Were the Hydro Dams Financed by the World Bank from 1976 to 2005 Worthwhile?

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Abstract

Because hydro dams are complex to design and usually involve long-term planning, they are particularly susceptible to cost and time overruns. The controversy surrounding their development remains an unresolved issue in the energy policy debate. This study re-examines the cost issues associated with a portfolio of 58 dams that were financed by the World Bank from 1976 to 2005. Further, an estimate is made of the value of the benefits produced by these investments to determine the magnitude of economic rates of return for the individual projects and the overall portfolio of dams. Even though this portfolio of dams suffered substantially from cost overruns, the net contribution of these dams has been positive and substantial. The ex-post real economic rate of return for the entire portfolio is estimated to be greater than 14 percent. The important policy implication of this study is that each investment in a hydro dam needs to be appraised taking into consideration the distribution and probabilities of costs that might be incurred as well as the potential benefits. Adequate margins must exist of ex-ante benefits over costs to account for the risks of cost overruns.

Highlights

- **An ex-post evaluation is made of hydroelectric dams financed by the World Bank.**
- **Cost overruns, time overruns, and the cost of time overruns are measured.**
- **The PV of benefits produced by this portfolio was 1.5 times the PV of the costs.**
- **Real cost overruns were 27% and cost of time overruns 3.5% of ex-ante costs.**
- **Risks of cost overruns must be evaluated in relation to projected benefits of dams.**

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1.0 Introduction

The objective of this paper is to analyze the net economic benefits arising from a portfolio of 58 hydro dam projects that were financed between 1976 and 2005 by the World Bank and for which project completion reports are available. This study both investigates the issues associated with the cost and time overruns that are common with the implementation of the dams and measures the actual economic benefits created by these dams. The benefits are measured from the time of each project's completion until 2014 and projected from 2014 until the end of the dam's planned useful life.

Previous studies using data for the period prior to 1986 have revealed the severity and chronology of cost overrun problems for hydropower dams financed by the World Bank, (Merrow and Shangraw, 1990; Bacon et al., 1996; Head, 2000). In addition, the historical pattern of cost escalation of large construction projects has been extensively documented (Flyvberg, 2007; Flyvberg et al., 2002, 2009; Pickrell, 1990, Sovacool et al., 2011). In what is perhaps the most comprehensive effort to date to investigate the problems of building dams, Ansar et al. (2014), using a reference class of projects for analyzing the performance of large dams, found that nine out of ten large dams constructed had cost overruns.

These studies suggest that there is substantial bias toward the underestimation of the capital costs of hydropower projects at the planning stage as compared with their actual costs upon completion. Construction delay is also identified as a major problem among such projects (Wachs, 1989; Merrow and Shangraw, 1990; Morris, 1990; Bacon et al., 1996; Flyvberg et al., 2002, 2009; Ansar et al., 2014; Sovacool et al., 2014).

Sovacool et al. (2014) presented a major study of the construction problems of the power industry. This comprehensive research describes the frequency and magnitude of construction cost overruns in the electricity sector, taking an outside look at the unique set of construction risks for various electricity-generation technologies, including nuclear power, solar technology, wind farms, and hydropower dams. The study identified significant variations in the frequency and severity of cost and time overruns in terms of size, location, and generation technology. Overall, about 75 percent of hydro-electricity projects had cost overruns.

Despite the efforts to understand the problem of cost overrun and the rationale behind building dams, less analysis has been published that takes into consideration the benefits side of hydropower dams (World Bank OED, 1996; Asmal, 2000). Thus, the justification for this study is two-fold. One is to re-examine the nature of the cost escalation of World-Bank-financed hydropower projects involving dam reservoirs where the component related to time overruns is estimated separately from the cost overrun. Bacon et al. (1996) estimated average cost overruns for hydropower projects financed by the World Bank to be 27 percent with a standard deviation of 38 percent. Our selection of 58 hydro dam projects allows us to undertake a study that, while overlapping with the dataset used by Bacon et al. (1996) on half of the projects, also adds 29 more recently constructed dams. By classifying the dataset in this way we are able to determine whether the avoidance of cost and time overruns by projects financed by the World Bank has improved over time.

