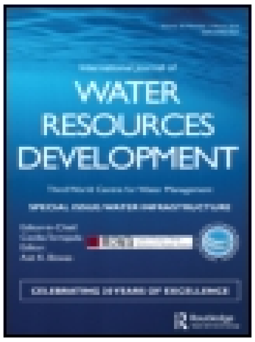

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Cost and schedule overruns in large hydropower dams: an assessment of projects completed since 2000

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ABSTRACT

This paper presents novel data on cost and schedule overruns in recent dam projects started and completed since 2000 and compares them with pre-existing data sets on projects started before 2000. Combining these data, a meta-data set was created of 184 cost overrun and 191 time overrun data points. For post-2000 projects, the average cost overrun was 33% and schedule overrun was 18% as compared with 46% and 37% respectively for pre-2000 projects. While a decrease in the averages was observed, the change in cost overruns is not statistically significant, whereas the change in time overruns is significant.

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Large dams; hydropower; forecasting; cost and schedule estimates; World Commission on Dams

Introduction

The World Commission on Dams (WCD) set out to ease the controversies of large hydropower implementation, while also attempting to improve the planning and implementation difficulties. Its report explained how to mitigate negative impacts and amplify the positive ones, and specifically to reduce cost and schedule overruns (WCD, 2000). The aim of this paper is therefore to examine whether there has been a change in cost and schedule overruns since 2000. To this end, the paper builds on earlier research that focused on hydropower dam projects built from the 1930s onwards, until recently (Ansar, Flyvbjerg, Budzier, & Lunn, 2014; Sovacool, Gilbert, & Nugent, 2014a; WCD, 2000) or focused on hydroelectric projects funded by the World Bank (Awojobi & Jenkins, 2015; Bacon, Besant-Jones, & Heidarian, 1996; Le Moigne, 1985). New data were collected on recent large hydropower projects completed post-2000, where large dams are defined as those with a height of at least 15 m (ICOLD, 2016), and compared it with all the available data sets from earlier research to demonstrate whether there has been an improvement in the time and cost performance of projects.

The importance of this research lies in its implications for future development in the planning and implementation of hydropower projects. The majority of the research into cost and time overruns to date has focused on demonstrating failures to adhere to cost and time schedules over time, but the data tends to be aggregated over long timescales

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Supplemental data for this article can be accessed here.

and very little research considers the trend in these data to demonstrate improvements, or lack thereof, over time. Various papers have indicated the profound impact of cost and time overruns on the economic value of major hydropower projects (Ansar et al., 2014; Awojobi & Jenkins, 2015; Bacon et al., 1996; Sovacool et al., 2014a; WCD, 2000) and have even recommended discontinuing plans to build large projects on this evidence (Ansar et al., 2014). Earlier research by Plummer Braeckman and Guthrie (2015) explained that time overruns (delays) in particular can have adverse impacts for a wide range of stakeholders on a project. Thus, an understanding of whether the situation is improving could be crucial for government decision-makers.

The paper compares data collected by earlier studies of hydropower projects with more recent data collected by the authors to establish the trend in cost and time overruns, specifically considering whether learning is taking place over time and if there is any impact of project size or geographical area on the results.

The paper is structured as follows. The next section sets out the theoretical framework and outlines the methods adopted. The data on cost and schedule overruns in projects completed pre- and post-2000 are then presented. Finally, the findings are summarized.

Theoretical framing

The overall framework of the research is presented in Figure 1. The dependent variables examined in this research are the percentage cost and time over- or underruns represented by the difference between the final pre-project estimates and the outturn.

This principal variable is a singular 'estimate' at a point in time, which for the purposes of this study is defined as the cost and time estimate used for financial closure or the last estimate prepared before construction begins (as in Bacon & Besant-Jones, 1998). As described further below, there are multiple cost estimates issued throughout the construction of a large project and it is important to be aware of these different estimates, otherwise it is very easy to inflate or deflate overruns (Invernizzi, Locatelli, & Brookes, 2017).

