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COST ANALYSIS OF LIGHT WATER REACTOR POWER PLANTS.(U)

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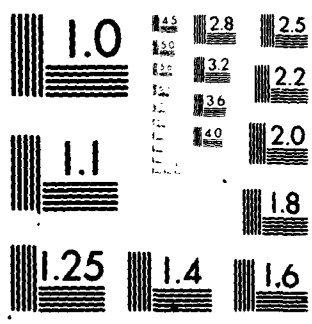

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William E. Mooz

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Abstract

This study centers on a statistical analysis of the licensing time, construction time, and capital cost of light water reactor power plants. The use of these econometric techniques allows the major cost driving variables to be identified through multivariate analysis of time series data on over 50 U.S. nuclear power plants. The analysis made in the study provides a clearer picture of the dynamic changes that have occurred in the cost of these power plants than does engineering cost estimates, and produces a tool that can be used to project LWR costs.

1. INTRODUCTION

The projection of capital costs of LWR power plants has traditionally been based on engineering cost estimates. Despite the fact that there are now over 60 operating nuclear power plants in the U.S., these estimates continue to be incorrect, and to understate the costs that are realized by substantial amounts. Several AEC sponsored studies of the problem were made in the early 1970s, but these studies continued to use traditional engineering estimates, and therefore did not provide a dynamic analysis of the trends that were underway. What was needed was a method of characterizing the cost effects of major physical, locational, and performance parameters of these plants that also integrated the effects of the social and political forces that have acted on the LWR from its very beginnings. Methods for doing this are not generally part of engineering cost estimation, but they are the stock in trade of economists. In 1974, a team at Harvard and MIT used statistical techniques to analyze the capital cost data that was then available. Even though the data base at that time was quite poor, they were able to successfully develop a regression equation that had the desirable properties outlined above, and to do it within severe time and funding constraints. The study that is the subject of this paper was inspired by the earlier work. It differs in that the data base is substantially larger and of higher quality, the adjustment of the data is done in a more rigorous fashion, and the statistical analyses are carried to much greater lengths. As a result, perceptions concerning the role of licensing time and construction time are developed, and the actual cost equations are probably more credible.

This paper has several main sections. In the first, the question of data, its availability, quality, and adjustment is discussed. The second deals with the questions of construction permit time, and construction time itself. The third treats capital costs, and the last lists the conclusions that may be reached from the study.

2. DATA

The analysis of LWR data is facilitated by the fact that a number of public and private organizations carefully record a myriad of facts about each nuclear power plant. These are published by the Department of Energy as well as by other organizations, and there is virtually no difference of opinion in the various data available. By July 1978, construction permits had been granted for 115 plants, of which 62 had completed construction. Capital costs for 54 of these were available for analysis. Forty of these plants had submitted capital cost data to the FERC, as required by law, seven additional plants had cost data supplied by their owners, and an additional seven were estimated by DOE. Accurate cost data on the remaining plants were unavailable because of a variety of reasons, mainly stemming from the fact that they were very early plants.

While data on the plants themselves is available, and while there are both techniques and indices for adjusting these data, quantitative measures of some extremely important variables are lacking. These include ratcheting, number and effect of regulations, degree of safety that is required from LWRs, and the amount of environmental safeguards necessary. As a result, proxies for this information need to be used.

Simply plotting the data versus the date the plant operating license was granted illustrates the dilemma that planners find themselves in. This is shown in Figure 1. Capital costs appear to be rising steadily, but so many other factors are changing concurrently that the true facts are masked. Among these factors are the plant size and location, the length of licensing hearings, the construction time, the degree of inflation, cooling methods, and a host of environmental and safety regulations. It is these variables that the study was designed to deal with.

3. DATA ADJUSTMENT

The non-cost data require no adjustment, but all costs are reported in mixed current dollars, and thus they cannot be used until they are adjusted to a constant dollar basis. The procedure to do this is simple in concept, but complex in execution. Conceptually, the total cost of the plant is disaggregated into the yearly cash flow that was experienced during the construction period. If the plant was built over a six year period, there would be six annual increments involved. Then each annual increment is adjusted to constant dollars by using the appropriate Handy-Whitman construction cost index, and the increments are summed to a constant dollar total. Where this conceptually simple system founders is when one tries to disaggregate the capital cost into the years it was spent. Records on this are almost never easily available. As a result, an "average" cash flow curve must be used. This curve has been developed by DOE specifically for LWR plants, and using this, a mathematical formula for the curve was developed, along with the algorithms necessary to disaggregate, adjust, and reaggregate.