The second focus of this study is an attempt to estimate the benefits side of this sample of hydro dams and to determine the net economic contribution of this portfolio of dams to the societies in which they are located. The results from this analysis serve to provide further information to guide appraisals of hydropower dam investments in an industry that has long been characterized by information asymmetries between project promoters and financiers.

If the actual cost of completing a dam is double the original estimate, the economic justification for reaching a decision to build the dam would still be valid if the present values (PVs) of the benefits realized are more than double the ‘biased’ cost estimates at appraisal.

Because each hydropower site is unique, one needs to know the value of potential benefits that can be produced before it can be suggested that hydro dams are a poor choice of electricity investment based on their past record of cost overruns. For example, the Chukha Dam in Bhutan had a real cost overrun of 175 percent, yet an ex-post evaluation of that dam has shown that on a total investment of US$ 403 million, an economic net present value (NPV) has been created in excess of US$ 4.7 billion (Dhakal and Jenkins, 2013).

With the effort internationally to meet the challenges of a stable energy future and combat climate change problems, there is a need to determine whether hydro dams can potentially serve as one instrument for meeting the clean energy policy targets.

2.0 Methods

For the analysis of cost overruns, four cost concepts are used: estimated nominal cost, estimated real cost (base year price), actual nominal cost, and actual real cost. The estimated nominal cost used in this study is the sum of base cost (using constant prices), plus an amount to reflect the provisions for physical and price contingencies. According to the World Bank appraisal methodology that has been used since 1976, cost estimates for projects should include a price contingency to account for expected changes in the price level of both imported and locally purchased inputs (Bacon et al., 1996). Therefore, the estimated real cost at appraisal is simply derived by deducting the price contingency from the estimated nominal project cost, but including physical contingencies. Projects appraised before 1976 are excluded from this analysis to maintain a consistent methodology for evaluating the cost performance of the selected projects for this study.

The change in the real cost schedule of a large project can be the result of two factors. First, real cost changes can come about because of changes in input quantities and real price adjustment; second, change orders will alter the real cost as a project is redesigned. The change in real cost reported here is the difference in cost between the real estimate of cost (which includes physical contingencies) at the time of appraisal – the point of decision making – and the actual real completion cost. Real cost overrun as measured in this study excludes cost changes owing to change orders.

The actual nominal cost (in current prices) is the completion cost of the project as reported in the World Bank's Implementation and Completion Reports (ICRs), while the actual real cost is the deflated values of the actual nominal costs. The impact of general inflation on the cost of a project will usually be transferred eventually to the consumers of the output of the project through the adjustment of electricity tariffs to reflect movements in the general level of prices. Hence, a budget overrun caused by general inflation should not be counted as a real cost overrun.

For a balanced view of the true value of dams, we propose an analytical framework that takes into consideration the uncertainties underlying both the costs and benefits of hydropower dams. The uncertainty underlying the benefit side is the volatile price of fuel that is avoided by undertaking the hydropower investment. The downside uncertainty in the cost of hydro is the risk of capital cost and time overruns. To find the effect of these risks and uncertainties on the outcome of our analysis, data for completed dams and parameters for evaluating the alternative plant are collected based on actual statistics from historical records such as the ICRs, post evaluation reports, and other historical sources. Data on the actual capital costs of open-cycle and combined-cycle plants financed by the World Bank and completed during the period covered by this study are used to estimate the fixed capital cost of the alternative plants which are avoided by constructing the hydropower dam (Staff Appraisal Reports (SARs) and ICRs for various projects).

2.1 Data and measurements

Information used for the analysis was collected from the World Bank's Project ICR and SAR for each of the 58 projects. In total, these projects account for more than 34 gigawatts (GW) of installed power-generation capacity.

Table 1 shows the composition of data used for this study. The cost per megawatt (MW) of an installed power station is also presented in 2010 constant US dollar (US$) prices. As shown in Table 1, the 58 hydroelectric projects are concentrated in Africa (13), Latin America (15), and Asia (22). Of the remaining plants, five are in Europe and three in Oceania. The average size (in MW) of the projects is much smaller in Africa and Oceania than in Latin America and Asia. The average cost per MW of capacity of projects when fully implemented is significantly lower in Asia (US$ 1.39 million/MW), than in Africa (US$ 2.38 million/MW), Latin America (US$ 2.05 million/MW), Europe (US$ 2.02 million/MW), and Oceania (US$ 4.35 million/MW) (Table 1, column 6).