The cost of undertaking the necessary studies and site investigation is such that a decision to proceed with these activities needs to be taken once there is reasonable

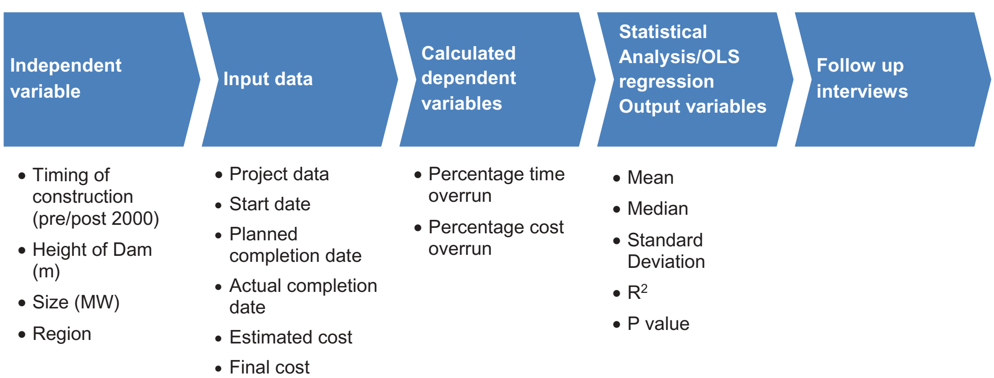

Figure 1. Graphical illustration of research.

certainty of the project proceeding, and yet it could be argued that the authorities cannot know whether a project should proceed until these investigations have been carried out (Hoek & Palmieri, 1998). Thus, decisions are made on estimates until more data are available. The WCD (2000, p. 268) notes that the decision to go ahead with the preparation for a project 'should not be a signal that the project will be implemented'. It would, however, be true to say that for some projects, particularly those that involve extensive underground works, full data on the site conditions are not known until the tunnelling is completed and thus cost and time estimations for underground works are particularly challenging (Eskesen, Tengborg, Kampmann, & Veicherts, 2004).

Cost estimates proceed through a process of refinements, as shown in Table 1. In the United States, the industry classifies cost estimates as classes 5 to 1, depending on the degree of accuracy and the use to which the estimate is expected to be put. Thus, a class 5 estimate is the earliest in the project and a class 1 cost estimate is used to check the tender. Generally, class 3 estimates are used for decision-making to give the initial project go-ahead. These estimates are expected to vary between 20% below and 30% above the estimate (cf. Invernizzi et al., 2017, for more information on estimation).

For this study, as far as possible, the time and cost to completion for the project has been compared with the class 1 cost and time estimates, that is, the final estimate before construction which is used when raising finance (as in Merrow, 2011). This will not include variation or change orders processed after project completion, for example, through arbitration (Awojobi & Jenkins, 2015). Financial closure is chosen as the price point because it represents the final point at which the government or sponsor can decide whether or not to proceed with the project. As final cost estimates, it would be expected that this includes forecasts of interest during construction, and contingencies including price contingencies (ADB, 2014). The final completion cost should include all finance charges, incentives, penalties, environmental and social management plans, and the use of contingencies (provisional sums included in the cost estimate to allow for any unforeseen costs). Other scholars chose a price point at the 'decision to build' (Ansar et al., 2014), which could be the financial close cost or could be earlier depending on when

Table 1. Cost estimation matrix for the hydropower industry.

	Primary characteristic	Secondary characteristic		
Estimate class	Maturity level of project deliverables (% of the complete definition)	End usage (typical purpose of the estimate)	Methodology (typical estimating method)	Expected accuracy range (typical variation in low and high ranges)
Class 5	0–2%	Concept screening	Capacity factored, parametric models, judgement or analogy	Low:–20% to –50% High: 30–100%
Class 4	1–15%	Study or feasibility	Equipment factored or parametric models	Low: –15% to –30% High: 20–50%
Class 3	10–40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	Low: –10% to –20% High: 10–30%
Class 2	30–75%	Control or bid/ tender	Detailed unit cost with forced detailed take-off	Low: –5% to –15% High: 5–20%
Class 1[a]	65–100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	Low: –3% to –10% High: 3–15%

Note: [a]Class 1 estimates used in this research – as highlighted.
Source: AACE (2013).

it is viewed that the final decision is taken. Sovacool, Gilbert, and Nugent (2014b) use the estimated cost from project documents of the final engineering, procurement and construction cost, which would be the final cost providing there was no significant change in scope of the project. Bacon et al. (1996), Awojobi and Jenkins (2015) and Le Moigne (1985) use the cost at financing by the World Bank, which would be the same as the estimate at financial closure as used in this paper.