When the exercise is performed on the 54 plants for which cost data are available, the results appear as shown in Figure 2. The general pattern does not look dissimilar from what we have already seen in Figure 1, but at least the inflationary effects have been removed. By so doing, all data are in a form to be analyzed.

4. CONSTRUCTION PERMIT TIME AND CONSTRUCTION TIME

There has been so much rhetoric about the role of these two time elements and their presumed effect upon capital costs that they require analysis prior to capital costs themselves.

The time to obtain a construction permit is involved with legal and procedural matters that happen before major construction occurs. Consequently one would not expect that this time would be statistically related to either the physical or performance parameters of the plant. This in fact turns out to be true. Statistical analysis only shows what is already generally known. Permits took increasingly longer to process until about 1971, when the system was made more responsive and they then decreased slightly. But there is essentially no relation that can be shown between the physical, performance, or locational data and the length of time required to obtain a permit.

Construction time is another story. The construction time data are shown in Figure 3, plotted against the date the construction permit was issued. The large scatter in the data is due to a variety of influences, and a better picture results from removing the effect of plant size and plotting the construction time per unit of capacity, in units of months per MWe, as shown in Figure 4. The data still show a great deal of scatter, but regression analysis allows an equation to be developed that explains about two-thirds of the variance in the data. Figure 5 illustrates the equation. Its terms include both expected and unexpected variables. As might be expected, bigger plants take longer to build, as does the second plant of a pair of duplicate plants--because usually construction doesn't start on it until about a year after its construction permit is issued. Because of some problems in delivery of NSSS made by Babcock-Wilcox, a term shows up in the equation reflecting this. On the unexpected side, a strong learning effect is recorded that shows that the architect engineering firms have reduced construction time about eight percent for each doubling of the number of plants built. This is shown in Figure 6. Also unexpected is the fact that the size coefficient appears linear, meaning that economies of scale in construction time which might have been expected do not in fact show up. Last there is a strong temporal term that describes the average increase in construction time to be about 4.5 months per year over the six year period examined.

An illustration of the construction time equation appears in Figure 7.

5. CAPITAL COSTS

The capital cost data are easier to deal with when one understands the relationships that derive for the construction permit time and the construction time. This is especially true because of the problem of colinearity that exists which makes it difficult to isolate whether or not the increases in capital costs that were seen earlier are in fact partially or wholly due to the concurrent increases in construction permit time and construction time. There are some statistical devices that allow this to be tested, and these were used in this analysis. One form of the regression equation is shown in Figure 8, and like the construction time equation, there are both expected and unexpected results. First let's look at the similarities with the construction time equation, since cost and construction time might be expected to show some of the same patterns. We can see that three of the equation terms have the same kind of effect. Costs are increasing each year and with the size of the plant; costs decrease as a function of the experience of the architect-engineer. Now let's examine some of the terms that are different. The construction time equation showed that plants using BW NSSS took longer to construct, but the cost equation shows that there was no additional cost due to this. This can be interpreted to mean that good project management dealt with the problem in a way that minimized its cost effect. The cost equation shows that plants built in the Northeast U.S. cost more; the construction time equation did not show that these plants took longer to build, so the additional costs must be due to other factors. There are three remaining equation terms. The first concerns whether a cooling tower is used. Plants that use cooling towers might be expected to cost more than those that do not, yet the regression equation doesn't show this, for reasons that are unexplained. The second two remaining terms concern the construction permit time and the construction time. As they appear in the equation, they do not contribute to the capital cost. But because of the colinearity question that was raised before, this must be carefully interpreted. The construction permit time itself does not contribute to increased costs. Yet a longer construction permit time delays the issuance of the construction permit, and the later the date of this, the higher the costs are. What apparently happens is that the newer the plant is, the more safety and environmental regulations it must comply with. Thus, delaying the issuance of the construction permit causes the plant to be more costly. With regard to the construction time, the correct interpretation is that variations in construction time that are not captured by the other equation terms do not affect capital costs. We saw this specifically in the case of the BW NSSS, and it appears true for other variations as well, again probably because of astute project management.