Table 1. Summary of data by region

Geographical location	Number of projects	Capacity (MW)	Average real cost (US$ million, 2010)			
			Real capital cost, estimated	Real capital cost, actual	Estimated cost/MW	Actual cost/MW
	[1]	[2]	[3]	[4]	[5]	[6]
Africa	13	1,388	2,698.6	3,307.9	1.945	2.384
Latin America	15	13,172	17,742.7	27,046.7	1.347	2.053
Asia	22	16,500	21,167.1	23,037.3	1.283	1.396
Europe	5	3,088	5,117.9	6,223.3	1.657	2.015
Oceania	3	116	389.3	506.1	3.348	4.352
Aggregate	**58**	**34,264**	**47,115.6**	**60,121.3**	**1.916**	**2.440**

Note: Columns 3 and 4 present the undiscounted but deflated sum of the actual costs incurred for all projects within each regional category. Figures in column 5 and 6 are weighted averages of cost per MW for various regions.

2.1.1 Cost overrun computation

The World Bank Project ICRs give the cost of a project along with the percentages of the total that are foreign and local costs. The actual project cost, however, is expressed in nominal dollar terms. To compute the actual real cost, it is necessary to spread the actual nominal cost over the entire construction period of the project. The approach used for the distribution of capital expenditure over the construction period of the projects follows the mathematical formulation by Drummond (2012), which is similar to that used by Bacon et al. (1996)[1].

The annual nominal costs are split into foreign and local components, and then deflated to the prices of the starting year. The domestic costs are first converted from nominal US$ to nominal domestic currency units using the market exchange rate for each period. These nominal amounts of domestic costs are deflated by the domestic price index, and then converted back into US$ of the starting year of the project using the market exchange rate for that year. The foreign costs are deflated with the manufacturing price index for the USA. Adding up these two components gives the actual real cost of the project, expressed in dollar terms[2].

This procedure is used to estimate the actual real costs of constructing the dams, as presented in Table 1, column 4. The real cost overrun is then computed as the deviation of the actual real cost from the estimated real cost, taken as a percentage of the estimated real cost. We estimate the nominal cost overrun as the percentage deviation of the actual completion cost

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[1] The spreading of the construction costs was carried out using the function:

$$Y_i = \frac{1}{2+p}\left[(s+1)\left(\frac{i}{I}\right)^{s}\left(p + \pi sin\left(\pi\left(\frac{i}{I}\right)^{s+1}\right)\right)\right]$$

where Y_i is the share of total capital expenditures allocated to period i of the entire construction span that is I years; S represents the skewness of the cost lay-out curve assumed to be 0.2 for a positively skewed curve over the construction cycle; p is the flatness of the curve, and it varies according to the length of construction cycle.

[2] Actual real cost (US$) is:

$$\sum_{i=0}^{T}\frac{C_i^{n\$} * FCX}{I_{o,i}^{F}} + \frac{1}{E_0^m}\sum_{i=0}^{T}\frac{C_i^{n\$} * (1 - FCX) * E_i^m}{I_{0,i}^{D}}$$

where $C^{n\$}$ denotes the actual nominal cost, FCX is the share of imported components of the total cost; I^F and I^D are the foreign and domestic price indices, respectively.

over the estimated real cost of constructing the hydropower dam. This includes both the changes resulting from price escalation and the real cost growth in excess of physical contingencies set aside during appraisal.

2.1.2 Cost of time overrun

Delays often occur during the implementation of a hydro dam project that extend the period of construction beyond its original schedule. Evidence from our sample of projects shows that more than 75 percent of the projects experience a time overrun of more than 10 percent of the initial time estimated for completion. In planning for power project investments with alternative forms of energy generation, it is important to consider the fact that there are both economic costs and benefits from delaying the construction of these projects. When there is time overrun, there are benefits in PV terms that accrue from cost savings from postponing the real capital expenditure outlays[3]. The actual project cost will be subjected to a longer period of discounting. These benefits, however, may not be significant enough to offset the cost of supplying power by alternative means during the period of delay[4].

