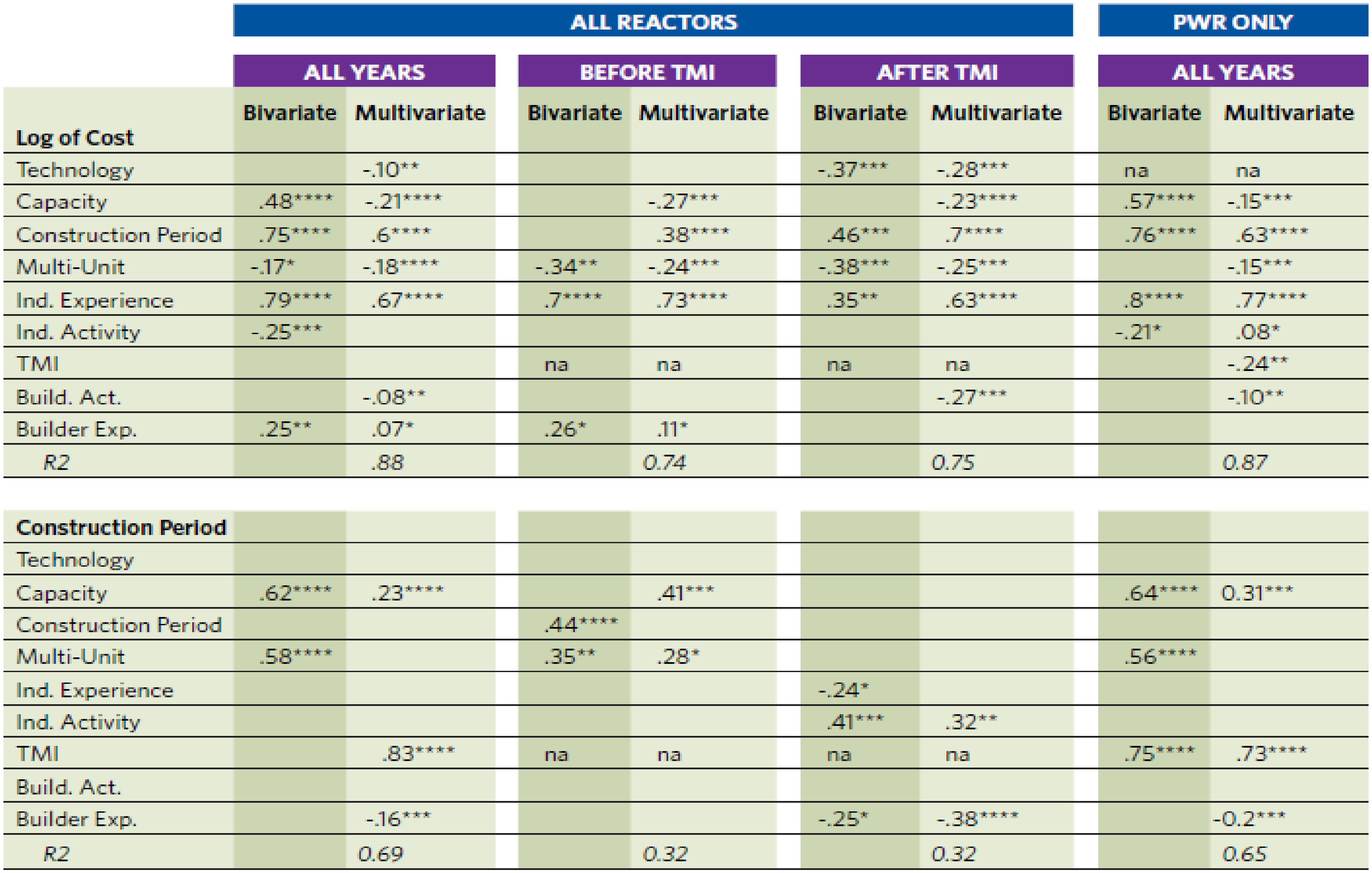
[48] The results are based on robust standard errors, since a test for heteroskedasticity produced a significant test statistic. Although a test for collinearity did not exceed traditional levels, the TMI variable exhibited substantial the collinearity. For statistical and substantive reasons, we have specified the model based on subsets of the data before and after TMI. We also considered a version of the model split before and after the regulatory “stalemate.” The results are similar. A statistical Appendix is available from the author.

[49] We have run the analyses on a linear and double log linear basis (i.e. all continuous variables are converted to logs) and the results are quite similar.

[50] Komanoff, 2010, shows the results of a much simpler model for France using a double log linear specification.

[51] We tested for a difference between Westinghouse and other PWR designs, but did not find it statistically significant.

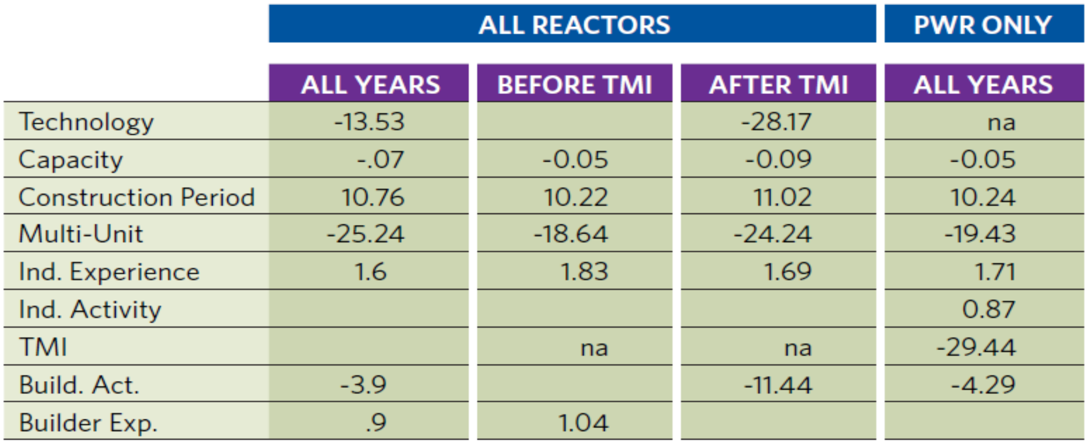
EXHIBIT III-8: REGRESSION RESULTS



	ALL REACTORS						PWR ONLY	
	ALL YEARS		BEFORE TMI		AFTER TMI		ALL YEARS	
Log of Cost	**Bivariate**	**Multivariate**	**Bivariate**	**Multivariate**	**Bivariate**	**Multivariate**	**Bivariate**	**Multivariate**
Technology		-.10**			-.37***	-.28***	na	na
Capacity	.48****	-.21****		-.27***		-.23****	.57****	-.15***
Construction Period	.75****	.6****		.38****	.46***	.7****	.76****	.63****
Multi-Unit	-.17*	-.18****	-.34**	-.24***	-.38***	-.25***		-.15***
Ind. Experience	.79****	.67****	.7****	.73****	.35**	.63****	.8****	.77****
Ind. Activity	-.25***						-.21*	.08*
TMI			na	na	na	na		-.24**
Build. Act.		-.08**				-.27***		-.10**
Builder Exp.	.25**	.07*	.26*	.11*				
R2		*.88*		*0.74*		*0.75*		*0.87*
Construction Period								
Technology								
Capacity	.62****	.23****		.41***			.64****	0.31***
Construction Period			.44****					
Multi-Unit	.58****		.35**	.28*			.56****	
Ind. Experience					-.24*			
Ind. Activity					.41***	.32**		
TMI		.83****	na	na	na	na	.75****	.73****
Build. Act.								
Builder Exp.		-.16***			-.25*	-.38****		-0.2***
R2		*0.69*		*0.32*		*0.32*		*0.65*

Notes: Significance levels based on robust standard errors: * = p <.1, ** = p < .05, *** = p<.01, **** = p< .0001. All Variable Inflation Factors (VIF) are less than 10.Beta coefficients shown with p <.1; but the Betas are calculated with all variables in the model. Dependent is log of cost. All other variables are absolute values.

EXHIBIT III-9: PERCENTAGE CHANGE IN OVERNIGHT COSTS ASSOCIATED WITH A ONE-UNIT CHANGE IN THE INDEPENDENT VARIABLE



	ALL REACTORS			PWR ONLY
	ALL YEARS	BEFORE TMI	AFTER TMI	ALL YEARS
Technology	-13.53		-28.17	na
Capacity	-.07	-0.05	-0.09	-0.05
Construction Period	10.76	10.22	11.02	10.24
Multi-Unit	-25.24	-18.64	-24.24	-19.43
Ind. Experience	1.6	1.83	1.69	1.71
Ind. Activity				0.87
TMI		na	na	-29.44
Build. Act.	-3.9		-11.44	-4.29
Builder Exp.	.9	1.04		

Industry activity and industry experience are not associated with lower costs. None of the coefficients indicate a statistically significant relationship in which increasing experience or activity is associated with lower costs. Every coefficient that is larger than its standard error indicates that industry experience and activity increases cost. Half of the relationships are statistically significant and indicate increasing cost with increasing experience and activity. The industry experience variable is statistically significant in the full set of reactors and in the pressurized water subset; industry activity is statistically significant in the latter. The industry experience variable has the largest effect on cost.

The builder characteristics have a mixed pattern.[52] Builder activity is associated with lower costs, about 4 percent per plant under construction, but builder experience is associated with higher costs, about 1 percent per plant completed. However, the indirect effects through the construction period tend to run in the opposite direction. In the case of builder experience, where all effects are statistically significant, the indirect effect offsets the direct effect. Again, the results are consistent with the failure of learning effects.

CONCLUSION

The hope/claim that costs of nuclear reactors will go down as more are built is not supported by the cross-national, bivariate analysis or the econometric analysis. The hypothesis fails to receive support in three-quarters of the statistical tests and the significant findings are more likely to support the opposite conclusion: costs of nuclear reactors increase as more are built.

The findings of the comparative France-U.S. analysis and the detailed econometric analysis of the U.S. data are consistent with what Grubler calls the “Bupp-Derian-Komanoff-

---

[52] Komanoff, 1981, found a significant effect for a specific builder. We tested a “low cost builder” variable but found that controlling for the other factors in the model, it was significant at the 10 percent level in only one specification of the model and did not explain much variance.

Taylor hypothesis."[53]The Bupp-Derian 1978 analysis was cited at length here because that early analysis antedates the regulatory and popular battles that attracted so much attention in the U.S. The findings in this analysis also replicate Komanoff's 1981 econometric analysis, [54]which was based on about half the reactors ultimately built in the U.S. Both the Komanoff analysis and this analysis found that:

- The project scale characteristics that appear to lower cost also lengthen the construction period, which leads to a frustrating and mixed outcome.
- Industry experience is associated with high costs.
- Builder experience is associated with lower costs. This analysis finds a more mixed result by distinguishing between cumulative experiences from the level of activity and including the much longer time frame.

The earlier finding that nuclear reactor construction suffers from cost escalation is broadly affirmed. Nuclear reactor cost projection suffers from severe problems, when confronted with the reality of underlying cost escalation.

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[53] Lovins, 1986 used this expression.

[54] Komanoff, 1981, found two effects that we have not. He found a "Northeast" effect. Our data show that this effect was limited to the early, pre-TMI period. He also found a specific effect associated with a single builder (Babcock and Wilcox). We tested a low cost builder variable and found it was not generally significant once the other variables are included in the analysis.