There is a difficulty in verifying cost data as they are often considered commercially sensitive (Sovacool et al., 2014b). Furthermore, there is a potential for bias in what is published: developers may wish to appear to have brought a project in on time and within cost; journalists may wish to report a sensational story with dramatic overruns; and others may have their own biases or may seek to report impartially, but are dependent on the information they can uncover (Nüsser & Baghel, 2017).

In summary, five data points for each project have been collected, apart from physical characteristics, as shown in Table 2. These are similar to those used by Awojobi and Jenkins (2015).

Within this overall framework, a range of independent variables is considered together with their impact on the dependent variables. The factors examined are a range factors drawn from the literature review namely the timing of construction, size and region. Each of which is considered further below.

Timing of construction

The first of these independent variables is the period in which the project was constructed, which is considered as a causally relevant factor (Schneider & Wagemann, 2012). Institutional learning expects that additional information may lead to additional knowledge and ultimately to improved performance (Gertler, Wolfe, & Shaw, 2002; Nonaka, 1994; Steele, 2011). This variable is related specifically to the date of the WCD (2000), as outlined above, to examine whether any 'learning' is taking place. The WCD made extensive recommendations on the improvement of project preparation, such as the increased use of multi-criteria analysis and risk analysis to determine the optimum project definition, and thus it would be reasonable to expect some learning to have

Table 2. Summary of data points.

Term	Definitions used in this paper
Start date	Actual date of starting construction activities or the 'start' date from the project documentation
Planned completion date	Stated planned completion date at the beginning of construction activities
Actual completion date	Synchronization of the last unit of the hydropower plant with the grid
Estimated cost	'Class 1' cost estimate published at the start date of construction used for the arrangement of finance (generally referred to as 'financial close') – the final decision-making point of the project
Final cost	Cost incurred to complete the plant (with completion defined as synchronization of the last unit of the hydropower plant with the grid)
Cost overrun = (calculated and expressed as a percentage)	(Final cost − estimated cost)/estimated cost
Planned time = (calculated)	Planned completion date − start date
Actual time = (calculated)	Actual completion date − start date
Time overrun = (calculated and expressed as a percentage)	(Actual time − planned time)/planned time

taken place since the date of this influential report in the year 2000 and its extensive dissemination, if not as a result of the report itself, then at least as a result of the discussion that the report prompted (Briscoe, 2010; Locher et al., 2010; Moore, Dore, & Gyawali, 2010). Indeed, such learning was the intent of the establishment of the WCD, which came from a workshop with a wide range of stakeholders called 'Learning from the Past – Looking at the Future'. One of the specific objectives set out by this group for the intended commission was: 'To develop and promote internationally acceptable standards for the planning, assessment, design, construction, operation and monitoring of large dam projects and, if the dams are built, ensure affected peoples are better off' (IUCN, 1997, p. 8). The proposition that learning has taken place over time in this sector is supported by practitioners such as Richard Taylor, Chief Executive of the International Hydropower Association (IHA): 'The knowledge and understanding that exists today, is way in advance of what it was in the last century. It would be really erroneous to imply that no learning has taken place' (Mintz, 2014).

However, scholars such as Gamez and Touran (2010) and Flyvbjerg, Holm, and Buhl (2002) rebut the theory that any learning has taken place in the development of large infrastructure over time. Indeed, Flyvbjerg et al. (2002, p. 290) found no statistically significant link and concluded that for transport projects, 'cost underestimation has not decreased over the past 70 years'; and similarly, Sovacool et al. (2014b) found no significant improvement in cost overruns in hydropower projects over time. Ansar et al. (2014) consider that two elements may explain why cost estimates are not closer to the actual outturn. They suggest a combination of errors and lack of information at the planning phase, which they refer to as 'planning fallacy' and deliberate intent to mislead, 'strategic misrepresentation'. Planning fallacy encompasses the tendency to be overoptimistic in the development of estimates. Hence the trend in adjustment of project estimates to reflect 'optimism bias' as the main cause of planning fallacy (Flyvbjerg, 2008; Plummer, 2014; Plummer Braeckman & Guthrie, 2016).

