Cost overruns and financial risk in the construction of nuclear power reactors: a critical appraisal

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Cost Overruns and Financial Risk in the Construction of Nuclear Power Reactors: A Critical Appraisal

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Abstract: Lovering and colleagues attempt to advance understanding of construction cost escalation risks inherent in building nuclear reactors and power plants, a laudable goal. Although we appreciate their focus on capital cost increases and overruns, we maintain in this critical appraisal that their study conceptualizes cost issues in a limiting way. Methodological choices in treating different cost categories by the authors mean that their conclusions are more narrowly applicable than they describe. We also argue that their study is factually incorrect in its criticism of the previous peer-reviewed literature. Earlier work, for instance, has compared historical construction costs for nuclear reactors with other energy sources, in many countries, and extending over several decades. Lastly, in failing to be transparent about the limitations of their own work, Lovering et al. have recourse to a selective choice of data, unbalanced analysis, and biased interpretation.

Keywords: construction cost overrun; nuclear power; nuclear energy; atomic energy

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It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suite theories, instead of theories to suite facts.

Sherlock Holmes, in Arthur Conan Doyle's *A Scandal in Bohemia*, 1891, p. 78.

Introduction

Despite sounding a bit dry, there can be little doubt that the topic of construction cost overruns is of central importance to energy and electricity planning, investment, policy, and regulation. As Bacon and Besant-Jones wrote (1998, p. 317) in the present journal almost two decades ago:

> The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to underpricing. The financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit.

In other words, evaluations of construction cost escalation and overruns have much to tell regarding inefficiencies in the allocation of resources, and can assist with estimating likelihoods of future infrastructure risks.

It is in this regard that we appreciate and understand the interest in this topic shown by Lovering, Yip, and Nordhaus (2016a), in their effort at analysing new global data on overnight nuclear construction costs. However, we disagree with their conclusion that there is "no inherent cost escalation trend associated nuclear technology."

In this response, we critique Lovering et al. on three grounds. First, we argue that a series of methodological choices undermine their conclusions and limit the applicability of their results in respect of both historical and future nuclear construction costs. Second, we question the reliability of the data underlying Lovering et. al. by discussing three recent studies that are global in scope and focus on trends from the past few decades of nuclear construction. Third, we express concerns that recent public declarations made by the authors when discussing their article are not based on their actual data or on reliable results. The first criticism refutes the piece's methodology; the second questions its comparative novelty; the third challenges the objectivity of the overall framing and interpretation.

Worrying methodological assumptions

Our first criticism is that the narrow definition of construction costs used by Lovering et. al. (2016a), overnight capital costs (OCC), is not an appropriate metric to judge nuclear construction costs. This cost is notionally what it would take to build a reactor "overnight", with financing and other time-related costs omitted. We raise three issues with this methodology:

- OCC are an inappropriate measure of power plant construction costs
- OCC and the author's definition of cost escalation do not include the full impacts of cost overruns
- Even if OCC was an appropriate metric, Lovering et. al. do not normalize them in a way that supports the study's conclusions regarding intrinsic technology costs

First, Lovering et. al. specifically exclude interest costs on the basis that they "are more predictable and have had far less variation over time and country" and because the authors want "to capture the cost intrinsic to the reactor technology." However, this contradicts subsequent statements in the study. The study notes that interest costs do have a significant effect on total direct costs for a nuclear plant, comprising an average of 46% of the total upfront cost of a US nuclear reactor. Moreover, the share of interest in overall construction costs varies considerably. The study notes that interest costs could comprise 12-54% of total upfront costs of a nuclear plant with reasonable cost of capital and construction time assumptions.

This contradictory stance indicates a major methodological limitation: excluding interest costs means the findings of this study are not a realistic picture of the costs of building a nuclear power plant, as the authors assert in their conclusion. Rather their data only examines part of a nuclear power plant's overall construction costs. No power plant can be built overnight. This is especially true for nuclear plants, which have some of the longest lead times of any power infrastructure (Sovacool et. al. 2014c). Long construction times and high financing costs are not just incidental, but intrinsic features of the nuclear option. Any nuclear developer must include the cost of financing in the calculation of overall construction costs. The academic literature has long recognized that narrowing the scope to only overnight costs paints a misleading picture of the full costs of a nuclear power plant (Marshall and Navarro 1991, Koomey and Hultman 2007).