IV. THE IMPACT OF NUCLEAR REACTORS AND CENTRAL STATION FACILITIES ON ALTERNATIVES

The analysis, estimation and projection of nuclear reactor construction costs are not typically academic exercises. They are policy-oriented activities intended to convince someone to spend the resources to construct a new nuclear reactor. The context of the decision and the alternatives available must also be taken into account in order to understand why a specific choice was made or to recommend a sound policy or choice for the future. A brief consideration of the context and alternatives adds important perspective to the historical analysis above and helps to frame the choices confronting policymakers today.

A costly technology suffering from severe cost escalation puts pressure on those involved in developing and deploying it. With large commitments of financial and institutional resources to the construction of reactors, there is a tendency to press projects ahead in spite of adverse economics. We have already seen an indication of this in the failure of price projection to reflect reality. The dysfunction of the system had other substantial impacts, especially on the choice of alternatives.

FRANCE

The French program suffered from demand reduction brought on by the oil price shocks of the 1970s. Much like the industry in the U.S., it did not adjust rapidly or well, instead building up excess capacity. Grubler notes the tension between the stimulus for more capacity to reduce dependence on oil and the demand reduction induced by the oil price shock, not unlike the tensions between climate change policy and the current recession-induced demand reduction.

> This period is overshadowed by the unfolding of the consequences of the two "oil shocks" that reinforced the political legitimacy of the ambitious nuclear investment program. The oil shocks also paved the way for the subsequent nuclear overcapacity, as slackening demand growth remained unreflected in the bullish demand and capacity expansion projections and orders.
>
> Thus the French PWR program remained at full throttle regardless of external circumstances. Orders of 5-6 reactors per year, supplemented by grid-connections of the first reactors commissioned in the previous period, and first operating experiences from initial reactors became available in the late 1970s.[55]
>
> The PEON Commission report in 1973 projected France's electricity demand as 400 TWh in 1985 and 750 TWh in 2000, compared to actual numbers of 300 and 430 TWh respectively (G-M-T, 2000:373). These over-projections of demand growth led subsequently to substantial (and costly) overcapacity in orders and construction, requiring not un-painful adjustments.[56]

The highly centralized French state monopoly was able to force projects through to

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[55] Grubler, 2009, p. 10

[56] Grubler, 2009, p. 9.

completion.[57]The ability of the centralized system to force reactors online also had the effect of justifying policies to promote wasteful use of electricity to absorb the surplus. These difficulties cascade and distort policy choices. The result was excess capacity that placed a burden on taxpayers and consumers. Schneider argues that as many as one-fifth to one-quarter of the reactors was not needed. The push to absorb the large excess of baseload capacity caused the abandonment of efficiency and conservation and created a peak load problem.

> In the 1980s significant overcapacities were built up in the power sectors as well as in refineries and nuclear fuel industries and most of the energy intelligence initiatives based on efficiency and conservation were abandoned. …
>
> Rather than downsizing its nuclear extension program, EDF develop a very aggressive two-front policy: long-term baseload power export contracts and dumping of electricity into competitive markets like space heating and hot water generation…
>
> France increasingly lacks peak load power whose consumption skyrocketed in the 1980s and 1990s in particular as a consequence of massive introduction of electric space heating…
>
> Today, per capita electricity consumption in France is almost a quarter higher than in Italy (that phased out nuclear energy after the Chernobyl accident in 1986) and 15% higher than the EU27 average.[58]

The dysfunctionalities of the system in France may be somewhat less apparent than in the U.S. (discussed below), but they are just as real.

> The system is entirely exempt from influential corrective elements. Once a decision is taken, there is no way back or out. Examples include the large overbuilding of nuclear capacity… By the middle of the 1980s, it was perfectly clear that the nuclear program was vastly oversized by some 12 to 16 units. But while 138 reactor orders were cancelled in the U.S. at various stages of implementation, absolutely no changes were made to the planning, even when electricity consumption did not even nearly follow forecasts. The reaction was to develop power export for dumping prices and to stimulate electricity consumption by any possible means (in particular thermal uses like heating, hot water production and cooking).[59]

The drive for policies that would increase consumption to absorb excess capacity had a side effect. There was little inclination to pursue alternative sources of generation. Consequently, "the energy efficiency + renewables efforts in France have remained severely

---

[57] Grubler, 2009, p. 15. "The institutional key to success in France was the extremely limited number of institutional actors: "mortals" never played any decisive role either in the technocratic decision-making process or in hindering rapid expansion. The senior actors were extraordinarily well coordinated through the "invisible hand" of a small technocratic elite—, the nationalized utility ÉDF and the state nuclear R&D organization CEA acted in a well-coordinated way, overcoming inevitable rivalries and differences of opinion. They ended up with a clearly formulated vision, mobilized the necessary resources, and proved quite apt in executing this extremely large-scale and complex technology program." The recent breakdown of this unanimity under the stress of failure has attracted considerable attention.

[58] Schneider, 2008, p. 7.

[59] Schneider, 2009, note 28.

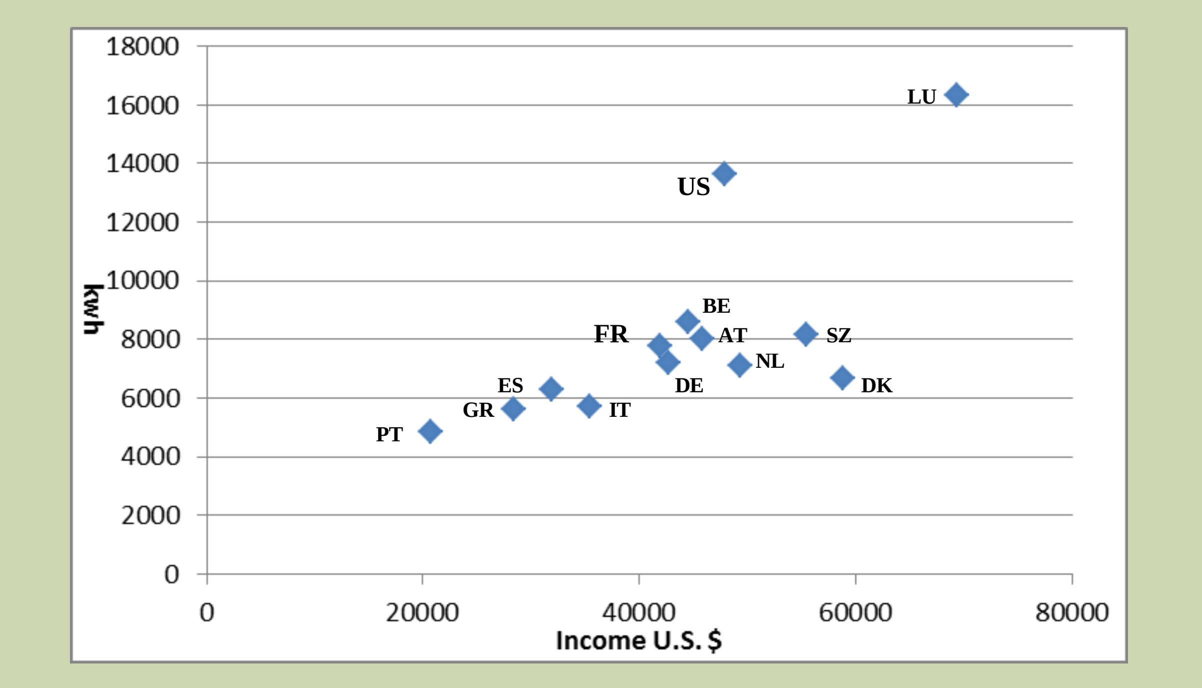
underdeveloped…. In 2008 Spain added more wind power capacity (4,600 MW) than France had installed in total by 2007 (4,060 MW).[60]

The critique of the French policy assumes that the outcome could have been different. This is true in an absolute sense – the choice of residential heating – and a relative sense – others pursued different paths. Cross-national comparisons require caution because there are many differences between nations that could explain the observed difference in policy choices and outcomes. Systematic studies of OECD nations support the qualitative observations.[61]

Exhibit IV-1 presents the consumption of electricity per capita plotted against income per capita for a subset of nations that is referred to as OECD – Europe. It excludes the former Soviet bloc nations, which have a very different energy background.[62] It also excludes Northern Europe (Nordic countries, which have different climates) and UK and Ireland (Islands that require different alternative energy resource endowments). By examining electricity consumption per capita per dollar of income in this set of nations that is matched on climate and also reasonably matched on renewable potential, the comparison is "fair." The United States is included for discussion below.

France has a relatively high level of consumption compared to the other nine nations and

EXHIBIT IV-1: ANNUAL ELECTRICITY CONSUMPTION IN WESTERN EUROPE AND THE U.S.



Sources and notes: World Bank per capita electricity consumption and Gross National Income.
http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC
http://data.worldbank.org/indicator/NY.GNP.PCAP.CD

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[60] Froggat and Schneider, 2010, p. 19.

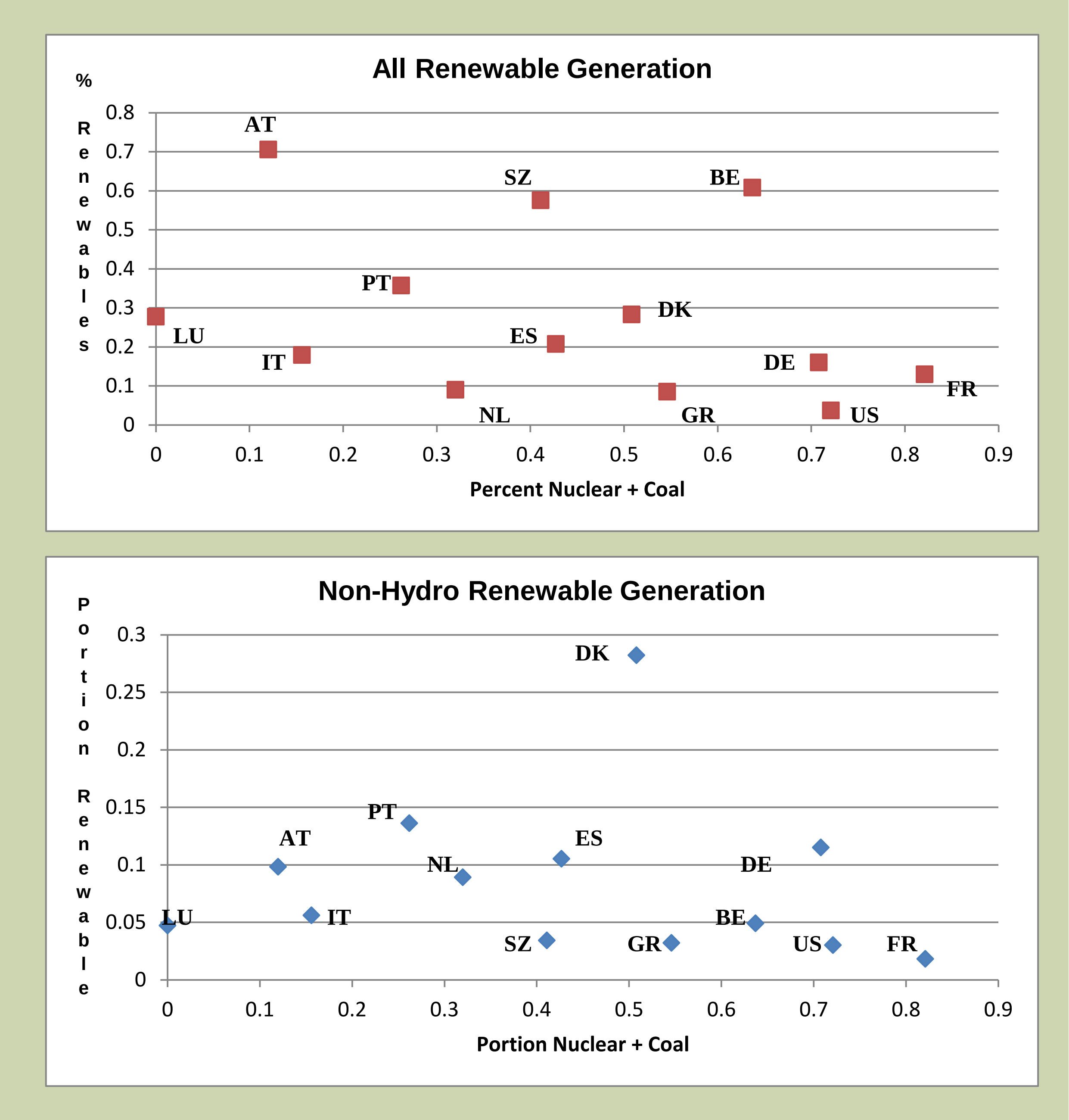
[61] Ibid, Geller, et al., 2006; Olz, 2007; Suding, 2007. Ragwitz and Held, 2007.