Although cost overrun and time overrun are not completely separable concepts in project appraisal, the cost implication of the latter is best explained by a marginal evaluation of the societal resource flows that may ultimately be beneficial to the society.

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[3]

$$\text{Cost savings} \quad = \sum_{i=1}^{T}[C_i^{r\$} * (1+r)^{-i}] - \sum_{j=1}^{Z}[C_j^{r\$} * (1+r)^{-j}]$$

where, i is the construction year within the scheduled period T; j is the construction year up to the actual completion period, Z; $C^{r\$}$ is the real capital expenditure on the hydro project during construction years.

[4] If the energy demanded goes unsupplied, the actual cost to the economy may be higher than the hypothetical marginal thermal supply cost that is used in the estimation of the cost of delays.

The cost of power generation through the best available alternative is our estimate of the economic value of the lost benefits of electricity generation that are the result of the delay in the construction of the hydropower facility. The most likely scenario is that with the delay in the dispatch of the hydro plant, during the peak and off-peak periods other thermal plants will be operated for more hours. These will be the plants with the highest running costs in the system, which would have been partially or fully retired as a result of the introduction of the hydro dam. The additional costs incurred will include the fuel and variable operating and maintenance costs incurred in keeping these marginal plants operating. Because we do not have information on the existing system into which the hydro dams would be integrated, we have simply chosen a level of efficiency of fuel consumption of 0.240 liters of heavy fuel oil (HFO) per kWh of electricity generated, which is broadly representative of the marginal fuel cost of single-cycle generation plants in developing countries. In addition, a variable operating and maintenance cost of US$ 15.5/MWh is added to the fuel cost of the additional generation from these plants.

This opportunity cost varies according to fluctuations in the oil price. For countries with a low cost of generating electricity with hydropower, such a delay will be more costly because of the relatively unfavorable cost of generating power from the alternative sources. The net social cost of delay is then measured as the difference between the marginal running cost of the alternative power generation and the cost savings from the postponed real investment in the dams.

A real discount rate of 10 percent is used to adjust both benefits and costs to bring them to a common point in time.

Most of the literature on this topic has identified time overrun as a major cause of cost overrun (Flyvberg et al., 2002; Ansar et al., 2014). In PV terms, this is not obvious, because it could equally be said that cost overrun is the cause of time overrun. When there is an increase in the cost of a project beyond that which was planned, and the project runs out of funds to finance the increase, it is often a time-consuming task to raise additional funds during the construction stage to complete the dam. The project sponsors are usually required, based on financing covenants, to seek approval from existing lenders before embarking on such an activity. This process of financing the cost escalation often takes a substantial amount of time out of the scheduled construction period.

2.2 Measuring the benefits of dams

As in the above estimation of the cost of time delays, the benefits of a hydropower dam can be quantified as the value of the avoided generation cost of the fossil-fuel-powered plants that would be required to be built and operated to supply the same volume of electricity as would be supplied by the hydro dam (Zuker and Jenkins, 1984). Thus, the benefits of the hydro dams, excluding the other benefits often associated with dams – such as irrigation and flood control services, and reduced carbon emissions – are measured in two parts: i) the cost savings on the fixed annual capital cost of the alternative electricity-generation plant; and ii) the marginal running cost of the alternative plant. Assuming that the next best alternative energy can be generated from a standard thermal plant, we value the electricity supplied as the cost per kWh saved, which includes both the rental cost of the capital invested and the marginal running cost (MRC) of the thermal plant[5].

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[5] The benefit of hydropower dam is measured as:

$$\sum_{t=0}^{Z+40}\left\{\left[K\frac{r(1+r)^N}{(1+r)^N-1}IC\right]+VOM+(f_t p_t)G_t\right\}(1+r)^{-t}$$

Data on the capital cost of single-cycle and combined-cycle power generation plants are collected from the World Bank database of implemented projects (SARs and ICRs). The annuity formula is used to estimate the annual capital cost per kW, which includes both the depreciation and economic opportunity cost of capital investment, where the economic life (N) of the alternative plant is assumed to be 25 years. The calculated annual capital cost per kW is then multiplied by the installed capacity size of the hydro to obtain the total fixed annual capital cost.