Second, the authors do not address time and cost overruns in calculating capital costs or cost escalation for nuclear technology, despite their central role. This is elided by the unfortunate way in which established literatures tend to use the term "cost escalation" in two ways when it comes to nuclear construction economics:

- First, to describe how aggregate nuclear capital costs have increased over time (Grubler 2010, Koomey and Hultman 2007);
- Second, to describe how the costs for an individual nuclear reactor climb during construction due to cost overruns (Sovacool et. al., 2014a,b,c).

When Lovering et. al. suggest "there is no inherent cost escalation trend associated with nuclear technology", they focus on the first definition of cost escalation. However, when calculating general historical costs for nuclear reactors, the second definition relating to cost overruns is just as important from a policy perspective and much more important from a financing perspective.

Our own work on the role of cost overruns in nuclear economics yields several points that deserve highlighting. First, almost all nuclear reactors suffer from cost overruns. Second, nuclear cost overruns occur in all countries. Third, cost overruns are much greater for nuclear than for other energy sources. Fourth, nuclear cost overruns are heavily influenced by interest costs and time overruns (Sovacool et. al., 2014a,b,c). Lovering, et. al. do not challenge this picture from the existing literature. Indeed, by failing to address the roles of interest costs or construction delays, their study effectively ignores some of the most important issues in understanding historical nuclear construction cost trends.

Third, while Lovering et. al. provide value from compiling comparative OCC figures, their conclusions regarding the meaning these figures are limited by a lack of normalized. Overnight capital costs in the study's sample are not normalized for input costs, such as labor, commodity costs, exchange rates, and interest rates. These factors impact both total capital costs and cost overruns for individual power projects (Sovacool et. al. 2014 a,b,c). Yet Lovering et. al. only briefly acknowledge the role these factors play in nuclear reactor costs and do not examine how they influence reported overnight capital cost outcomes across their sample.

Admittedly, controlling for these factors may be difficult – they vary significantly both over time and by location. However, if the goal is to assess cost trends for a specific reactor technology (as Lovering et. al. aim to do), then assessing these factors is absolutely essential in order properly to account for technological learning over time and to exclude the potential impacts of these factors on technology cost trends. Without thoroughly examining these factors, the applicability of Lovering et. al.'s conclusions regarding global cost trends is narrower than they purport.

Similarly, Lovering et. al. focus on overnight capital cost trends within individual countries, without a full analysis across countries with normalized currencies. Major cost trends are only assessed in comparison with other reactors in the same country. Yet when seeking to determine cost trends for a specific technology, global comparisons are more appropriate (provided material, labor, and other factors are already normalized).

The case of South Korean nuclear power provides a good illustration. Lovering et. al. argue that South Korea provides a strong counter example to the picture of escalating overnight capital costs in other countries, noting that "from the first reactor in Korea in 1971, costs fell by 50%" for the most recent reactors constructed. This analysis relates to a limited sample of only 24-28 reactors,[1] yet the resulting picture of apparently declining in-country nuclear costs plays a central role in their main general conclusions. Beyond this, however, there is a more important issue in this country-level focus.

Although the authors do not discuss or analyze the differences, they normalize overnight capital costs for currency differences across all countries in the samples shown in Figures 12 and 13. Compared to the global reactor fleet in these figures, the overnight capital costs of recent South Korean nuclear reactors (around $2,000/KW) are still at the high end compared to the prevailing capital costs of reactors that began construction in the 1970's (around $1,000-2,000/KW). This is especially notable as the lower normalized prices from the 1970's apply to a period when nuclear was beginning commercialization, when learning might be expected to begin driving costs down.

Moreover, Lovering et. al. repeatedly use terms that have the effect of depreciating capital cost escalations in some countries as 'mild' or 'milder'. Yet currency-normalized cost estimates for the U.S.,

[1] As explained in the next section, there are an inconsistent number of South Korean nuclear reactors in the study.