[62] The European nations included are Austria, Belgium, Denmark, France Germany, Greece, Italy, Luxemburg, Netherlands, Portugal, Spain and Switzerland.

U.S. consumption is much higher than the European average. Thus effects of the French overbuilding of nuclear reactors and the resulting energy inefficiency compared to other European nations, which was noted earlier, is evident in this graph. Controlling for income, we find that the U.S. consumes almost 50 percent more electricity per capita, per dollar of income, than France.

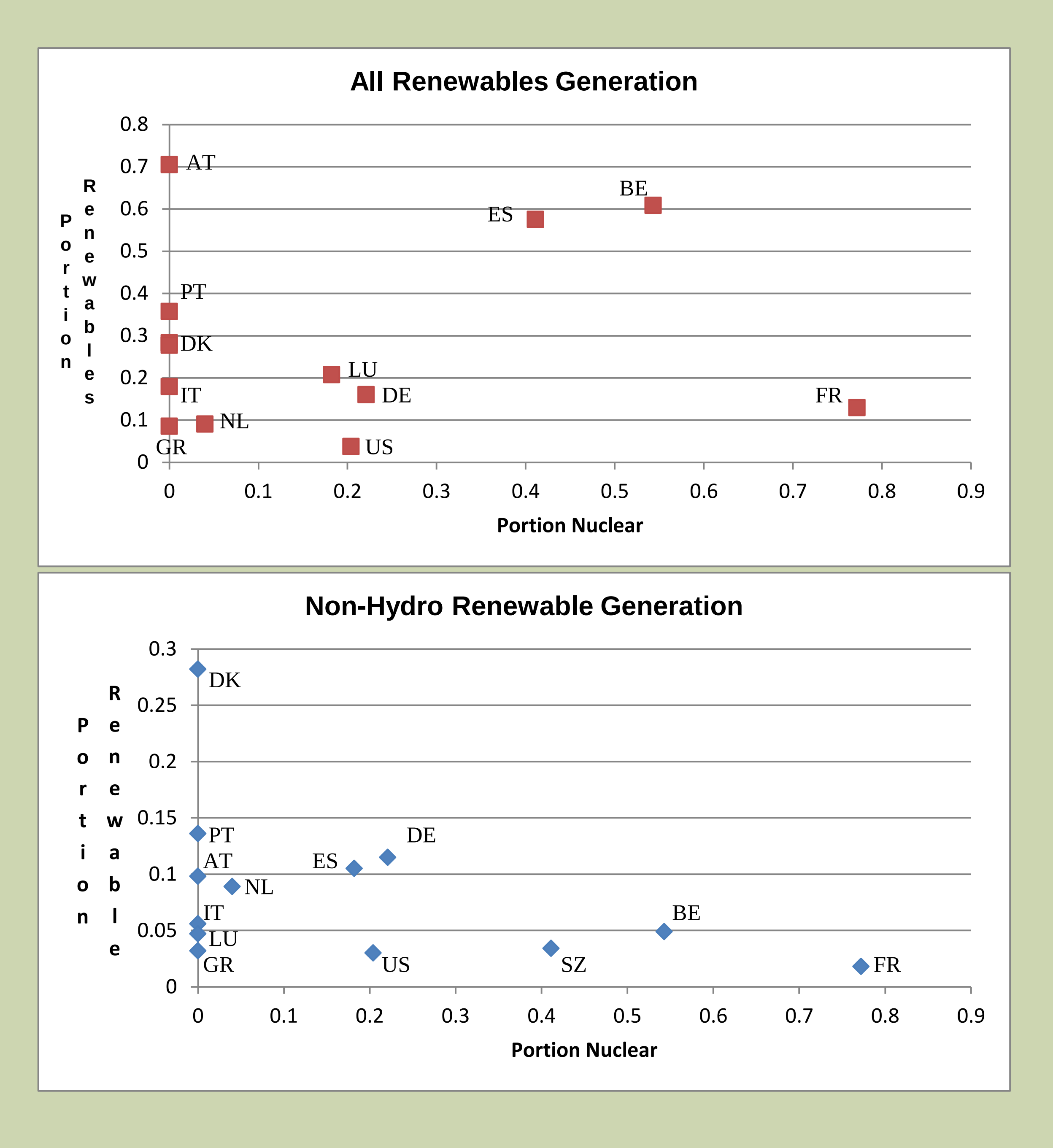
Looking at the generation mix of these nations the crowding out process also appears (see Exhibits IV-2 and IV-3). The presence of central station and/or nuclear are associated with

EXHIBIT IV-2: CENTRAL STATION V. RENEWABLE GENERATION, CROSS NATIONAL, 2007



Sources: International Energy Agency, *Electricity/Heat: 2007*.

EXHIBIT IV-3: NUCLEAR V. RENEWABLE GENERATION, CROSS NATIONAL, 2007



Sources: International Energy Agency, *Electricity/Heat: 2007*.

lower levels of reliance on renewables. While there are many complex factors that underlie such cross national comparisons on an individual country basis, the U.S. and France stand out in this set of countries. Combined with the historical and econometric analysis of those two nations presented above, this reinforces the conclusion that crowding out occurs. More evidence on crowding out in the U.S. is examined in the next section.

THE UNITED STATES

Qualitative Analysis

In the highly centralized French system the dysfunctional process of crowding out renewable energy and efficiency played out as singular authoritarian decisions that produce excess capacity. Because the U.S. system is decentralized and more transparent, the dysfunctionality played out differently. Construction decisions were made by individual utilities subject to public utility commission oversight at the state level. In the U.S., about half the reactors ordered were cancelled or abandoned; with a great deal of contention about the recovery of those costs. That history has been reviewed in detail by others.[63]Historical evidence suggests that the playing field between energy production sources is never level when large central station projects are concerned.

Utilities prefer central station approaches for a number of reasons.[64]

- First and foremost, central station units enable them to increase their income by significantly building their rate base with one facility.
- They have greater control over central station facilities.
- The size of nuclear projects is so large that resources are always constrained and choices are biased in favor nuclear reactors.
- Utility financial resources are tied up for a decade or more.
- Management time is focused on the large project, particularly in the construction phase.
- The need for alternatives is reduced; indeed, alternatives become a threat to the large facilities because reductions in demand raise questions about the need to for large additions to supply.
- The problem is compounded when there is an institutional disparity between the alternative technologies. When technologies have powerful incumbent interests behind them, they are likely to better able to work the process. With deep pockets to cover the loan transaction costs and powerful political connections, bigger utilities will be much better positioned to get the lion's share of the subsidies. This is true of all central station facilities, particularly nuclear reactors.

Examples of this phenomenon were commonplace during the last round of reactor construction in the 1970s.

The recent effort to "jumpstart" the nuclear industry at the federal level underscores the crowding-out problem. In 2007, Congress allocated $18.5 billion for loan guarantees to build about a half dozen, first-of-a-kind nuclear reactors using new designs. The $18.5 billion

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[63] Komanoff, 1992, Tomain, 1985.
[64] Cooper, 2009e.

EXHIBIT IV-4: HISTORIC EXAMPLES OF CROWDING OUT IN THE U.S.

When the New York and New England utilities were embarking on their first round of reactor construction, Hydro-Quebec offered to sell large amounts of electricity into New England for less than one cent per kilowatt-hour under contracts lasting thirty years or more. In Maine, Vermont, and New York, the utilities seeking to build nuclear reactors lobbied furiously against such purchases, claiming that new reactors would match the price and be more reliable. In each state, the utilities were successful, but none of their nuclear reactors cost less than ten times the Hydro-Quebec offering price. By now, the regional cost of these choices easily exceeds $10,000 per family.

When Maine's utilities were committed to building two reactors at Seabrook in New Hampshire, the Maine Public Utilities Commission considered the price that should be paid to buy biomass-fired cogeneration from Maine's paper companies and independent power plant developers. The utilities assured the PUC that biomass would never be a significant resource, that the most that could be produced was about 40 megawatts. Only after the PUC forced their disengagement from Seabrook did they support development of a biomass resource that to date has produced more than twenty times their 1982 estimate. A 1994 paper done for Mainewatch Institute --"Energy Choices Revisited: An Examination of the Costs and Benefits of Maine's Energy Policy"(Economic Research Associates, 1994) documents the extent to which the Maine economy was much better off in terms of jobs, taxes and electricity prices than would have been the case had the Maine utilities retained their ownership in Seabrook.

Throughout the 1980s, New Hampshire Governor John Sununu, a strong supporter of the Seabrook reactor, refused to permit expansion of transmission capacity through New Hampshire that might have enabled Massachusetts to meet its needs less expensively by buying hydroelectric power from Canada or biomass-fired power from Maine.

As the Long Island Lighting Company struggled throughout the 1980s to complete the Shoreham reactor, it refused to expand its gas system into growing Long Island communities in order to assure that company resources were not diverted from finishing Shoreham and that demand forecasts showing a need for Shoreham were not undercut.

Throughout the Northeast, utilities systematically underestimated the amount of cost effective energy efficiency available in their territories as they struggled to cope with cost overruns at Seabrook, Shoreham, Millstone III and Nine Mile II, to say nothing of the costs of cancelled reactors at half a dozen other sites. Years and dollars were wasted on conferences and studies. Not until the 1990s did the success of energy efficiency programs in the region begin to demonstrate the extent of the potential of energy efficiency to deliver energy services at costs far below those of new reactors.

Source: Bradford, 2009.

reflected cost projections published in 2004 by academics at the University of Chicago under a grant from the Department of Energy that put the cost of nuclear reactors in the range of $1,000 to $2,000 per kilowatt-hour. Today, utilities put the costs at $4,000 to $5,000 per kWh, and Wall Street analysts put it at $6,000 to $7,000 per kWh. Just three years later, the $18.5 billion will now only fund two projects. With the collapse of the climate legislation in the 111th Congress, the industry has been seeking to increase the size of the fund in the appropriations process. Funding for renewable resources has been cut, while funding for nuclear has been protected and efforts have been made to increase those funds.[65]

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[65] Ling, 2010; Goode, 2010; Solar City, 2010. Weiner, 2010; AP, 2010.