In the context of this analysis, the MRC is taken as the value of the fuel and the variable operating and maintenance (VOM) expense that would be necessary to operate the alternative plants if the hydro dams had not been implemented. This value of fuel is a function of the price (p_t) of HFO and the amount of fuel required per unit of electricity to be generated (f_t). The fuel price is adjusted upward by a markup of 20 percent when calculating the fuel cost for all the regions except China, where a 10 percent margin is applied because of the relatively low cost of transaction. This margin/markup on price is to cover port charges, transportation cost, insurance, and distribution cost (IEA, 2014).

Fuel requirement per kWh varies across the projects, depending on the capacity factor and net capacity size of the hydropower generating system. For projects with capacity size > 200MW and projected load factor > 50 percent, we assumed that the substitute generation would have been a combined-cycle configuration, and otherwise, that a single-cycle plant would have been the more likely choice. This assumption is plausible in the context of this study. Assuming a 33 percent efficiency rating for the single-cycle plant and 52 percent for the

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where K represents the capital cost and N is the economic life of the alternative plant. IC denotes the installed capacity in MW, and G the equivalent electricity output expected to be generated from hydropower facility in period t; f stands for fuel requirement in liter/kWh, and p for price of fuel at period t. Fixed operating and maintenance costs have been estimated to be similar for both the hydropower facility and the oil-fired plant (EIA, 2013). Hence, we do not include fixed operating and maintenance in the formula for estimating the hydro benefit.

combined cycle, the fuel requirement is calculated to be 0.240 liter/kWh and 0.152 liter/kWh of HFO for the single and combined cycle respectively. Data for net electricity generation are available from the World Bank post evaluation reports for various projects. The variable operating and maintenance cost for the single-cycle plant is set at US$ 16.00 per MWh and for a combined-cycle plant at US$ 3.40 per MWh (EIA, 2013).

Since this type of project produces benefits over long periods of time, the results are expected to be sensitive to the choice of discount rate. Therefore, a range of discount rates are considered in a sensitivity analysis to test the robustness of the results of the analysis.

Once the benefits (cost savings) of the hydropower projects are estimated, the net benefits of the dams are derived by subtracting the actual cost of the dam projects from their estimated benefits and then expressed as the stream of net benefits over time in real PV terms, using 2014 as the base year. The value of electricity that is estimated in this study includes all generation costs, but does not include any differentiated transmission and distribution costs if these were not included in the project reports.

3.0 Results and discussion of findings

3.1 Findings on cost overruns

In Table 2, both the impacts of inflation and the real cost overruns are reported. As shown in column 2, the cumulative movements in prices have, on average, increased the nominal cost of these projects by 58.7 percent of the estimated real base cost. The estimated real base cost includes the non-price contingencies that are usually included at the time of appraisal, but excludes the price contingencies. The range of total nominal escalation of costs ranges from 106.8 percent of base cost estimates in Latin America to 26.4 percent in Asia. In Africa, Europe and Oceania, the rates of cost escalation were 50.6, 30.6, and 44.9 percent, respectively.

The values of the real cost overruns are measured as the excess of the change in actual real costs over what has been estimated as non-price contingencies, expressed as a percentage of estimated real cost. The averages are weighted averages of the various projects, where the weights are the proportion of MWe capacity represented by each project in the total sample.