The unexpected result is that the size term in the equation appears linear, and this implies that there are no demonstrable economies of scale in the data. The equation explains about 75 percent of the variance in the data, and an illustration of its use appears in Figure 9. Based upon the equation, and similar regression analyses, we can determine from the data that average capital costs have increased about $140/KWe/year from 1966 to 1972, with no explicit insights into the reasons. Costs in the Northeast average about $200/KWe higher than the rest of the country. The data do not demonstrate economies of scale, nor do they show that duplicate plants cost less. Finally, the construction permit time does not appear to be a determinant of cost, and construction time anomalies also do not appear to be cost determinants.

6. CONCLUSIONS

We have already discussed many of the insights that derive from this analysis. Here we simply note some of the conclusions that may be relevant to the projection of LWR costs, or the projection of the costs of other nuclear technologies, such as the LMFBR.

The average cost of plants coming on line in 1979 is about $1200/KWe in 1978 dollars. This cost has been rising steadily, and there is no evidence in the data to suggest that it will not continue to rise. The causes of this could not be isolated, but appear unrelated to the licensing process or construction delays. It is more likely that continually revised regulations are at least partially responsible, but this was not shown in the analysis. The architect-engineer is a key factor in costs. Experienced AEs bring plants in at lower costs. Expected economies of scale can not be demonstrated from the data, and building duplicate plants can not be demonstrated to be less costly. Cost projections for future plants should note these trends and perhaps use them as an extrapolated base case, rather than rely solely upon engineering cost estimates. Finally, to the extent that other nuclear technologies are subject to the same social, environmental, technological, and regulatory climate that the LWR has been, cost estimates for these technologies should take heed of the dynamic behavior of LWR costs, in that they might be indicative of what could happen.