At the state level, the crowding out is expressed in a variety of forms. States influence choices about how to meet the future need for electricity through integrated resource plans and utility planning processes, essentially deciding what is built by deciding for which projects the utilities will be allowed to recover the costs. Utilities have been vigorously opposing renewable and efficiency alternatives, especially in the states where they want to build nuclear reactors.

- They oppose legislation that seeks to promote alternatives.[66]
- They manipulate tariffs and power purchasing authority to undermine the alternatives.[67]
- They build excess capacity of large central station facilities, to dampen demand for alternatives.[68]
- They put extremely high price estimates on alternatives like efficiency, while low-balling the cost of new nuclear reactors.[69]

Quantitative Evidence

To examine the crowding out hypothesis in the U.S., we operationalize several measures of the "crowd" and of the "crowding out" state and utility levels.

The reliance on central station facilities as a percent of total generation in 1990 captures the historic commitment to central station generation.

Central Station History = % of Generation from Coal or Nuclear in 1990

The year 1990 is a good candidate to operationalize this aspect since it is just about at the end of the nuclear reactor building cycle and before the dash to natural gas facilities that typified the 1990s. Renewables are expected to play a smaller role the higher the percentage of central station facilities, which is the essence of crowding out. This is a simple arithmetic relationship that reflects historic choices made by utilities about which forms of generation to rely on. We would also expect the percentage of central station facilities to be negatively related to policies to promote efficiency and renewables on a going forward basis.

To capture the contemporary "crowd" we identify which states have plans to build central station facilities in the years ahead. The application for a nuclear reactor license for a new facility is taken as an indicator nuclear of intentions.

Nuclear plans = License application filed with the NRC

0 = No, 1 = Yes

Plans to build coal facilities are taken as an orientation toward coal. The coal plans are

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[66] *Solar Thermal Magazine*, 2010; Snyder, 2007.

[67] Falchek, 2010.

[68] Cardinale, 2010.

[69] Id., "They are trying to block glean energy by trying to flood the market with cheap, dirty energy… "If you build these giant plants, there will be no demand for clean energy. The clean technologies are here today. People have solar panels. The companies are blocking the market.

identified in the EIA database through 2013. The online date projected for the nuclear reactors contemplated tended to be farther out (2016-2020) reflecting the longer time frame needed to build nuclear reactors. We created a variable for central station intentions of nuclear or coal facilities.

Central Station Plans = nuclear license or coal plant projected

0 = none, 1 = nuclear or coal, 2 = nuclear and coal

We operationalized six measures of crowding out, three each for renewables and efficiency. The three renewable measures are

Renewables 1990 = % of generation from all renewables

Non-hydro renewables 1990 = % of generation from non-hydro renewables

Current RPS goals = % target

The three efficiency measures are

Spending % = Incremental Spending/Total Revenue, 2006

Energy Saved % = Energy saved in utility programs/total consumption
Cumulative 1992-2006

Efficiency Score = ACEEE utility program score

All variables were measured at the state level. We were also able to measure the first two efficiency variables at the utility level.

The results are presented in Exhibit IV-5. They provide strong support for the crowding out hypothesis. The greater the commitment to central station facilities, the weaker the commitment and poorer the performance with respect to efficiency and renewables. In every case the greater the role of central station facilities the less the role of efficiency and renewables.

The average levels of efficiency and renewables are much higher in the states that had lower commitments to central station facilities. The states with nuclear reactors and coal plants generally have one-third or less the level of commitment and plans for renewables and efficiency. States with plans for either nuclear or coal facilities fall between the two extremes. States with pending nuclear licenses have much lower levels of past efficiency and renewables and weaker programs to promote future efficiency and renewables. The individual utilities with plans for nuclear reactors have much lower levels of efficiency spending and achieved savings.

The correlation coefficients presented in the table support this analysis. Every correlation coefficient between central station facilities and the efficiency and renewable measures is negative. The larger the role of central station facilities and nuclear reactors, the lower the level of performance on efficiency and renewables. Two-thirds are statistically significant and four-fifths are larger than their standard errors.

EXHIBIT IV-5: TESTING THE CROWDING OUT HYPOTHESIS IN THE U.S.

Category Means	Renewable % of 1990 Generation	Non-hydro Renewables as % of 1990 Generation	RPS Goal (%) 2010	Efficiency Spend as % of 2006 Revenue'	Energy Saved % of total Energy	ACEEE Utility Efficiency Program Score 92 – '06
Central Station						
Plans 2009						
None	19.23	0.61	16.22	0.95	2.78	9.08
Nuke or Coal	7.48	0.02	11.26	0.46	1.13	5.21
Nuke & Coal	4.04	0.0	7.36	0.29	0.60	1.79
Nuke License: State						
None	15.09	0.40	14.33	0.82	2.29	7.72
Pending	6.66	0.03	9.58	0.25	0.58	3.38
Nuke License Utility						
None				0.47	2.42	
Pending				0.06	0.94	
Correlation (Significance)						
Central station	-.50	-..06	-.10	-.28	-.37	-.27
as % of Total	(.002)	(.696)	(.477)	(.012)	(.0070	(.052)
1990 Generation						
Central Station	-.29	-.19	-.29	-.34	-.39	-.42
Plans	(.039)	(.178)	(.037)	(.016)	(.051)	(.002)
Nuclear License	-.18	-.10	-.20	-.30	-.33	-.34
Pending State Utility	(.039)	(.491)	(.166)	(.033)	(.017)	(.009)
				-.20	-.13	
				(.046)	(.186)	

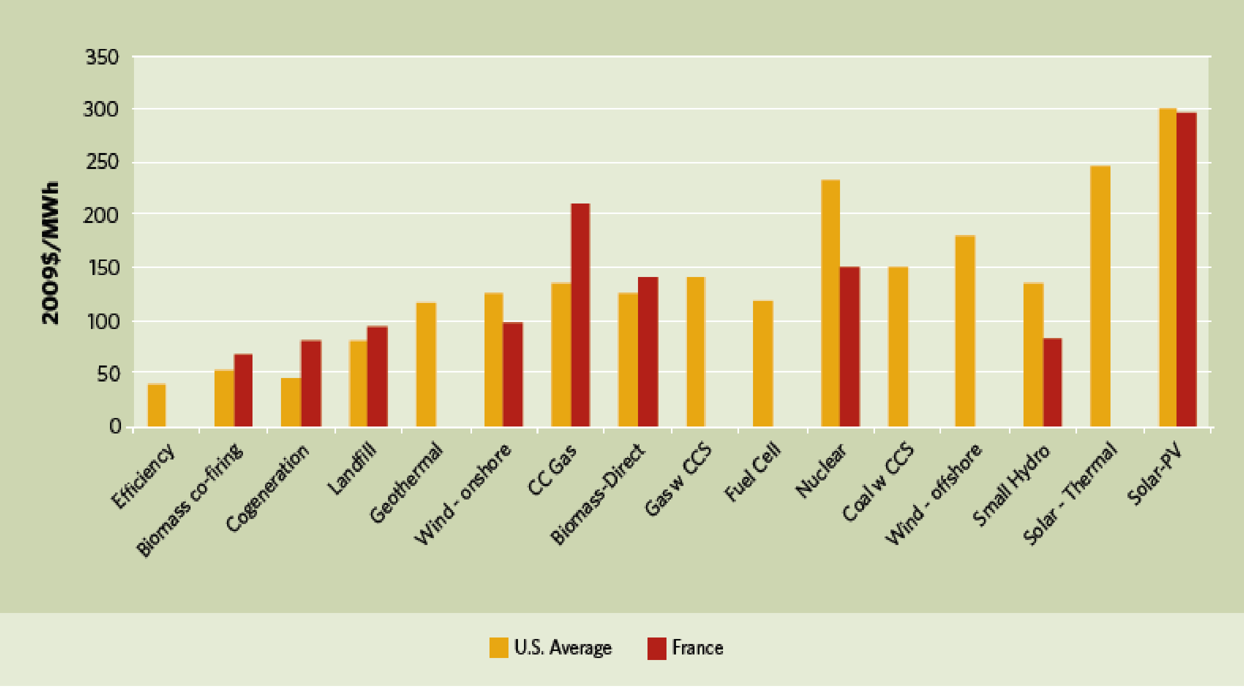
Sources: Efficiency Spend, Energy Saved, Chichetti, 2009; Generation, U.S. DOE, State Data Tables; RPS, http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm#chart, ACEEE, State Scorecard, 2007,

TECHNOLOGY CHOICES AND ALTERNATIVE RESOURCES

Grubler's comments, cited above, on the current cost estimates of nuclear reactors that should be included in the analysis of low carbon alternatives remind us that the purpose of the exercise of cost analysis and estimation is to establish a benchmark for policy decisions about which technologies to implement (see Exhibit IV-6). Schneider's observations on the decisions made to expand exports and domestic consumption to absorb excess nuclear capacity remind us that policy choices are critically important.

Given the hype about the French nuclear program in the U.S. and the decision to expand export of power and domestic consumption to absorb excess nuclear capacity remind us that policy choices are critically important. In the U.S., the historic debate around nuclear tended to focus on the comparison of nuclear and coal. Today, the range of alternatives considered is much broader.

EXHIBIT IV-6: REFERENCE COSTS FOR ELECTRICITY GENERATION



Source: France: Ministry of Ecology, Energy and Sustainable Development, *Public Summary of Reference Costs for Electricity Generation,* 2009; United States: Congressional Budget Office, 2008, p.13; Kaplan, 2008, California Energy Commission, 2009, p. 18; Lazard, 2008, p. 10; Lazard, 2009, p. 2; Lovins, sheikh, and Markevich, 2008, Draft, p. 2; Moody's, 2008, p. 15; National Research Council of the National Academies, 2009, p. 58; Renewable Energy Policy Network for the 21st Century, 2008, p. 11.

The convergence of French rectors to U.S. reactor costs may be surprising. However, there are no surprises in the estimation of the cost of other technologies, as shown in Exhibit IV-5, which compares French estimates of the cost of half a dozen generation technologies to recent estimates of the cost of a similar, albeit wider, set of technologies in the U.S. The alternatives are less costly by a wide margin. The lowest cost potential resource shown in Exhibit IV-1, above, efficiency, would appear to be much more available in the U.S. than France.