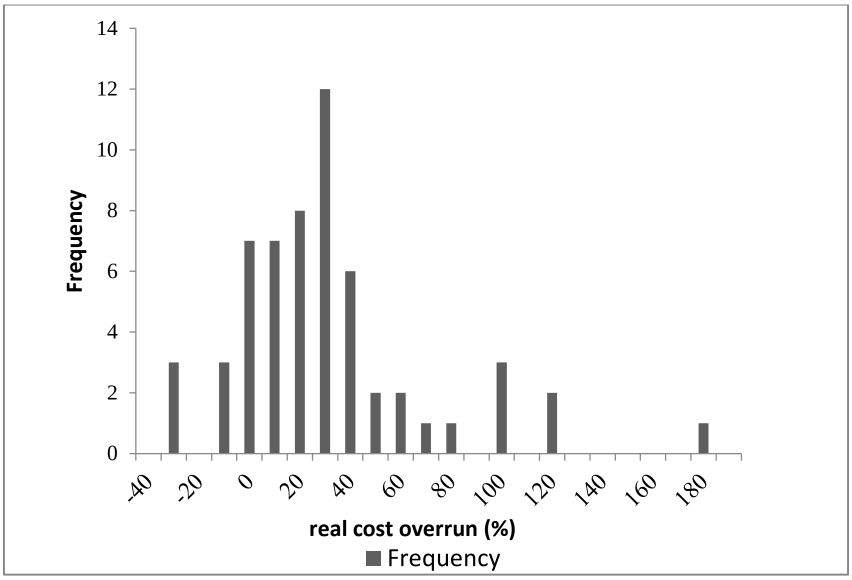

Figure 1. **Distribution of real cost overruns**

The distribution of real cost overruns for our sample data is shown in Figure 1. About 78 percent of the projects incurred construction costs beyond those estimated at the appraisal stage. More than half of the projects had real cost overruns above 20 percent, with 2 out of 10 projects having actual real cost overruns above 50 percent of their estimated real cost. The standard deviation of the percentage real cost overruns is 34.7 percent. This implies that, even if sensitivity analysis had been performed at the appraisal stage for a 20 percent increase in project cost, as commonly practiced, there would still have been substantial cost overruns for many of these projects. Overall, the average real cost overrun is found to be 27 percent for the entire set of 58 projects (Table 2, column 5), which is exactly the same average found by Bacon et al. (1996) for an earlier set of hydro dams that partially overlaps with the set studied here.

Table 2. Estimated average cost overruns across regions

	Number of projects [1]	Nominal cost overrun as percentage of estimated real cost (%) [2]	Estimated price contingency as percentage of estimated real cost (%) [3]	Actual price escalation as percentage of estimated real cost (%) [4]	Real cost overrun as percentage of estimated real cost (%) [5]
Africa	13	50.6	21.7	25.5	25.1
Latin America	15	106.8	21.9	52.7	54.0
Asia	22	26.4	16.3	18.7	7.7
Europe	5	30.6	12.1	15.2	15.4
Oceania	3	44.9	18.9	18.6	26.2
Weighted average	***58***	***58.7***	***17.3***	***31.7***	***27.0***

By region, the lowest of the real cost overruns are found for the 22 dams built in Asia, averaging only 7.7 percent over those projected. The experience of Asia is in contrast to that of Latin America, where the real costs are on average 54 percent greater than initial estimates, with a cost overrun 7 times that estimated for the Asian region. Except for Chile, every country in Latin America has witnessed very high real cost overruns.

The average real cost overrun computed for the hydropower projects implemented in Africa is 25.1 percent of estimated cost, while for Oceania the error is 26.2 percent for a smaller sample of projects. For projects in Europe, the average error of real cost estimates is 15 percent.

It is clear that the project managers and consultants associated with the planning of these projects have greatly underestimated both the average magnitude and the range of physical contingencies required by these dam projects. Clearly the uncertainty in the estimation of costs by engineers has led to a very significant downward bias in the estimated costs as compared to actual experience. The pattern of results across the regions, when compared to those of the Asian region, shows that there is room for learning that could help to improve the cost performance of hydropower dams to be implemented in other regions, particularly Latin America.

Furthermore, Table 2 shows that the projects implemented in Latin America have suffered more from inflation than those in other regions.

Table 3. Incidence of cost overrun by size of installed capacity

Size: installed capacity (MW)	Number of Projects [1]	Actual real cost growth as percentage of estimated real cost (%) [2]	Estimated physical contingencies as percentage of estimated real cost (%) [3]	Real cost overrun as percentage of estimated real cost (%) [4]	Nominal cost overrun as percentage of estimated real cost (%) [5]
0–99	17	40.8	10.7	30.1	47.1
100–299	12	33.3	10.5	22.8	40.5
300–699	13	23.2	9.1	14.0	29.5
700–1,499	8	36.5	10.2	26.4	51.2
1,500 and above	8	42.1	9.7	32.4	76.5
Weighted average	***58***	***36.8***	***9.8***	***27.0***	***58.7***

Table 3 shows the results of the analysis of data for the incidence of cost overrun by size of electricity capacity installed (MW). There is no simple direct relationship between the degree of cost overrun and the size of a dam’s capacity. What is observed, however, is that projects of extreme size, such as very small hydro projects with installed capacity below 100 MW and very large ones that are above 1500 MW, have not performed well in terms of cost planning. Table 3, column 4, shows that the very small projects on an average had, by the time of completion, cost overruns of 30.1 percent of real cost estimates at appraisal. Similarly the large projects had average real cost overruns of 32.4 percent.