France, West Germany, Canada, India, and South Korea are 1-10 times overnight capital costs during initial commercialization (Grubler 2010, Koomey and Hultman 2007).

Limited comparative novelty

Another element in our critique of Lovering et al. is that their study is not as novel as claimed, with questionable reliability compared to previous work. They posit that "drawing any strong conclusions about future power costs based… [on the U.S. experience] … would be ill advised." They also claim that "past studies have been limited in their scope, focusing primarily on cost trends in the 1970s and 1980 for the US and France." Yet a series of recent studies led by some of the present authors (Sovacool 2014a, 2014b, 2014c) cover reactors beyond France and the US, and look beyond the 1970s and 1980s.

To elaborate, these recent studies address a sample of 180 reactors built from 1969 to 2005 across 7 countries—Canada, France, India, Japan, Switzerland, the United Kingdom, and the United States—worth some $449 billion in investment and 177,591 MWe of capacity. Although France and the US admittedly constitute a large part of this sample, 47 of these reactors were built in other countries.

This total sample is not as large or as recent as Lovering et al.'s 349 reactors. However, it only includes data that has been verified in each instance by a publicly available source unlike Lovering et. al. We believe this verification confers additional confidence in data quality. For example, the key country underlying Lovering et. al's conclusion that nuclear does not have an inherent cost trend is South Korea. The data behind this conclusion are overnight capital costs reported privately by a nuclear power utility. Due to the self-reported nature of this data, it is impossible to independently verify its reliability.

Similarly, several inconsistencies in Lovering et. al.'s article raise potential concerns about data quality for South Korea. Lovering et. al. claim to only include data for completed nuclear facilities. However, there are an inconsistent number of South Korean nuclear reactors cited in their study:

section 2 says 24, figure 10 appears to show 25, Table 1 says 28, section 3.1.2. says 26, and the appendix says 26. As of 2014, there were 24 nuclear reactors in South Korea. Several nuclear reactors have either recently been completed or are due for completion in 2016. According to Lovering et. al.'s criteria, at least some of these reactors should not be included in the study as they were not complete. The South Korean nuclear utility likely reported cost estimates for these reactors instead of actual completion costs. It is unclear to what degree this inconsistency impacts Lovering et. al.'s results but it does raise concerns about the reliability of self-reported data.

Comparably, the results from Sovacool 2014 a, b, c, show a different picture than Lovering et. al. Although Lovering et. al. do not cite these studies, they are readily accessible, received wide attention (ex. Roberts 2014; Shahan 2014; and De Vos 2015), and their underlying data is fully publically available in Sovacool et. al. 2014b. Moreover, nuclear reactors formed only one subset of these other studies, which compared nuclear overruns with those for hydroelectric dams, thermal plants (a category that included natural gas and coal facilities, among others), wind farms, solar energy facilities, and transmission networks. We would argue that the data in these studies is more reliable while its broader scope provides a better basis for necessarily comparative policy conclusions.

In addition, and critically, unlike Lovering et. al., Sovacool 2014 a, b, c, include both interest rates and normalized currencies. Drawing on a cross-national dataset from Sovacool et al. 2014b, Figure 1 shows the median nuclear reactor in that sample to have an overrun on a percentage basis of 65%, normalizing to 578 $/kWe. The top quartile was particularly extreme, with more than 25% of nuclear reactors having overruns above 179% and 1,425 $/kWe. Moreover, this recent dataset suggests that overruns afflicted greater than 97 percent of nuclear projects. Sixty-four projects in this sample had cost overruns exceeding $1 billion, and the single highest overrun had a cost escalation of more than 1200%. This picture contrasts strongly with the impression given in Lovering et. al.