The cost estimates in Exhibit IV-6 are generally static. They do not fully reflect the process of nuclear cost escalation we have demonstrated throughout this paper. Moreover, they do not fully reflect the likely process of cost declines for other technologies over time. The renewables, in particular, are not afflicted by the underlying processes that afflict nuclear. The expectation is that the costs of alternatives will decline over time.[70]

Given the availability of low-cost alternatives, the choice for meeting electricity needs comes down to an evaluation of the resource endowment. While cross-national comparisons of resources are challenging, and detailed analyses tend to be at a large regional level (e.g. North America v. Europe), it is quite clear that the U.S. has a much wider range of options than France, as shown in Exhibit IV-7. Moreover, a detailed analysis of wind sites shows that the North

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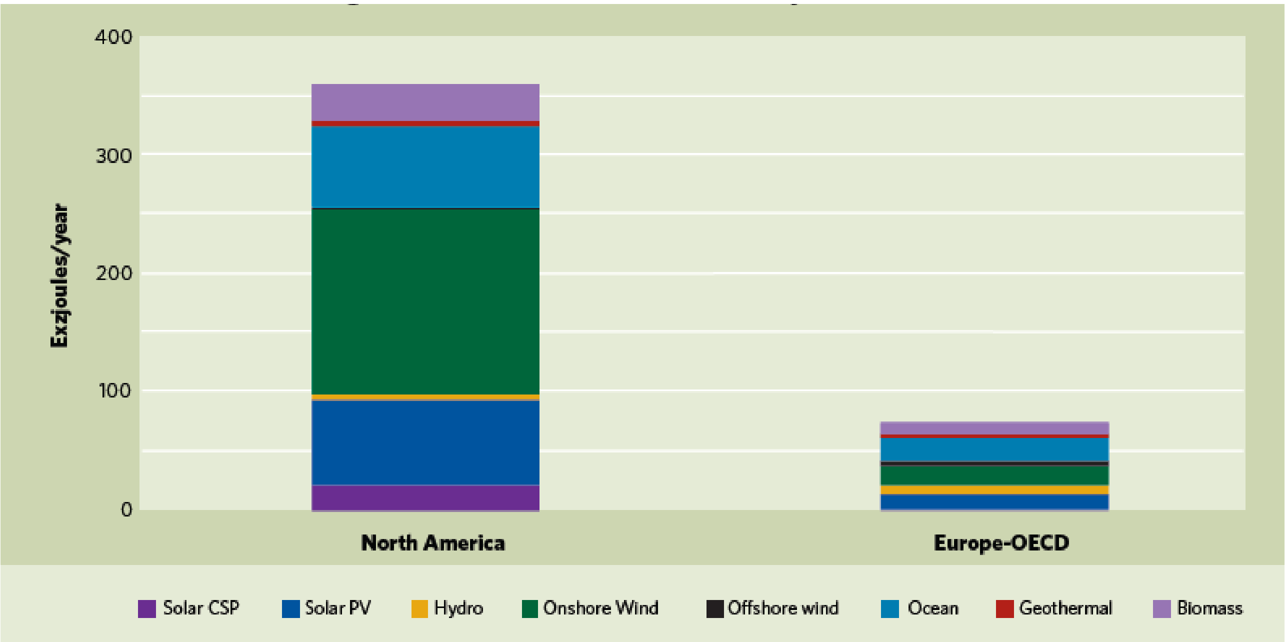
[70] National Renewable Laboratory; 2005; Lazard, 2009; Venkataraman, 2010; Wiser, et al, 20009. ;

America has about 50 percent more attractive sites than Europe and maps suggest France is not well endowed with wind resources.[71] The U.S. advantage in solar is even greater, while biomass and geothermal opportunities appear to be about equally available in the U.S. and Europe. It should also be noted that the price of coal and gas used in the French analysis of conventional fuels is substantially higher than the price in the U.S.

EXHIBIT IV-7: POTENTIAL ELECTRICITY FROM RENEWABLE RESOURCES: NORTH AMERICA COMPARED TO EUROPE



Source: Hootwijk, 2008.

CONCLUSION

The implicit assumption of the analysis of alternatives is that policy matters. The statistical evidence from the U.S. and Europe suggests that it does. At one level, crowding out is a mathematical tautology – if a nation relies more heavily on one type of technology, it is likely to have less of others. At another level, the tautology is the result of policy choices. The decision to rely on a technology is a conscious one. The upper graph in Exhibit IV-8 makes this point by plotting an evaluation of the effectiveness of policies to promote onshore wind and biomass against the portion of generation accounted for by nuclear in Europe. In this graph it is clear that the impression of French policy is correct. The lower graph shows the relationship between efficiency policy and energy savings in the U.S. Again, there is a clear relationship between policy and outcomes.

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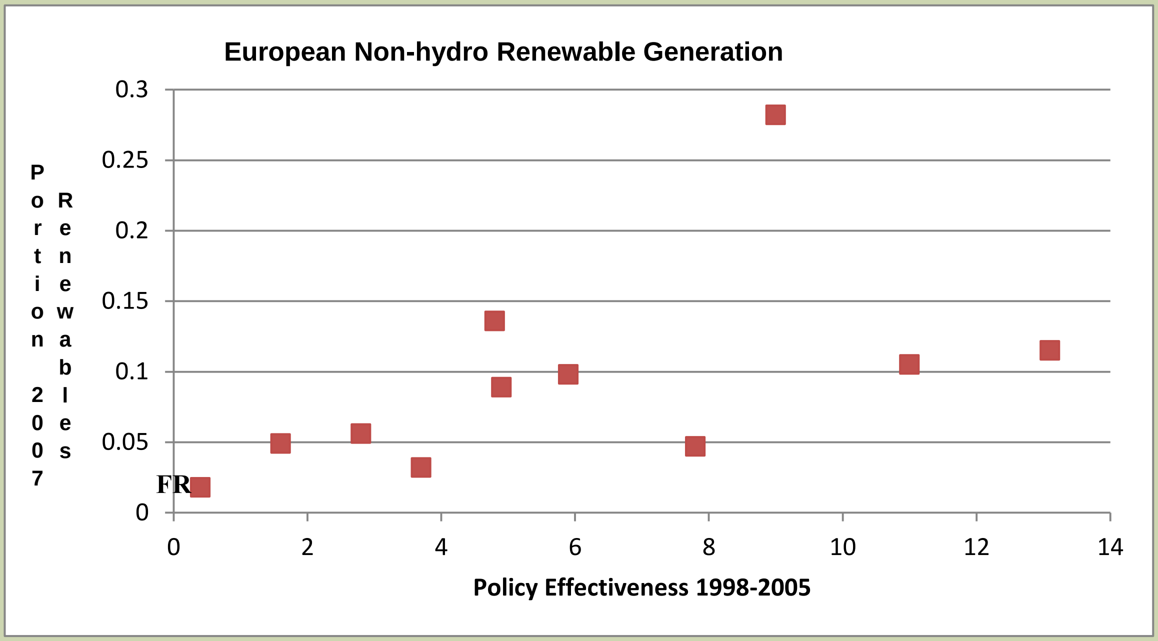
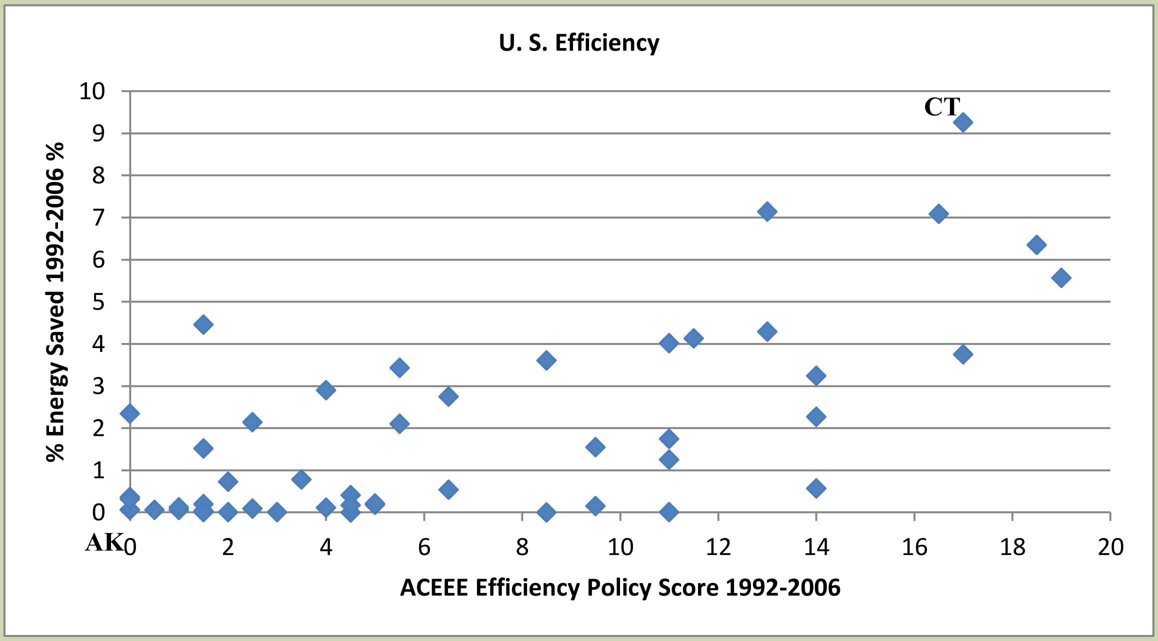
[71] Hoogwik, 2008; Breyer, 2009; Kosnik, 2008; Archer and Jacobson, 2005.

EXHIBIT V-8: RENEWABLE AND EFFICIENCY POLICIES AFFECT OUTCOMES



Sources: Ragwitzand Held, 2007; International Energy Agency, *Electricity/Heat: 2007*. Nations included are Austria, Belgium, Denmark, France, Germany, Greece, Italy, Luxembourg, the Netherlands, Portugal, Spain, Switzerland and the United States.



Sources: Energy Saved, Chichetti, 2009; ACEEE, State Scorecard, 2007.

The more frank members of the utility industry have publicly acknowledged the problem that new nuclear reactors face. John Rowe, Chairman and CEO of Exelon Corporation, which owns more nuclear reactors than any other utility in the U.S., has recently admitted a dramatic change in the cost of low-carbon resources that shows the cost of nuclear 2.5 times higher in 2010 than in 2008, an increase that parallels the increases noted earlier and discussed further below. Exelon's view of carbon abatement options in 2008 and 2010 reflects the detailed analysis presented in Exhibit IV-6 above. The result is that the economic prospects of nuclear reactors have dimmed substantially, as shown in Exhibit IV-9, where the cost of various technologies are sown in terms of their cost per ton of carbon dioxide emitted at an assumed price of $40 per ton of carbon dioxide. Even with loan guarantees and tax subsidies, in this analysis nuclear reactors costs are well above the projected price of carbon. Efficiency, natural gas, cogeneration and wind with tax incentives are below the projected price of carbon. Exelon acted on this analysis in 2010, withdrawing its license application for a nuclear reactor and making a large quantity of existing wind capacity at a cost per KW that is one fifth the cost of a new nuclear reactor, a purchase that "will instantly make Exelon on of the nation's largest wind operators.[72]

History suggests that the prospects for reactor costs were never anywhere nearly a bright as the early cost projections suggested. Whether it was hype or cost escalation, keeping in mind that cost escalation really sets in after construction begins, it now appears that, even with substantial subsidies, nuclear is more costly than a dozen alternatives.