Projects in the medium-sized category of installed capacity (300–699 MW) seem to have better estimates at appraisal, with relatively lower real cost overruns of 14 percent on average of the real cost estimates during planning. Physical contingency estimates do not differ much for the various size categories: physical contingency estimate is about 9–10 percent of real cost estimates. This shows evidence of a common methodology used by the World Bank in estimating contingencies.

Table 4. Comparison of cost overruns for different periods

Projects completed	Number of projects	Estimated physical contingencies as percentage of estimated real cost (%) [1]	Real cost overrun as percentage of estimated real cost (%) [2]	Estimated price contingency as percentage of estimated real cost (%) [3]	Actual price escalation as percentage of estimated real cost (%) [4]	Nominal cost overrun as percentage of estimated real cost (%) [5]
Before 1987	29	9.8	21.5	16.2	33.6	55.1
After 1987	29	9.9	39.3	19.6	27.4	66.7
Weighted average	***58***	***9.8***	***27.0***	***17.3***	***31.7***	***58.7***

Table 4 compares the cost overrun estimations for the 29 hydropower dams that were included in the data set used by Bacon et al. (1996) and completed prior to 1987 with the measured cost overrun of dams completed between 1987 and 2005. This is a case in which there is little evidence of learning by doing. While the estimated average physical contingencies for both set of dams were identical at 9.8 percent, the actual cost overruns in the later set were about 80 percent higher than in those sets that were included in the Bacon study (Table 4, column 2).

At the appraisal stage, an average of 17.3 percent change in price level is projected for the 58 projects selected for this study. The actual results show that there was a 31.7 percent change in nominal costs owing to price escalation. Taking into account the error between the estimated price contingency and the actual price escalation, expressed as a percentage of estimated real cost, the cost overrun that is due to inflation is computed to have averaged 14.4 percent. When three extreme outliers[6] were excluded from the results, the average error that is due to the inflation forecast was only 2 percent. This reveals that the inflation forecast for cost projections in the World Bank projects have not in most cases been systematically biased. Errors in the forecasting of prices, however, are a significant source of risk when planning the financing arrangements of projects.

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[6] All the outliers were identified from the Latin American region (Yacyreta Dam, completed in 1990 in Argentina; Paulo Afonso, completed in 1984 in Brazil; La Fortuna HPP, completed in 1984 in Panama). Individually, these projects had nominal cost overruns above 120 percent and cumulative price escalations exceeding 70 percent of initial cost estimates.

3.2 Findings on time overruns

Of the dams in this study, 58 percent experienced time overruns, with an average time overrun of 12 months, or 16 percent of the scheduled completion time for the project[7]. The overall net cost of the time overrun was 3.5 percent of the estimated real construction cost of these dams (Table 5, column 7). This cost could have been avoided if there had been no delays in constructing these dams. In Africa, 9 out of the 13 projects implemented in the region had experienced significant time overrun. The average overrun was 16.3 percent of the estimated construction schedule at appraisal stage, and the cost of time overrun to the society averaged 8.4 percent of the estimated real cost of the project. In Latin America, time overruns occurred for 11 out of the 15 projects covered by this analysis. The average time slippage was 17 months, or 23 percent of the estimated construction schedule, at a cost of 4.4 percent of the estimated real cost of the projects.

Projects implemented in Asia showed better implementation performance than the other regions. The construction schedule estimates at appraisal were relatively more realistic. With an average construction schedule length of 89 months there was an average delay in completion of only 8 months. Of the 22 projects implemented, only 11 had significant time overruns, the cost of time overruns amounting to 1.9 percent of the estimated real cost of the projects.

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[7] This is the weight-adjusted average of installed capacity for each project to the total installed capacity for all the projects in this sample.