Size

The second independent variable is size, as indicated by both dam height (m) and the capacity of the plant (MW). With this variable the link to project complexity can be explored. Bacon and Besant-Jones (1998) show that large projects have larger cost and time overruns even in proportion to their size, as do Sovacool et al. (2014b). Awojobi and Jenkins (2016, p. 25) found for most regions that 'dams with relatively large installed capacity are more likely to have cost overruns'. Larger projects are likely to be more complex, particularly as they often involve resettlement (Vanclay, 2016) and extensive underground works and are thus more prone to planning error than small projects. Hoek and Palmieri (1998, p. 3) note that projects involving tunnelling are difficult to estimate: 'It is generally neither physically nor economically feasible to drill a sufficient number of boreholes or excavate a sufficient number of exploration adits to investigate all the rock units along the route.' Authors (e.g., Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2014; Kirchherr, Pohlner, & Charles, 2016; Kirchherr, Charles, & Walton, 2016) have ranked the size of projects by their MW capacity. By contrast, the International Commission on Large Dams (ICOLD) defines dams by the height of the reservoir wall, such that a large dam is one more than 15 m from the lowest foundation to the crest. Both MW capacity and dam height have been used to represent size and explore whether larger projects are proportionately more delayed than smaller projects.

Region

The third independent variable is region, that is, the continental area in which the project is located. Awojobi and Jenkins (2016) contend that projects in one region are more likely to experience variation than others; Flyvbjerg et al. (2002, p. 285) conclude that 'geography matters to cost underestimation' for transport projects. Meanwhile, the WCD (2000) found that projects in Asia were more prone to overruns. Sovacool et al. (2014b) hypothesize a connection between location and overruns based on lower accountability and a weaker economy. They speculate that cost and time overruns are more likely in developing countries as 'emerging and developing economies are likely to see a comparative lack of experienced teams, potentially increasing labour costs, requiring foreign laborers, and delaying projects' (p. 912). However, their analysis did not support the hypothesis that governance affects cost and time overruns. A reason for this finding may be the presence of international contractors in developing countries which can at least partially ameliorate the impact of local capacity shortfalls (Wignaraja, 2009).

The hypotheses of this research are summarized in Table 3, which guides the subsequent analysis.

Methods

A basic statistical analysis was carried out in an approach (Figures 1 and 2) similar to that followed by Awojobi and Jenkins (2015) using the definitions shown in Table 2. Data were gathered from a variety of sources: government information, financiers' documents (including carbon finance), developers' documents, press releases and other reports. This data collection mirrored the data-collection approach chosen by Sovacool et al. (2014b). Occasionally conflicting and yet seemingly robust data points were identified for a single project. For example, the different data for the Nam Ngum 5 project in Laos, provided by the developer and a non-governmental organization (NGO). For these types of conflicting data, a conservative approach was adopted and only the most minor schedule or cost underrun identified and the greatest cost or schedule overrun identified were

Table 3. Summary of research hypotheses.

	Hypothesis	Specification	Explanation	Variable
1	Learning has an impact	Projects started since 2000 have a lower cost and time overruns than those started before 2000	WCD (2000) has triggered learning	Projects before/ after 2000
2	Size matters	Larger more complex projects are more likely to feature cost and time overruns	Large projects are subject to higher levels of complexity, such as underground works	Capacity (MW) and dam height (m)
3	Location matters	Projects in developing regions are more likely to be delayed/have cost overruns than others	Poorer regions may have less capacity, which includes planning capacity	Region (Africa, Asia, Europe, Americas)

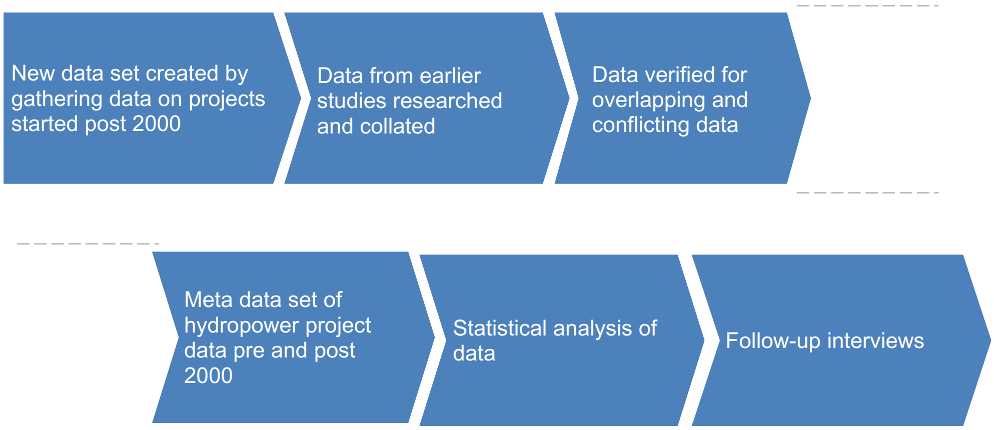

Figure 2. Data collection and analysis.

included in the eventual data set. This approach may imply that the data may understate cost and schedule underruns and overstate cost and schedule overruns.