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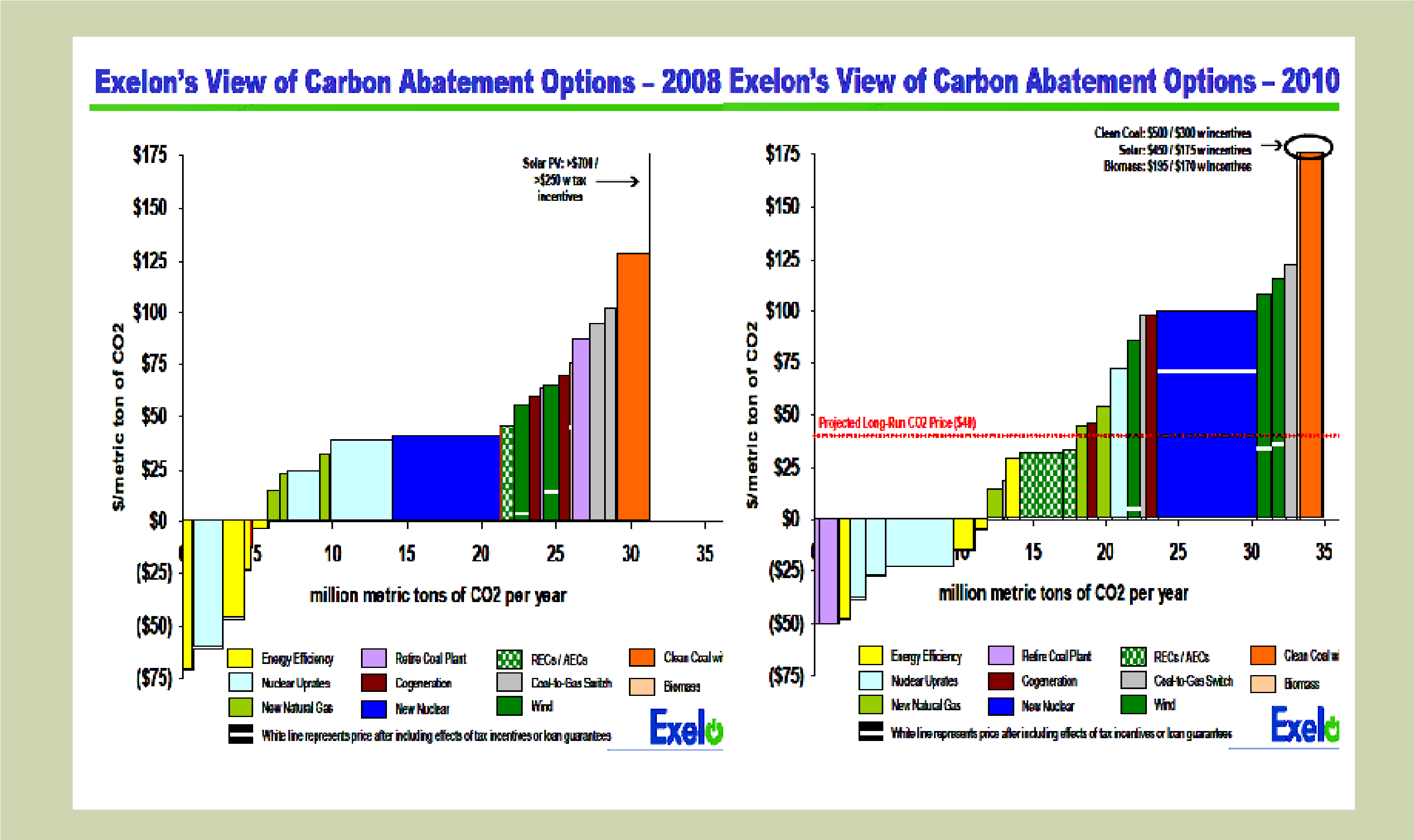
[72] Wald, 2010.

EXHIBIT IV-9: NUCLEAR COST ESCALATION AND THE SUPERIOR ECONOMICS OF ALTERNATIVE LOW CARBON RESOURCES



Source: Rowe, 2010

VI. CONCLUSION: THE PAST IS PROLOGUE

THE PERSISTENT TREND OF ESCALATION AND UNDERESTIMATION OF COSTS

Looking back on the history of the construction costs of nuclear reactors that were actually built and the current experience of construction and cost estimation presents a sobering view. The promise of low cost power was never met and repeated assurances that costs could soon be under control were never fulfilled. In 1981 Bupp and Derian shined a spotlight on this endless, unjustified optimism by citing a 1975, Public *Utility Fortnightly* article that gushed about the benefits of nuclear reactors.

> The enormous benefits of nuclear power were reflected in an early 1975 *Public Utilities Fortnightly* survey of all American utilities that operated nuclear power plants as part of their electrical generating systems. The 24 companies concluded that "the peaceful atom" had saved their customers more than $750 million in their 1974 bills that they would have owed had their electricity come from fossil fuels. They also reported that in the same year "power from the atom" had saved "the equivalent of more than 247 million barrels of oil."[73]

The skepticism expressed early on by Bupp and Derian was ratified by in a dramatic 1985 cover story in *Forbes* magazine.

> The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power, with an additional $140 billion to come before the decade is out, and only the blind, or the biased, can now think that most of the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible.[74]

What happened in that decade to so dramatically change the perception of nuclear reactors? From an economic point of view, this paper has shown that nothing much had changed. As shown in Exhibit V-1, all that happened was that the cost escalation problems inherent in nuclear reactor construction had become apparent. The truth about the economics of nuclear reactors could no longer be hidden beneath hope and hype about learning curves, standardization and economies of scale. As we have seen, a handful of analysts were able to see past the hype and were already identifying problems in the late 1970s. By early 1985, however, a business-oriented journalist could see the full implications of the evolving cost trend and declare it a "fiasco."

Indeed, one thing that had happened by 1985 was that the tendency of nuclear vendors and enthusiasts to underestimate the costs could no longer be ignored. As shown in Exhibit V-2, the vendors and utilities that are advocates of nuclear reactors continue to do what they have

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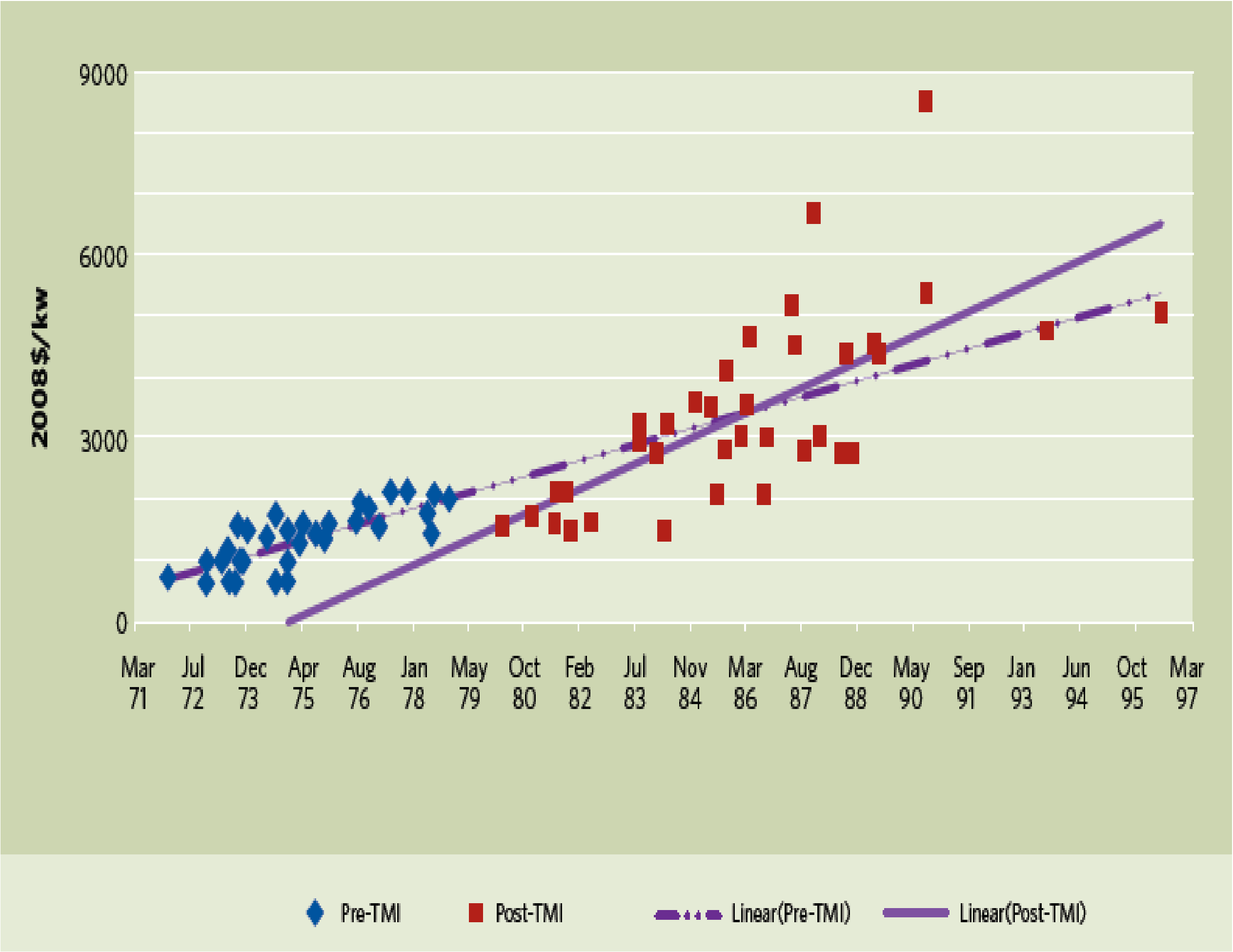
[73] Bupp and Derian, 1981, pp. 7-8

[74] Cook, 1986.

always done, underestimate the costs. It includes seven projections from the mid-1960s as well as almost 50 projections that have been offered for the new nuclear reactor construction since 2000. The exhibit includes Komanoff's 1981 projections of costs as an early analyst's projections.