INSERT FIGURE 1 HERE

Table 1 (also drawing from Sovacool 2014 a, b, c) shows nuclear power in a comparative context. It is an outlier in relation to frequencies and magnitudes of both construction overruns and time overruns. This dataset indicates that nuclear is indeed anomalous when compared for overall capital costs over time and incidence and frequency of cost overruns. Recent evidence also indicates that capital costs for solar and wind have been declining, independent of changes in commodity, labor, and other input costs (Wiser and Bolinger 2015, Bolinger and Seel 2015).

INSERT TABLE 1 HERE

Lovering et al. do briefly compare nuclear with other technologies in section 4.4.3. However, they do not fully analyse how overnight capital cost increases or cost overruns for nuclear power relate to those of other technologies. Drawn from peer-reviewed studies looking at cost overruns across different types of infrastructure, Figure 2, for instance, clearly shows that nuclear reactors have the highest mean cost escalation (117%), compared to only 71% for hydroelectric dams, 13% for thermal power plants, 8 percent for wind farms, and 1 percent for solar energy facilities. This comparison is critical, as it is only by such means that it can be determined whether nuclear cost escalations are typical or atypical in the power sector.

INSERT FIGURE 2 HERE

Biased interpretation

Our final criticism is not entirely specific to Lovering et al., but a more general point concerning the tendency for the advocates of any specific form of energy - whether nuclear, renewables, or specific fossil fuels - to interpret data selectively whether they are in industry or beyond. Many analysts on both “sides” of the nuclear debate sometimes use their data in a way that suits their purposes. We have some concerns that Lovering et. al. are selectively interpreting the results of their study in a way not justified by the data, particularly in light of the limitations we have discussed.

Lovering and colleagues have repeatedly referred to their data or analysis publicly as reflecting the "real costs of nuclear power" (Lovering 2015), as offering a "complete construction cost history" of the industry (Lovering et al. 2016b), or proving that "nuclear plants can be built quickly, safely, and cheaply" (Nordhaus 2016). In light of both Lovering et. al.'s actual results and our previous criticisms, these characterizations of their study are misleading and inaccurate. Even within their study there is potential selective interpretation – as noted earlier, the authors consistently used qualitative terms like "mild" or "milder" in describing OCC cost escalation that did not objectively assess what the data was presenting.

This potentially selective interpretation of data and presentation of results speaks to a larger challenge in analyzing nuclear construction costs. Some scholars have even found a long-run pattern of selective use by nuclear advocates over the past few decades in a practice known as tactical data 'trimming' (Shrader-Frechette, 2011) of the full economic costs reactors. Efforts to trim the documented cost of nuclear energy are too numerous to document comprehensively here. Examples include: over-estimations of load-factors and lifetimes of reactors; grave underestimations of construction times; and assumptions of economies of scale in vast reactor programs that never eventuate [eg: (Spangler, 1983)(Ramana, 2009)(Thomas, 2010b)(Gross et al., 2013)(Keepin & Wynne, 1984)]. Other instances involve discounting for future waste costs externalized to utilities and consumers (Jackson, 2008); insufficient attention to potentially significant on-site engineering costs in overall cost estimates; and claims that designs of new reactors are complete when in fact they require expensive alteration and development during the construction process which raises costs (Thomas, 2010).

Liability and insurance are another key factor in evaluating the comparative costs of nuclear power – with many arguing that published figures fail to represent the full costs of nuclear power (Pearce, 2012; Verbruggen, Laes, & Lemmens, 2014). Though differing between jurisdictions, de facto or de jure caps are ubiquitous on the total amount of insurance cover applicable, such as to address only a fraction of the total cost of a severe nuclear accident. The neglect of this factor alone constitutes a "hidden subsidy" to nuclear power, since it is the public that would pay the balance of costs in the event of an accident (Eeckhoudt, Schieber, & Schneider, 2000). It is remarkable that this factor remains so neglected, despite major utilities admitting that full liability insurance would make nuclear power commercially unviable (Schrader-Frechette, 2012).