As with Sovacool et al. (2014a), all costs are considered in US dollars as much of the information collected was quoted in dollars, particularly that from the World Bank and other financiers. In addition, an attempt was made to collect data in the local currency relevant to the project location (as discussed by Ansar et al., 2014). Yet, these data are rarely available and the effort of conversion is complicated by exchange rates and dates, as already outlined by Sovacool et al. (2014a, pp. 153ff.). Correctly calculating the impact of currency devaluation would depend on accurate information on the extent of local versus foreign costs and local versus foreign finance, the timing of loan drawdowns and repayments and the timing and currency of project income streams together with the government's foreign exchange management regime. This information is not easily available since many projects involve complex financing structures (Head, 2000). For example, the Nam Theun II project was financed using a combination of nine international banks and seven Thai banks together with support from export credit, bilateral and multilateral funding agencies (World Bank, 2005). With the increasing number of private or public–private partnerships developing hydropower projects, very little data on financing and revenues are made public (Merme, Ahlers, & Gupta, 2014). This range of unknowns makes any attempt at estimating local currency equivalence fraught with error, particularly for projects in developing countries. These projects tend not to hedge their foreign currency exposure as hedging instruments are either not available or expensive (World Bank, 2003). The inclusion or exclusion of inflation in overrun calculation varies (Invernizzi et al., 2017). No adjustment is made for the effects of inflation as this should be reflected as part of the cost overrun (since cost increases should have been budgeted for in the estimates).

Cost and schedule overruns for large hydropower dams were previously studied by various scholars, as outlined above. A meta-data set of all available data from these previous studies was collated, as depicted in Figure 2 and detailed in Table 4. The data set is available for Awojobi and Jenkins (2015), Sovacool et al. (2014a), Le Moigne (1985) and Bacon et al. (1996), and all these data were used to construct a data set on

Table 4. Characteristics of meta-data set and numbers of projects.

Implementation period	Size (MW)		Location	
Pre-2000	< 100	58	Africa	36
Post-2000	100–500	87	Asia	89
	> 500	67	Europe	19
			North America	11
			South America	59

hydropower projects completed before 2000. The data for Ansar et al. (2014) have not been shared publicly (Abaffy, 2016); the data set for WCD (2000) was never made public for confidentiality reasons.

The analysis uses an ordinary least squares (OLS) regression model with schedule and cost overruns (both in percentage terms) as the dependent variables, as outlined above. Summary data are provided in Table 5; the regression is shown in detail in Appendix A in the supplemental data online at https://doi.org/10.1080/07900627.2019.1568232.

The model follows previous studies (Ansar et al. (2014), Awojobi & Jenkins, 2015) in the selection of similar control variables. Following Ansar et al. (2014), dam size, capacity and schedule or cost estimate were transformed to account for excessive skewness. While using the square root for dam size transformation, a logarithmic transformation was used for the capacity and estimates variables. However, overruns were not transformed as it did not significantly improve accuracy. Multicollinearity was not detected during a variance inflation factor (VIF) analysis, so it can be assumed that there is no high correlation between two or more independent variables. In order to avoid a dummy variable trap, the Asia dummy was excluded (as explained by Suits, 1957). Thus, all regional variables were to be seen relative to projects built in Asia (e.g., the dummy for North America gives an indication on how much larger or smaller overruns in North America are on average than in Asia). A Breusch–Pagan test (as introduced by Breusch & Pagan, 1979) for heteroskedasticity showed that the variances from the error terms of the regression are seemingly independent of the values of the independent variable. However, as the test's *p*-value is only slightly above the 95% confidence threshold, heteroskedasticity-consistent covariance matrix estimators were used to improve the accuracy of the model

Table 5. Descriptive statistics.