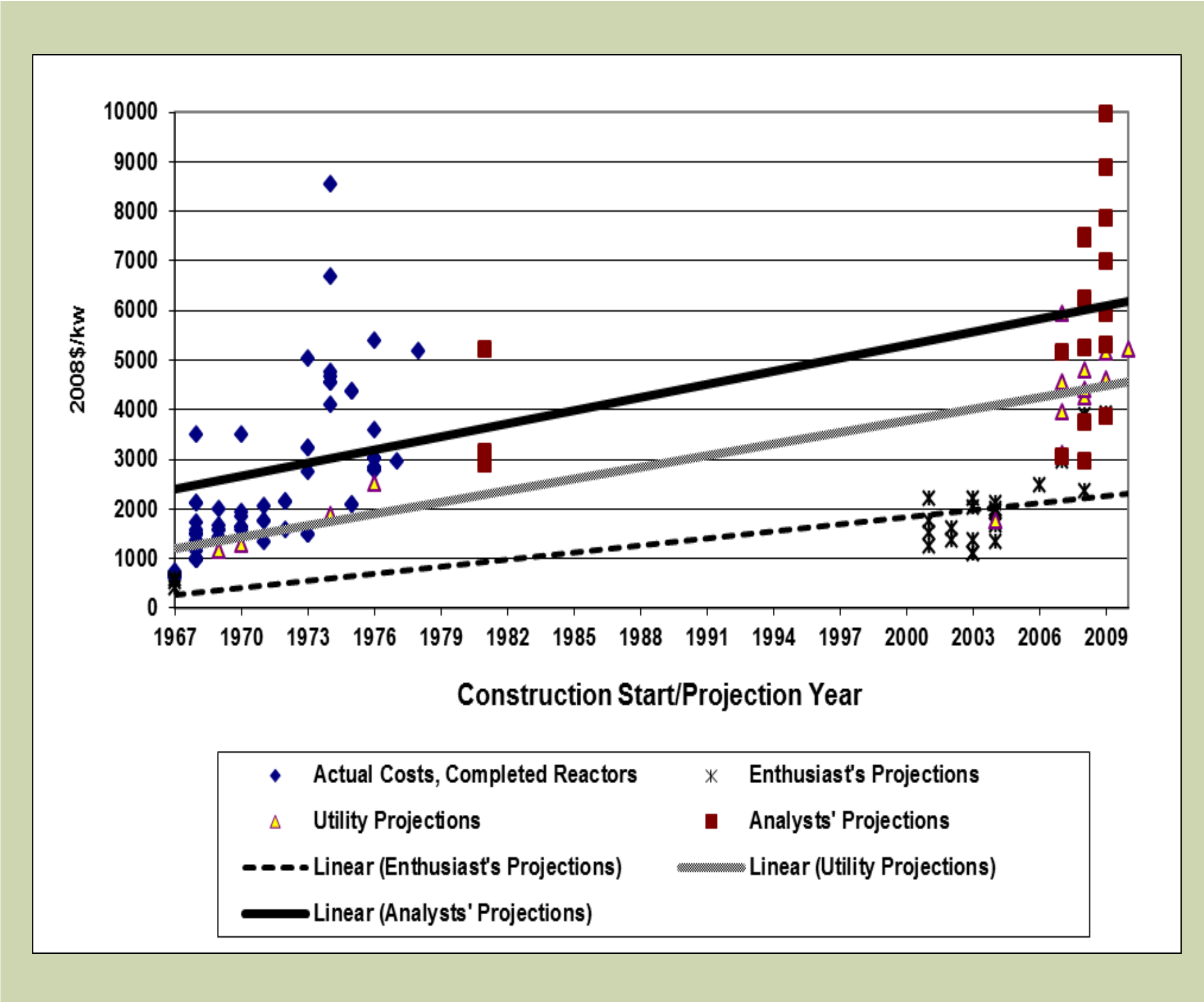
EXHIBIT V-1: THE PERSISTENT ESCALATION OF U.S. REACTOR CONSTRUCTION COSTS



Source: Cooper, database

Exhibit V-2 makes two things clear. First, cost escalation in the plagued nuclear construction throughout the history of the industry. Second, the obvious tendency of vendors and enthusiasts to underestimate costs is clear. In contrast to the fiasco in the 1970s and 1980s, however, this time there are track records and alternative estimates from Wall Street and independent analysts with which to challenge the wildly optimistic projections. The lesson for policymakers is clear: nuclear reactor construction is extremely expensive today and is likely to become even more expensive over time.

Exhibit V-2: Initial Cost Projections Vastly Underestimate Actual Costs



Source: Cooper, 2009, database.

The Contemporary Problems in Cost Projection and Project Start-up

The nuclear industry is experiencing the early phases of the problems described above. The European/Evolutionary Pressurized Water Reactor (EPR) is the design the French are currently struggling with in France and Finland and the design that has been proposed for three projects in the U.S. The continuing severe difficulties of Finland's Olkiluoto nuclear reactor being built by Areva, the French majority state-owned nuclear firm, provide a reminder of how these problems unfold.[75] Touted as the turnkey project to replace the aging cohort of nuclear reactors, the project has fallen three and a half years behind schedule and more than 75% over budget.[76] The delay has caused the sponsors of the project to face the

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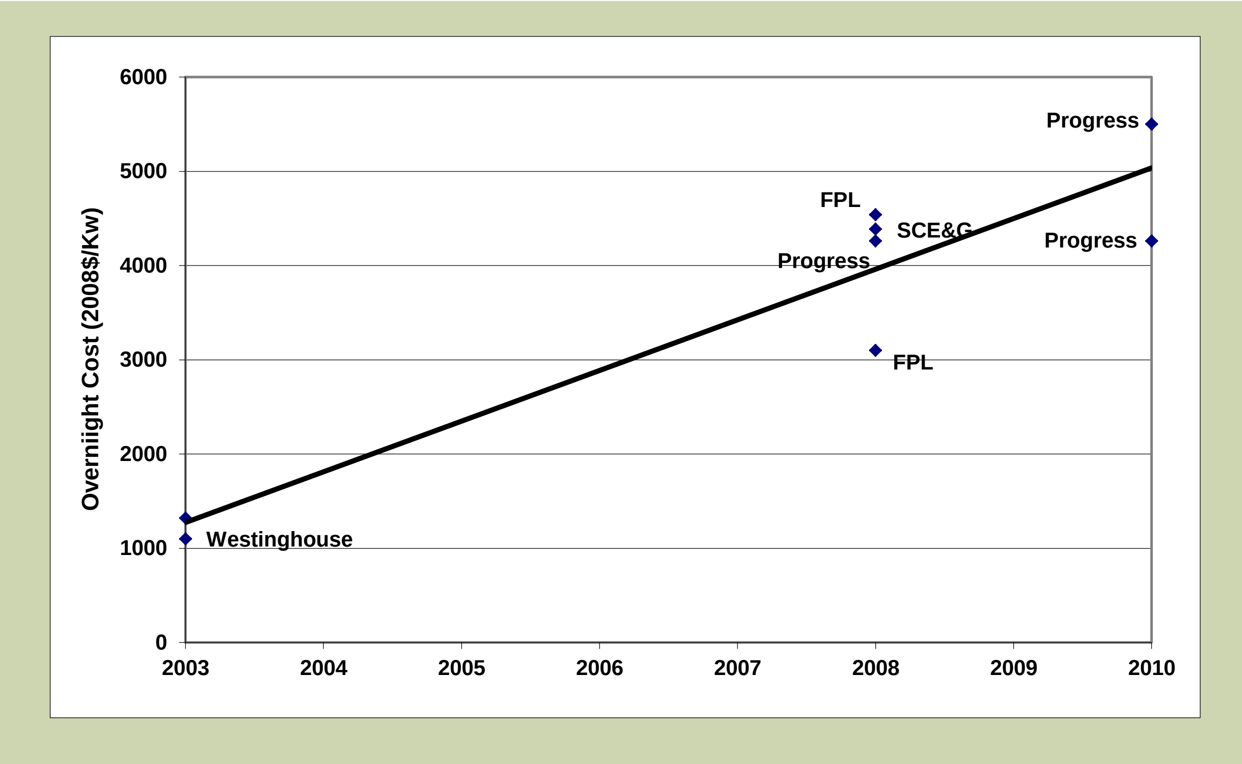
[75] Areva's difficulties are not limited to this plant, Schneider, 2009, Thomas, 2010.

[76] *International Herald Tribune*, "France: Areva Profit Falls Due to New Reactor," February 25, 2009; update

problem of purchasing expensive replacement power, the costs of which they are trying to recover from the reactor builder. The cost overruns and the cost of replacement power could more than double the cost of the reactor.[77]

Projections of the cost of U.S. reactors have been escalating and design problems abound.[78] Even focusing on utility and vendor estimates of the reactor design that is the one favored by those seeking to build new reactors (the AP-1000), the experience of cost projection is alarming. Projected costs have increased three-fold (see Exhibit V-3). The AP-1000 is by far the most popular design among the utilities seeking licenses. Its vendor claimed that being an extension of an earlier design it would have fewer difficulties getting licensed and built. But, as Exhibit V-3 shows, it ran into significant design problems. The history of cost projections is emblematic of the economic problem nuclear power faces. The vendor started with an extremely low price.[79] By the time the utilities began to put a price tag on it for actual implementation five years later, the cost had more than tripled. The most recent estimate puts the upper bound on cost at almost five times the original low estimate. A similar fate has befallen other designs as well.[80]

EXHIBIT V-3: THE TROUBLED HISTORY OF THE U.S. NUCLEAR RENAISSANCE: AS SEEN THROUGH THE COST OF THE AP-1000 (VENDOR AND UTILITIES ONLY)



Source: Cooper 2009, database, updated.

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[77] Kanter, 2009. The Finnish also find themselves in need of alternative low carbon sources of electricity to meet its climate change targets.
[78] Harding, 2007; Standard and Poor's, 2009.
[79] Westinghouse, 2003.
[80] This is true of the South Texas Project and Calvert Cliffs.

The pre-construction phase of the "nuclear renaissance" in the U.S. has experienced several characteristics similar to the previous round of nuclear reactor construction in the U.S., beyond the obvious fact that cost projections have escalated rapidly (see Exhibit V-4).

- There have been numerous design problems and dissatisfaction at the NRC with the reactor design (AP-1000) chosen most often by those proposing to build new nuclear reactors. Even with an expedited review process, these serious design issues are likely to delay the projects.
- Decrease in demand and the low cost of important alternatives like natural gas have combined with the long lead times and lumpy, sunk costs of these projects to call their viability into question.
- The large size of the projects compared to the balance sheets of most utilities proposing new reactors and uncertainties about the need for these reactors and ability of the utilities to execute these projects has resulted in repeated downgrades of utility credit ratings.

Because the U.S. industry is decentralized and each individual project has encountered difficulties, the litany of problems creates a long list. The highly centralized French system has only two primary players – EDF and AREVA – but they have encountered a similar, even more profound set of problem because they have plants under construction. As Exhibit V-5 shows, a recent internal review by a very senior official presents a thorough critique of the institutional organization, execution and design of the reactor that is being built abroad and proposed for the U.S. that demonstrates the French are having exactly the same problems as the U.S. had in the past and appears to be having in the present. Ironically, as the final recommendation shows, the competition between nuclear reactor construction and renewables is affirmed with the proposal to secure funds earmarked for renewables for nuclear reactors.

ANALYTIC CONCLUSIONS

The analysis in this paper challenges the claim that standardization, learning or large increases in the number of reactors under construction will lower costs. These claims are contradicted by the evidence from the two largest national nuclear construction programs in capitalist economies: the U.S. and France. Among the most important findings of this analysis are the following:

- Standardization has been difficult to achieve and there has not resulted in lower costs, while the increasing complexity of nuclear reactor projects results in higher costs;
- Assumptions about learning effects lowering costs are unsupported by empirical data. Costs may rise with increasing experience, rather than fall;
- Building larger reactors to achieve economies of scale to lower costs does not come close to offsetting the project and industry factors that drive costs up;

EXHIBIT V-4: COST ESCALATION, DESIGN PROBLEMS, DELAYS, CANCELLATIONS AND NEGATIVE FINANCIAL INDICATORS IN THE 'NUCLEAR RENAISSANCE'