Yet another often-underpriced attribute of nuclear power performance is the persistent economic cost of accidents and incidents when they do occur. Wheatly et al. (2016a, 2016b) have published recent statistical analyses of 216 nuclear energy accidents and incidents around the world over the past seven decades. Catastrophic accidents can be extremely expensive, with Chernobyl estimated to have cost $259 billion and Fukushima $166 billion, with most of those costs borne by the public. Wheatly et al. also estimated that such costs will continue into the future. They calculated incident and accident rates for 2014 at a conservative range of 0.0025-0.0035, or 1-1.4 events per year over the entire nuclear fleet. They also noted that when a nuclear event of at least $20 million in damage occurs, the probability that it transforms into a catastrophe with damage larger than one billion dollars is almost ten percent. Under the status quo, they projected at least one Fukushima-scale accident (or larger) accident with 50% probability every 60-150 years. This inherent financial risk of nuclear power is almost never fully monetized.

In addition, the typically higher levels of government involvement often make state secrecy an issue in the documenting of nuclear economics – for example in the UK (Massey, 1988). Here, there is widespread disquiet at persistent secrecy in provision of key information concerning nuclear economics provided to the European Commission for evaluating the granting of state aid (Leftly, 2015). There are also ongoing concerns about the reliability of information on China's nuclear new build program (Yi-Chong, n.d.). Lastly, content analyses have documented that even International Atomic Energy Agency technical reports and international nuclear physics articles rely on a process of ”selective remembrance” where unfavorable data, especially historical data, are consistently and at times comprehensively ignored (Sovacool & Ramana 2015).

It is in all these ways and many more that nuclear costs are the subject of unusual levels of obscurity – and opportunities for bias. Lovering et al. therefore in no way provide a “complete” or “real” picture of nuclear costs.

Conclusion

In conclusion, several methodological decisions limit the applicability of Lovering et. al's analysis to overall nuclear construction costs. Difficulties concerning the impact of interest costs on total installed costs, the role of cost overruns, accounting for independent cost variables, the normalizing of global data, and comparisons with existing energy sources all serve to blunt Lovering et. al's implied critique of earlier studies. Indeed, several conclusions in the existing literature remain unrefuted:

- Nuclear energy displays serious cost escalations both in the form of rising capital costs over time and in cost overruns at individual plants;
- There are regional and temporal variations in these trends, but similar patterns nonetheless persist across countries and timeframes;
- Compared to other technologies, the intensity of these cost escalations is highly distinctive of nuclear reactors;
- Policymakers and energy modelers addressing nuclear energy need to be aware of elevated capital costs, the critical role of interest rates, and the near certainty of cost and time overruns.

In many ways, the effect of Lovering et al's analysis is to further cloud the waters rather than clear them.

Nevertheless, Lovering et. al.'s dataset does provide a contribution to the available literature on overnight construction costs. While we believe it does not justify the extent of their conclusions and we have some data quality concerns, additional data (if properly interpreted and limitations recognized) can only improve collective understanding of nuclear cost issues. Therefore, we call on Lovering and colleagues to publically release their dataset and supporting information to the degree possible. It would be interesting to see what happens when one adds interest and normalized currencies to their data, or integrates their dataset with others such as ours. A more established platform of transparent and accessible data can refine our knowledge of the drivers and dynamics of construction risks for power plants.

Further, Lovering et al.'s analysis does illustrate the need for future research and greatly improved data collection and availability. In undertaking our earlier analyses (Sovacool et. al., 2014 a,b,c), some of the present authors repeatedly encountered data quality issues with existing articles, archives, and internet resources. Only a relatively small sample of accurate and reliable construction data is available for energy systems. With most data concentrated in Europe or North America, this is highly geographically incomplete. We therefore encourage major energy institutions such as the International Energy Agency, U.S. Energy Information Administration, Nuclear Energy Agency, International Atomic Energy Agency, and the International Renewable Energy Agency to formalize the reporting and verification of basic energy construction data.

Lastly, although we have concerns about the methodology, novelty, and balance of Lovering et al.'s study, we do appreciate the increased visibility their piece brings to the topic of cost escalation and overruns. Like them, we have a desire to properly contextualize this key aspect of nuclear performance.

With so much at stake, everybody has a shared interest – like Sherlock Holmes in our epigram – in avoiding misrepresentations of all kinds.

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