Cost overrun (underrun), 184 projects	Cost overrun (%)	Height (m)	Capacity (MW)	Cost estimate (US$ millions)
Standard deviation	73%	60.32	2412	2641
Mean	43%	91.31	953	979
Maximum	513%	335.0	22,500	24,738
Minimum	−46%		6.30	4.33
Coefficient of variation	1.79%	0.66	2.52	2.69
Skewness coefficient	3.41%	1.06	6.16	6.07
Schedule overrun (-underrun), 191 projects	**Schedule overrun (%)**	**Height (m)**	**Capacity (MW)**	**Schedule estimate (months)**
Standard deviation	51%	63.17	2290	22.46
Mean	32%	97.31	939	62.62
Maximum	402%	335.00	22,500	150
Minimum	−35%		6.30	11
Coefficient of variation	1.53%	0.65	2.43	0.36
Skewness coefficient	4.00%	1.06	6.38	1.05

(following Mackinnon & White, 1985). In particular, the HC3 estimator was used, as suggested by Long and Ervin (2000), for samples with $N < 250$.

Following the analysis, the results were discussed in interviews with industry experts. Four experts were interviewed, all engineers either from engineering consultancies or the World Bank. The authors also presented the initial results at the HYDRO 2017 conference in Seville, Spain. This gave industry context to the findings and postulated rational explanations for the effects uncovered.

Results and discussion

Novel data were collected on cost variation from estimate for 42 projects and schedule variation data for 60 projects between 1994 and 2015. This, when combined with the other data from previous studies, resulted in 184 cost overrun data points and 191 time overrun data points, of which 40 and 55 respectively relate to completed projects that commenced construction after 2000 ('post-2000'). The novel data (shown in Appendix B in the supplemental data online) collected constitutes a data set of similar size to previous studies such as Awojobi and Jenkins (2015).

The findings regarding cost and schedule overruns are summarized in Table 6 and discussed below.

Overall overruns

The cost overruns identified largely correspond with the average cost overrun of rail (45%) and roads (20%), were higher than those for mining (14%), thermal generation (6%) and wind (8%), but significantly surpassed by the average cost overruns for nuclear plants (117–207%), as summarized in Table 7. As such, these are not extraordinary levels of cost overrun for large infrastructure projects.

Table 6. Cost and schedule overruns for large dam projects.

		Newly collected data set	Ansar et al. (2014)	Awojobi and Jenkins (2015)[a]	Bacon et al. (1996)	Sovacool et al. (2014a)	Le Moigne (1985)	WCD (2000)	Meta-data set
Cost overrun	Average (mean)	25%	96%[b]	27%	27%	71%	51%[c]	56%	43%
	Median	20%	27%	21%	18%[c]	70%[c]	37%[c]	n.a.	25%
	Standard deviation	32%	n.a.	38%	38%	67%[c]	35%[c]	n.a.	73%
Schedule overrun	Average (mean)	19%	44%	16%	28%	64%	61%[c]	n.a.	32%
	Median	14%	27%	18%	21%[c]	32%[c]	24%[c]	n.a.	20%
	Standard deviation	32%	n.a.	19%	28%	90%[c]	68%[c]	n.a.	51%
Number of projects analyzed	Cost schedule	42 60	245 245	58 58	70 70	60 42	17 9	81	184 191
	Date range of projects	1994–2015	1934–2007	1976–2005	1965–1986	1936–2013	n.a.	n.a.	1936–2015

Notes: [a]Additional data were provided by the original authors.
[b]Cost overruns were calculated with local currency cost equivalents.
[c]Calculated from the original study data.

Table 7. Previous research on average cost for infrastructure.

	Cost overruns (%)	Reference
Solar facility	1%	Sovacool et al. (2014a, p. 154)
Thermal power plant	12.6%	Sovacool et al. (2014a, p. 154)
Wind farms	8%	Sovacool et al. (2014a, p. 154)
Mining	14%	Bertisen and Davis (2008)
Roads	20%	Ansar et al. (2014, p. 54)
Rail	45%	Ansar et al. (2014, p. 54)
Nuclear	207%	Schlissel and Biewald (2008)
	117%	Sovacool et al. (2014a, p. 154)

Learning has an impact

A descriptive comparison of all projects which were started and completed post-2000 or started before 2000 was performed, as shown in Table 6. The average cost overrun changes from 46% pre-2000 to 34% post-2000 and the post-2000 projects have an average time overrun of 18% as compared with a pre-2000 average of 37% (Table 8).

The regression analysis (Table 9) does indicate an improvement in schedule overruns since 2000, which is statistically significant at a greater than 95% confidence level. That is, on average and everything else being equal, if the same project that was built before 2000 was built after 2000 in the same place, the model suggests it would have a lower schedule

Table 8. Meta-data set comparison with pre- to post-2000 projects.