Month	Event
Jan-08	MidAmerican cancels proposed Idaho reactor (1)
Feb-08	NRC suspends application for *South Texas Project* reactors because application is incomplete (NRG has since reapplied) (2)
Feb-08	Florida Power and Light revises cost estimates for *Turkey Point* reactors from around \$8 billion to \$24 billion (3)
Mar-08	Progress Energy triples cost estimates for *Levy County* reactors to \$17 billion (4)
Aug-08	Constellation increases cost estimates for *Calvert Cliffs* reactors from \$2 billion to \$9.6 billion (5)
Oct-08	Progress Energy increases cost estimates for *Shearon Harris* reactors from \$4.4 billion to \$9.3 billion (6)
Nov-08	Duke Energy increases cost estimates for *William States Lee* reactors from \$5 billion to around \$11 billion (7)
Dec-08	TVA increases cost estimates for *Bellefonte* reactors from \$6.4 billion to \$10.4 billion (8)
Mar-09	Entergy suspends application for *River Bend* reactor in Louisiana (9)
Mar-09	Entergy suspends application for *Grand Gulf* reactor in Mississippi (10)
Apr-09	AmerenUE cancels proposed *Callaway* reactor (11)
May-09	Exelon cancels two proposed *Victoria County* reactors (Has since reapplied for an Early Site Permit) (12)
May-09	Progress Energy in Florida announces at least a 20-month delay on planned reactors at *Levy County* (13)
May-09	PPL's cost estimates for one reactor at *Bell Bend* skyrockets from \$4 billion to \$13-15 billion (14)
May-09	Moody's downgrades PPL to negative outlook over proposed reactor at *Bell Bend* (15)
Jul-09	Moody's and Fitch downgrade SCE&G due to proposed *VC Summer* reactors (16)
Aug-09	TVA cancels three proposed reactors at *Bellefonte* site (17)
Aug-09	Constellation delays NRC's review of *Nine Mile Point* application to September 2010, a one-year delay (18)
Aug-09	NRC delays the scheduled publication of the final environmental review for Constellation's *Calvert Cliffs* in Maryland to February 2011, a delay of 13 months (19)
Aug-09	TVA delays proposed *Bellefonte* reactor from 2016 to 2020-2022 (20)
Sep-09	AP-1000 design in 17th revision; NRC announces more problems that will likely delay AP-1000 designs like *Shearon-Harris, Lee,* and *Vogtle* reactors
Sep-09	Duke delays *William States Lee* reactors from 2016 to 2021 (21)
Sep-09	Moody's gives negative credit rating to Oglethorpe over planned investment in *Vogtle* reactors (22)
Oct-09	NRC identifies significant safety issues with AP-1000 shield design, potentially signaling delays with over half of the proposed reactors in the US (23)

Oct-09	New cost estimates for *South Texas Project* reactors go up $4 billion, a 30% increase (24)
Nov-09	Fitch downgrades SCANA over risks posed by SCE&G's two nuclear reactors at *VC Summer* (25)
Nov-09	Areva announces plans to modify EPR reactor design at the request of safety bodies in the UK, France, and Finland (26)
Dec-09	Unistar asks NRC to suspend application for *Nine Mile Point 3* reactor (27)
Jan-10	FP&L announces that they'll suspend plans for *Turkey Point* reactors based on decision of Florida PSC to reduce proposed rate hike from $1.26 billion to $75.5 million (28)
Jan-10	Progress Energy announces that they'll slow the *Levy County* process based on the same Florida PSC decision, in which they got none of a $500 million rate hike request (29)
Jan-10	Fitch puts FP&L (*Turkey Point* reactors) on ratings watch 'Negative' after decision by Florida PSC to not provide CWIP (30)
Feb-10	Progress Energy extends delay on L*evy County* reactors to at least 36 months. (31)
Feb-10	Toshiba and Westinghouse indicate that regulatory problems will delay reactors in Florida (*Turkey Point* and *Levy County*) for up to 3 years. (32)
Mar-10	FP&L announces delay of *Turkey Point* reactors past 2018, signals interest in federal loan guarantees. (33)
Apr-10	Moody's downgrades FP&L from low to moderate risk over *Turkey Point* reactors. (34)
Apr-10	NRC states that design-review certification of US-APWR will take at least an additional six months, shifting deadlines well into 2011. (35)
May-10	Cost estimates move from $17.2 billion for the two reactors to $22.5 billion for *Levy County* reactors. (36)
May-10	Fitch downgrades Progress Energy (*Levy County* and *Shearon Harris* reactors) to just above junk bond status. (37)
May-10	TVA opts to go with old Babcock and Wilcox design for single reactor at *Bellefonte*, citing untested status of new designs. (38)
May-10	The timeline for the two *Levy County* reactors has been pushed back again, with the first due in 2021, the second some 18 months later. The original timeline had the reactors set to come online in 2016 and 2018 respectively. (39)

Sources

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EXHIBIT V-5: CONTEMPORARY FRENCH NUCLEAR EXECUTION PROBLEMS

The credibility of both the EPR model and the ability of the French nuclear industry to successfully build new plants have been seriously undermined by the difficulties encountered on the Olkiluoto site in Finland and on the third Flamanville reactor.

Similarly, while the average capacity of nuclear power worldwide - measured by the capacity factor Kd – has increased over the past fifteen years, the French nuclear plant capacity has sharply declined in recent years

It is therefore important to quickly rectify the situation, by taking the necessary emergency measures, and thus enable the French nuclear industry, which has the capacity, to position itself in the new civilian nuclear power markets. Otherwise the credibility, and therefore the very existence of this industrial tool around AREVA would be threatened.

It also follows from these findings and recommendations that some lessons learned for the Olkiluoto, Flamanville 3 sites, and Le Taishan (China), should be imperatively carried out before starting the actual construction of Penly 3.

The resulting complexity of the EPR, arising from the choice of design, specifically the level of power, the containment, the core catcher and the redundancy of the security systems is certainly a handicap for its construction and therefore its cost. These factors explain, in part, the difficulties encountered in Finland or in Flamanville. Therefore, the further optimization of the EPR should be pursued with the feedback from the reactors under construction and the knowledge of past achievements. The optimization will be carried out jointly by EDF and AREVA, in conjunction with the ASN in order to progress in the detailed design with the same level of safety.

Our industry must improve its competitiveness and become attractive to investors

This requires determined action by companies. This will also require a change in industrial culture.

The main areas of industrial progress are clearly identified and are already resulting in an intense effort from all the nuclear industry actors: reduction of the duration of construction, standardization and construction of the same models, simplification of the design, construction of several units on the same site, increased efficiency of plant management.

The strengthening of the competitiveness of the French civilian nuclear energy also requires genuine commitments from the government, whose main lines could be:

- Pursue the implementation of a carbon tax on CO_2;
- Push for the extension of plant operation to 60 years, while keeping to same level of safety;
- Plan a moderate but steady increase for electricity prices (in constant euros) to enable the preparation for the long term financing of the park renewal;
- Ensure that the transfer price of electricity by EDF under the Nome law covers the full cost of the park renewal;
- Pursue political efforts to obtain that all the multilateral financings earmarked for the renewable energies are also open to nuclear power.

Roussely, pp. 3…4… 14

- As a result, more recent, more complex technologies are more costly to construct;
- French technology sold abroad may encounter unique cost escalation problems; and
- Cost projections are liable to be underestimated and manipulated for political purposes.

Finding similarities and differences between the economic processes in the French and American nuclear industries also serves to dispel myths about the U.S. industry that have become common wisdom that can mislead policymakers. The idea that one can, or should, copy a foreign model is suspect, once one understands that the "success" of that model is limited and that the conditions for "success" are unique. The French could not replicate or export their own "success" when they sought to "frenchify" the American design on which their initial success was built.

Crowding out is an unintended, but natural, even inevitable, result of the commitment to nuclear construction.

- Choices about which technologies should be pursued need to reflect not only the cost of a specific technology, but also the cost of alternatives and the resources available. Crowding out makes it more difficult to pursue least cost alternatives.

- The U.S. has many lower cost options available than the French, so that even if nuclear once did make sense in France, it does not in the U.S.

POLICY IMPLICATIONS

The failure of the nuclear industry to exhibit economic characteristics or processes that would lower costs over time has major implications for the ongoing debate over nuclear power in the U.S. This comparison of the French and U.S. nuclear construction programs suggests that the U.S. has the worst of both worlds. The problematic characteristics that both the U.S. and French industries possess stem from the inherent nature of the technology and point toward rising costs. At the same time, the U.S. lacks the characteristics that the French industry had that were associated with its early "success," although it must be stressed that those positive characteristics were eventually overwhelmed by the negative traits of the technology.

At present, nuclear power is quite uneconomic in the U.S., far more costly than a wide range of low-carbon alternatives, not to mention conventional sources of electricity.[81] It is also an extremely inflexible choice, requiring long lead times and tying up huge quantities of capital, which render it far more risky than the alternatives.[82] Because of its high cost and high risk characteristics, Wall Street has made it clear that nuclear reactors cannot be funded in capital markets, so the industry is pushing for a large increase in direct subsidies from taxpayers (through federal loan guarantees and tax breaks) and ratepayers (through guaranteed advanced

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[81] Cooper, 2009a.
[82] Cooper, 2009b.

recovery of construction costs).[83]

Virtually all of the projects have suffered major, negative events. By 2010 a loan guarantee program of $18.5 billion, which was secured in 2007 and was expected to support half a dozen “first-of-a-kind” reactors, would support just two projects. Additional resources to secure the first generation of new reactors are being sought, but the industry has also realized it cannot sustain a building cycle without much greater subsidies. The nuclear industry is now demanding a permanent unlimited federal loan guarantee program and approval by state regulators of advance ratepayer payments (construction work in progress). History is repeating itself.

One of the key implications of this analysis for U.S. policymakers is that it would be a mistake to count on the economic processes frequently cited to suggest that costs will decline. Some of the early studies of the cost of a new generation of nuclear reactors oriented their policies in this direction. Given that the French program existed in an environment that was highly favorable to these cost-reducing processes, the fact that it failed to achieve any of the major gains suggest these processes cannot be relied on to lower future costs.

Grubler’s caution to policy planners that the cost of French technology may be higher than currently projected is an ironic echo of the admonition that Bupp and Derian gave over thirty years ago. As they saw it, the Europeans had bought the hope and hype of the American nuclear industry to their detriment.

> It is also now apparent that the “learning by doing” process is particularly slow in the nuclear power business, and that the benefits of it are not easily transferred from one power plant to the next, much less from one country to another. Many European reactor manufactures recognized this only quite belatedly, and again at high cost. In retrospect, it was naïve of Europeans to believe that by rushing ahead to get on the light water bandwagon in the late 1960s and they would benefit from American experience and avoid “relearning.” By the mid-1970s it was clear to both reactor manufacturers and electric utilities in Europe that foreign construction experience was only marginally relevant to their own needs.[84]

The irony is that the French, who embraced the technology more than any other nation, managed to control cost escalation better than the Americans, until they tried to develop their own, larger design. Their contemporary efforts to export the technology have also encountered problems. Three cautionary lessons about the “importation” of foreign business models and technologies should be drawn from this analysis of the French and American nuclear industries.

- Policymakers should not be under any illusions about the prospects for nuclear reactor costs coming down over time or with increasing numbers of units.
- Policymakers should not be under any illusion about the ability to import technology and business models. The domestic “success” of the exporter may

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[83] Cooper, 2009b.

[84] Bupp and Derian, 1978, 154…155…156.

entail unique conditions at home and the ability to transfer the technology to a new environment without incurring additional costs may be limited.

- Even if the costs can be pinned down with some precision, the full range of options should be considered carefully because the opportunities available to each nation are different. If the technology that is being considered for import is not the least-cost technology, the fact that the exporter has become "specialized" in that technology may reflect the fact that its home market has fewer options.

The bottom line on nuclear power is clear. If the industry is launched with massive direct subsidies, this analysis shows it is very likely it will remain a ward of the state, as has been true throughout its history in France, a great burden on ratepayers, as has been the case throughout its history in the U.S. and it will retard the development of lower cost alternatives, as it has done in both the U.S. and France. The repeated and increasingly shrill complaints that the federal government is not doing enough fast enough to support nuclear reactor construction, is a strong indicator that in addition to importing French technology, the U.S. may be importing French nuclear socialism. Policymakers should look carefully before they commit large sums to a project, a technology and a company that is suffering severe design, management, and financial difficulties and resist efforts to force the government into making large loans on terms that put taxpayers at risk in order to "save" a project or an industry that may not be salvageable.

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