FIG. 1

TOTAL CAPITAL COSTS

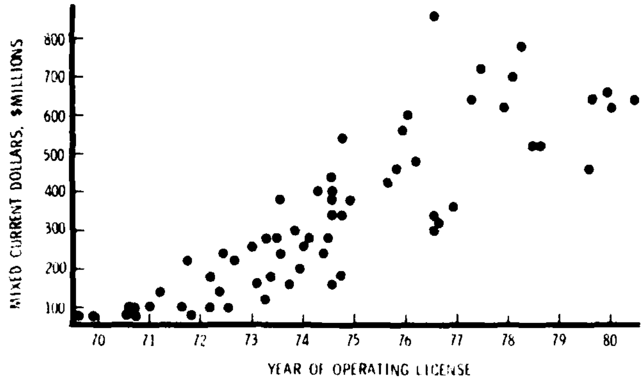


FIG. 2

TOTAL CAPITAL COSTS

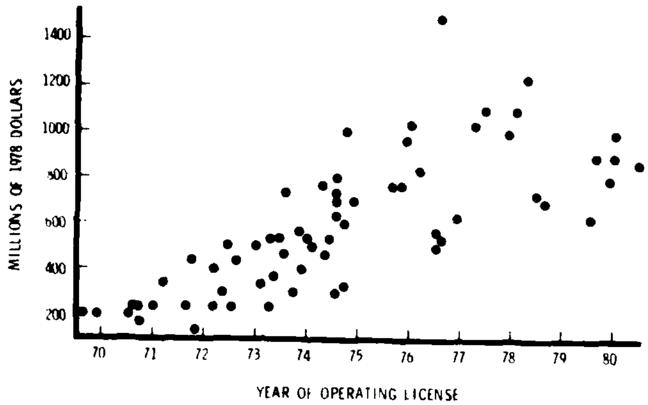


FIG. 3

CONSTRUCTION TIME

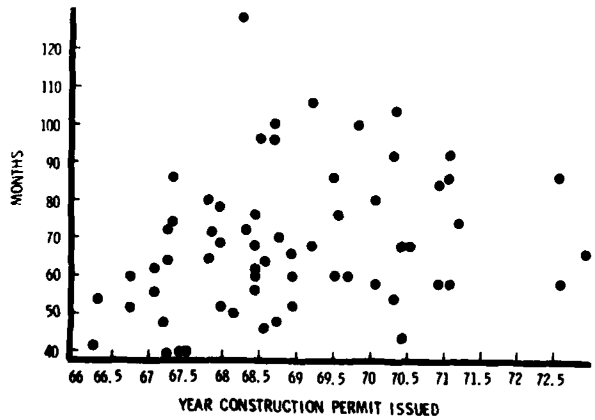


FIG.
CONSTRUCTION TIME

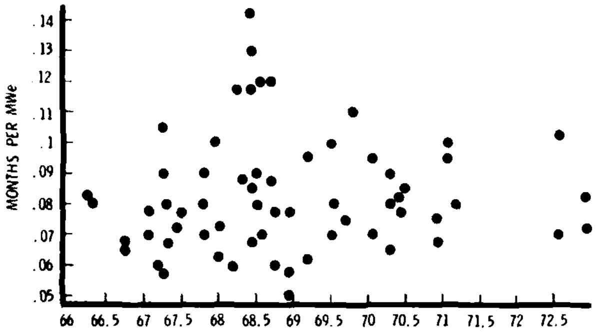


FIG. 5

CONSTRUCTION TIME

TIME = - 2.68 + 4.5 CPIS + 0.04 SIZE + 15.9 BW
(-3.6) (4.0) (4.1) (3.8)

- 6.9 LN + 11.5 DUP2
(-4.1) (3.4)

- CPIS TERM APPEARS LINEAR
- SIZE TERM APPEARS LINEAR
- LEARNING CURVE SLOPE – 8%
- R^2 = 63%

Fig. 6

ILLUSTRATION OF LEARNING CURVE

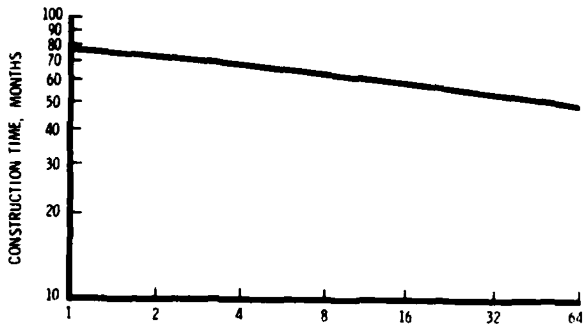


FIG. 7

ILLUSTRATION OF CONSTRUCTION TIME EQUATION

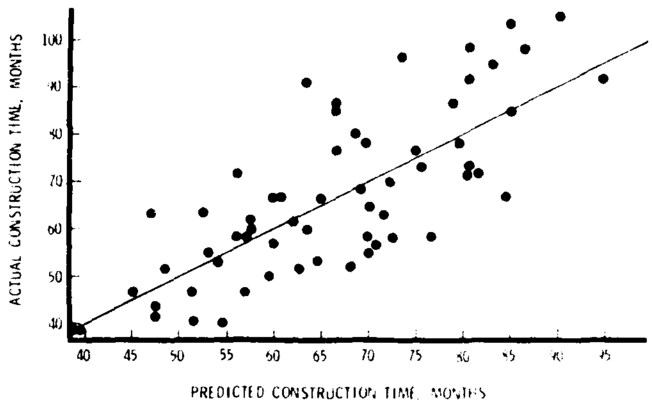


FIG. 8

CAPITAL COSTS

$$\text{LOG COST} = -9.3 + 0.22\ \text{CPIS} + 1.0\ (10^{-3})\ \text{SIZE} + 0.05\ \text{TOWER}$$
(−5.4) (8.5) (5.7) (0.8)

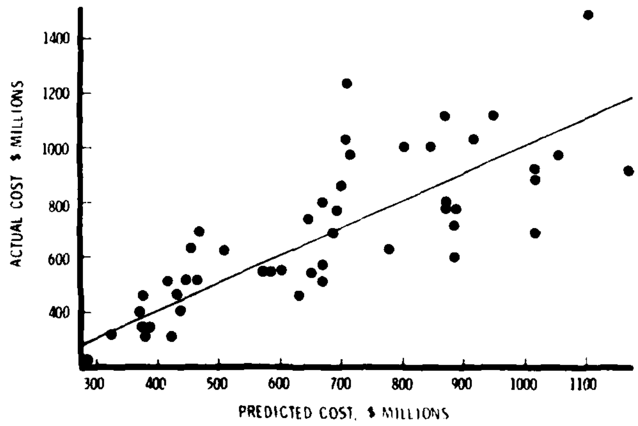
$$+\ 0.1\ \text{BW} + 0.3\ \text{LOC1} - 0.16\ \text{LN} + 1.8\ (10^{-3})\ \text{T1RSID}$$
(1.1) (4.7) (−4.3) (0.2)

$$+\ 3.0\ (10^{-3})\ \text{T2RSID}$$
(1.2)

- CPIS TERM APPEARS LINEAR
- SIZE TERM APPEARS LINEAR
- LEARNING CURVE SLOPE ~ 8%
- R^2 ~ 75%

FIG. 9

ILLUSTRATION OF COST EQUATION



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