		Full data set, pre-2000	Full data set, post 2000
Cost overrun	Average (mean) (%)	46%	34%
	Median (%)	25%	24%
	Standard deviation (%)	81%	31%
Schedule overrun	Average (mean) (%)	37%	18%
	Median (%)	20%	24%
	Standard deviation (%)	61%	32%
	Number of projects analyzed	144 (cost)	40 (cost)
		136 (schedule)	55 (schedule)
	Date range of projects	1936–2000	2000–15

Table 9. Ordinary least squares (OLS) regression analysis.

Variable	Cost overrun	Schedule overrun
After 2000 Dummy	0.171 (0.269)	−0.458** (0.181)
Dam Size (m)[a]	0.045** (0.022)	0.029** (0.014)
Capacity (MW)[b]	0.173** (0.08)	0.104*** (0.040)
Cost/Schedule Estimate[b]	−0.059 (0.058)	−0.631*** (0.168)
Africa Dummy	−0.112 (0.143)	−0.064 (0.085)
Europe Dummy	−0.214 (0.174)	−0.145 (0.110)
North America Dummy	−0.409 (0.323)	−0.402** (0.176)
South America Dummy	−0.121 (0.174)	−0.099 (0.109)
Linear time trend	−0.004 (0.174)	0.005 (0.004)
Constant	−0.337 (0.558)	1.981*** (0.552)
Observations	149	169
R^2	0.153	0.206
Adjusted R^2	0.098	0.161
Residual standard error (d.f. = 139/159)	0.738	0.462
F-statistic (d.f. = 9; 139/159)	1.875*	2.561***

Notes: For further details, see in Appendix A in the supplemental data online.
*90%; **95%, ***99%.
[a]Square root.
[b]Log transformed.

overrun. However, the analysis does not show a similar result for cost overruns since 2000. Therefore, the results do not fully corroborate the initial hypothesis regarding learning over time with respect to cost (thus echoing Awojobi & Jenkins, 2015, pp. 227ff., and Flyvbjerg, 2014, pp. 10ff.).

This difference between the results for cost and time overruns was not an intuitive result, so interviews were conducted with industry experts to discuss possible explanations for this result. None of the interviewees related the results to the WCD. Three key explanations were postulated:

- One factor that was emphasized by several interviewees is the increased use of acceleration payments to address time slippage, particularly in the private sector. In using acceleration payments, contractors may be paid additional amounts to increase their work rates and recover earlier delays; this leads to higher cost overruns but lower time overruns (Gerk & Qassim, 2008; Ng, Deng, Lam, & Skitmore, 2000). Changes in the available range of forms of contract for hydropower financing have increased the potential for private sector involvement in hydropower (Oud, 2002). As noted repeatedly in interviews, this has increased the focus on acceleration payments as the private sector is very sensitive to time.
- Projects are now more often fully financed before they start as the private sector will not take the risk to commence without secure financing (Briscoe, 1999), whereas previously governments might start a project without sufficient finance, which was then delayed while further funds were arranged (Head, 2000; Plummer Braeckman & Guthrie, 2015). This may imply that fewer projects are delayed during implementation from lack of finance, and would explain a reduction in delay, but would need further assessment as to the precise impact on cost.
- It was suggested that the use of modern techniques may have improved implementation times. A particular example of this is tunnel-boring machines that can accelerate tunnelling progress beyond that of a traditional drill-and-blast method (Girmscheid & Schexnayder, 2002). However, these machines are expensive and can cause extended delays when they run into difficulties (Barton, 2012). This question deserves further detailed analysis.

Size matters

According to the model, dam height and plant capacity have a statistically significant impact on both cost and schedule overruns on a 95% confidence level, respectively. The MW size of a plant is considered more indicative of complexity than dam height, that is, dam complexity does not depend solely on dam height (Fencl, Mather, Costigan, & Daniels, 2015). Overall, the findings regarding size are consistent with mega-project scholars (e.g., Ansar et al., 2014; Flyvbjerg, 2014; Bruzelius, Flyvbjerg, & Rothengatter, 2002), who have stated that larger projects face proportionally greater overruns than small projects.

