Revisiting the Nuclear Power Construction Costs Escalation Curse

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Introduction

Nuclear power competitiveness depends on its capital costs, inasmuch as they represent, on average, 80% of the levelized cost of electricity. However, from the first wave of nuclear reactors constructed back in the late 60's and 70's, to the on-going construction of Generation III+ reactors in Finland and France, nuclear power seems to be doomed to a cost escalation curse.

If this cost increasing trend goes on, nuclear power will become more expensive while competing technologies will become cheaper. Therefore, determining how to escape this curse is vital for nuclear power to remain a competitive energy source. In this sense, we revisited the French nuclear experience due to the recent publication of the actual construction costs of the nuclear fleet. With this new information, we have identified cost's main drivers and we found some important lessons to take into account to ease the cost escalation phenomenon.

The Construction Cost Escalation Curse in Nuclear Power

The continuous cost revisions and delays in the construction of the latest generation of reactors revives the fear of the cost escalation that has characterized nuclear power and raises concerns about the economic viability of this energy source. For instance, the construction of the first EPR in France revealed that even when this reactor was initially thought as no more costly than its predecessor (the N4 reactor) this would not be the case. At the beginning of 2005, the costs of this project were €3.3 billion. However, this figure was revised in 2011, when EDF announced that the costs had reached €6 billion. This situation worsened with the latest EDF press release in 2012; it was acknowledged that the cost for the Flamanville 3 reactor had risen to €8.5 billion.

For the Westinghouse latest design (AP1000) the situation is very similar. The first cost estimations done both by the MIT and Chicago University on 2003, partially based on the applications submitted to the Nuclear Regulatory Commission were around USD 2400/kW. Nevertheless, these costs were later revised in the MIT (2009) report, which suggest an important increase given that the range of overnight costs was USD2010 3.650/kW to USD2010 5.100/kW. Similarly, Chicago University (2010) forecasts for the AP1000 came up with an average cost of USD2010 4.210/kW.

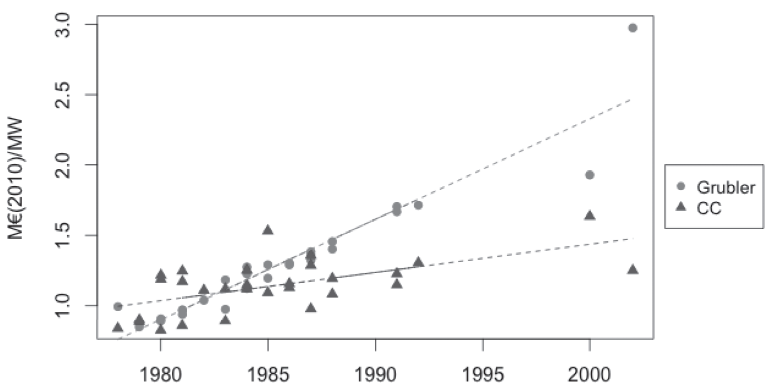

Figure 1: Grubler's and Cour de Comptes Costs for the French Nuclear Fleet by Pair of Reactors

This phenomenon has been widely studied in the U.S. given that the cost escalation there was severe. If we compare the costs of the last nuclear power plant in USD2010/MW with those of the first one, we find that they were 7 times greater.

For the French case, the cost assessment done by Grubler (2011) pointed out that the units installed in 1974 were 3.5 times less costly, in constant euros, than the post 1990 installed reactors. This finding led to the thinking that cost escalation is inherent in nuclear power, given that even under the best conditions, as prevailing in France (i.e., centralized decision making, high degree of standardization and regulatory stability), the construction costs have also risen significantly.

The so called negative learning by doing found by Grubler for the French case was shocking, because even with higher cost escalation and a more diverse nuclear fleet, the econometric studies done for the U.S. case had found positive learning effects[1] at the firm level. However, we revisited the French experience due to the availability of the new information contained in *Cour des Comptes*[2] report and we found positive learning effects when building the same type of reactors.

It is important to mention that the centralized nature of the French nuclear power program not only allowed a fast deployment of this technology but also shielded its costs against private eyes and public scrutiny. For this reason, the

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previous cost assessment was done using cost estimates rather than the actual costs. As we can see in Figure 1, the cost escalation with the *Cour des Comptes* was less severe than what was thought. By using the actual costs we found an average cost increase rate equal to 4.6% per year, while by using Grubler's estimates we computed an increase of 5.8% per year.