Location matters

The model does not suggest a statistically significant influence of the region in which the project is constructed (apart from North America). This finding that 'location does not matter' may be explained by an increasingly globalized hydropower industry with projects in Asia being carried out by European players, projects in Europe by Chinese players, and thus a significant cross-fertilization of ideas and approaches across locations (Kirchherr, Matthews, Charles, & Walton, 2017). That said, the finding that location is not a significant driver of cost overrun is generally surprising as in-country governance is known to affect project outcomes (Plummer, 2014). The data at the continent level are not sufficiently granular to highlight the differences in governance structures between countries in a region. Further research could consider this analysis at country level if a larger data set could be established.

Of the 10 North American projects included in the sample, only two were built since 2000, demonstrating the maturity of the North American industry. These 10 projects have average time overruns better than other regions (statistically significant at 95%). While this may be explained by the long history of hydropower development in the United States and Canada, the data set is too small to draw strong conclusions. Canada, particularly, has developed a strong implementation strategy for dealing with First Nation consultation and benefit sharing (Fortin, 2001).

Limitations

This study is as dependent as all similar studies on the availability of data. In this the authors had a choice: to rely on wider but less verifiable data or to restrict the analysis only to those projects that have externally verified published results. Even if one were to restrict analysis to the latter, it is impossible to deduce whether any misreporting is created by the bias of the reporter. In this research, it was decided to rely on a wider data set. It is acknowledged that data may have been collected, at times, where it was not possible to verify that it exactly pertained to the definition of class 5 presented in Table 1. Thus, some of the data presented here may contain potential inaccuracies as regards the definitions identified, while the overall sample remains impartial. Yet, it is found (echoing King, Keohane, & Verba, 1994, pp. 6ff.) that an important topic is worth studying even if relevant information can only be partially accessed and verified. Some studies may use an earlier cost estimate, and this choice of an earlier less certain estimate could lead to different variations.

Effects of delay

The results summarized in Table 10 have demonstrated that there is some improvement in the management of delay in large hydropower projects since 2000. Earlier research by Plummer (2014) estimated that the delay to the Bujagali project cost Uganda in the region of 1% of gross domestic product (GDP) per year that the project was delayed. As indicated in the same study, the impacts of delay vary considerably from one project to another and are often not as easy to identify as cost overruns, but can still have highly significant impacts, not least for those who have no access to electricity and are left without the power necessary for development. The average time taken for construction for the 55 projects in the post-2000 part of the data set was 56.5 months (or just over 4.5 years). According to the data, the average project incurred an 18% or 10-month delay. If this project had suffered the same average time overrun as its pre-2000 comparators,

Table 10. Summary of the findings.

	Hypothesis		Findings
1	Learning has an impact	Yes/no	Statistically significant improvement in schedule overruns since 2000, but no statistically significant improvement (or deterioration) in cost overruns. Thus, the initial hypothesis that motivated this paper was not fully proven. There is evidence that learning may at least have had some impact on time management, but the interviewees tied this to more recent changes in practice rather than the World Commission on Dams (WCD)
2	Size matters	Yes	Data showed that size indeed matters as larger projects were more prone to delay, and this complexity needs careful management
3	Location matters	Yes/no	Location is not shown to matter significantly, although this contradicts other research on the importance of the particular governance framework in place. This is probably because continent-level analysis is too broad and implies the need for more granular analysis

that is, 37%, then it would have experienced an additional 11-month delay. While there is, of course, no such thing as an average project, these figures give an indication of the quantum of impact on projects.

The full data set of cost and schedule over- or underrun data points and references to sources is available from the authors on request. The new data collected are summarized in Appendix B in the supplemental data online.

Conclusions

This research set out to identify whether learning was visible in the implementation management of large hydropower dam projects. In particular, the intent was to explore whether the seminal work of the WCD provided information that has improved estimation and implementation practices. In addition, consideration was given as to whether size and location were significant drivers for cost and time overruns.

The data showed improving averages for time and cost overrun, but only the decrease in the average time overrun was statistically significant. A suggested explanation for this in the increasing use of acceleration payments (minimizing schedule slippage, but increasing cost overruns) in the hydropower industry since 2000, particularly in the growing number of private sector projects. Statistical evidence was found for a relationship between overruns and project size, that is, larger more complex projects are more likely to encounter overruns. The region-specific analysis produced no firm evidence of recent improvements in one region over another.

Further research could collect more data on cost and schedule overruns in large hydropower projects and consider analysis at a country level. Indeed, as an industry, the hydropower sector needs more reliable, public, standardized data on costs and financing. Further research will also be needed to develop a robust and detailed explanation of the recent improvements in time management and to examine in greater detail issues such as acceleration payments, modern technology and the impact of private financing.

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