Lessons from the French Experience

We used the actual expenditures for the construction of the 58 commercial reactors currently operating in France[3], to identify the main drivers of the increase in costs. We have used a principal component linear regression model in which the costs are determined by an index of the cost of labor, capacity, experience and safety indicators.

We found that the increase in labor costs was an important driver of the escalation. Although we are using the construction costs expressed in constant euros, it is important to recognize that during the period in which the reactors were constructed, the cost of labor in France increased much more rapidly than the inflation index that was used to homogenize the cost data.

In regard to capacity, we found that by increasing the size 1%, we might expect a cost increase of 1.31%. Nevertheless, this result does not reject economies of scale, because the construction of bigger reactors not only entailed a capacity augmentation but also a technological change. This result does not come as a surprise, given that it is well documented that for the U.S. experience the scale-up meant more complex reactors and longer lead-times that resulted in more expensive units per MW installed.

Our results also indicate that as the number of reactors built, at the same *palier*[4] and of the same type, increased, construction costs decreased. To our knowledge, this is the first time that is possible to confirm the existence of learning effects in the French nuclear power program by using public data. This result allows us to conclude that constructing similar types of reactors is one of the main elements that prevented a severe cost escalation in France.

Our last result says that those reactors with better safety performance were more expensive. Then achieving higher safety levels also helped to explain the cost escalation in the French nuclear fleet.

Discussion

After analyzing the construction costs of the *Cour de Comptes* report, we found that the escalation was about a factor of 1.5 between the first and the last unit, thus the cost increase was less severe than it was originally believed, and by no means comparable with the U.S. case.

On the basis of the analysis using the *Cour des Comptes* data, there is every reason to believe that the construction cost escalation in France is mainly due to the increase in the labor costs but also the scaling-up strategy. The increase in the reactor size induced greater complexity and lead-times, which in turn meant an augmentation in costs per MW.

For this reason, capacity could be one of the starting points in rethinking nuclear power strategy. In this sense, several authors such as Kessides (2012) and Rosner and Goldberg (2011b) have outlined the advantages of installing small modular reactors. They argue that since these reactors have shorter construction schedules, they have lower market risk, thus a lower cost of capital.

Our analysis also revealed that although overall experience did not translate into lower costs, some gains were achieved due to the construction of same types of reactors. These learning effects suggest that standardization is a successful strategy to overcome delays and uncertainties during the construction process and thus reduce the cost of the following reactors of the same series.

In this context, it would be interesting to study the construction costs of the nuclear fleet in Russia and China. Both countries have highly centralized and state-oriented energy sectors, both have experience in nuclear power and have envisioned the construction of an important number of reactors in the near future.

In Russia, there is only one supplier, the state-owned vendor ROSATOM, who has constructed more than 35 reactors, is now constructing 10 reactors and has plans to install 17 more. In the Chinese nuclear power program four different vendors coming from Russia, France, Canada and China have supplied the installed reactors and at the present time China is building 28 new reactors. If the construction costs become public one day the comparison between these two nuclear programs can shed some light in the gains of diversity versus the learning effects through standardization in nuclear power.

The results regarding the safety indicators show that the most expensive reactors have achieved better safety performance. This result might indicate that reducing the risk of a serious accident has also played its role in the French cost escalation, either because the regulatory safety standards have increased or because EDF internalized safety concerns in the conception of new designs. In any case, this finding supports what has been often argued by nuclear industry, that is that the newest designs although more expensive, have also embodied better safety features.

Footnotes

[1] See Cantor and Hewlett (1988) and McCabe (1996)

[2] *Cour de Comptes* is the French governement audit agency.

[3] In the *Cour des Comptes* report the costs are reported by pair of reactors.

[4] In the French nuclear fleet, the reactors are classified in three groups called Palier. This category collects all the reactors with the same capacity. In the first Palier, we find 34 units all of them with 900 MW. The second Palier groups 20 reactors with 1300 MW and in the last Palier there are only 4 units with 1450 MW each one.

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