Table 5. Incidence and cost of time overruns across various regions

Region	Number of projects [1]	Number of projects with time overrun [2]	Average capacity (MW) [3]	Scheduled (months) [4]	Slippage (months) [5]	Average time overrun (%) [6]	Cost of time overrun (%) [7]
Africa	13	9	113	62	10	16.4	8.4
Latin America	15	9	873	79	17	23.2	4.4
Asia	22	11	783	89	8	10.2	1.9
Europe	5	4	673	78	18	22.6	7.3
Oceania	3	1	39	57	7	14.4	0.3
Weighted average	***58***	***34***	***610***	***83***	***12***	***16.3***	***3.5***

The cost of time overrun is measured for projects that had actual time of construction exceed their schedule by more than six months. Out of the total sample, 24 projects had no delay beyond six months, so we assumed that there is no cost of time overrun for this set of projects.

For a small sample of 5 projects in Europe, the average time overrun was 18 months, or 22.6 percent of the estimated construction time during planning. The net cost of not making electricity available as scheduled was 7.3 percent of the estimated real cost. Of the 3 projects constructed in Oceania, only 1 had a substantial delay in construction time of 26.9 percent of time planned for its completion. When averaged for the region, time overrun was estimated to be 14.4 percent, and the associated cost to society of this overrun averaged 0.3 percent of estimated real cost.

In addition to our findings on the severity of time overrun across regions, an investigation was conducted to determine whether the bias in the estimated time for constructing these projects varied by size of dam. Table 6 gives a summary of the variations between the scheduled length of construction and the actual completion period of projects, distributed according to size of the project.

Table 6. Distribution of the net social cost of time overrun by size

Size: installed capacity (MW)	Number of projects [1]	Scheduled (months) [2]	Slippage (months) [3]	Average time overrun (%) [4]	Cost of time overrun (%) [5]
0–99	17	61	12	25.4	1.0
100–299	12	59	14	23.4	7.6
300–699	13	69	16	22.0	5.0
700–1,499	8	84	19	25.3	0.5
1,500 and above	8	92	8	8.7	4.1
Weighted average	***58***	***83***	***12***	***16.3***	***3.5***

Table 6, column 4, shows the time overrun across the various sizes of hydropower projects. While average the time overrun of this set of dams was 16.3 percent of the scheduled time, there was a wide difference between the 8 large dams (> 1,500 MW capacity), which had only an 8.7 percent time overrun, and the remaining 50 dams, which had an average time overrun of 24 percent of the initial scheduled time for completion. In terms of the costs of the time overruns, the highest costs of 7.6 and 5 percent were incurred by dams of 100–299 MW and 300–699 MW in size, respectively.

Table 7. Comparison of cost of time overruns for different periods

Projects completed	Number of projects	Average capacity (MW) [1]	Scheduled (months) [2]	Slippage (months) [3]	Average time overrun (%) [4]	Cost of time overrun (%) [5]
Before 1987	29	402	77	16	20.2	9.5
After 1987	29	817	87	11	14.4	0.5
Weighted average	***58***	***610***	***83***	***12***	***16.3***	***3.5***

In the earlier study by Bacon et al. (1996) it was found that the average slippage in the actual construction length of hydropower projects was 28 percent of the time scheduled. In Table 7 a comparison is made between the 29 dams completed prior to 1987 and those completed after 1987. The difference in performance is striking. For the earlier period the slippage in schedule was 16 months, or a time overrun of 20.2 percent, while in the latter period the slippage was 11 months, or 14.4 percent. This same pattern carries over into the calculation of the costs of the time overruns, which were 9.5 percent for dams built in the earlier period, but were reduced to 0.5 percent for dams built after 1987. This is evidence that planning methods for the implementation of hydropower projects financed by the World Bank have improved significantly over the last two decades of the period of this study.

The estimated economic cost of time overruns in these results are relatively small compared to the magnitude of the real cost overruns. While the extension to the implementation schedules for the completion of the dams may be significant in terms of calendar months, the real costs imposed by these delays is only 3.5 percent of the initial real cost estimate for the projects. These estimates include the impact of the delay on both the PV of construction costs and the PV of the increased running costs of the electricity system as it tries to make up for the loss in electricity generated by the dams as a result of the delay.

3.3 Findings on net benefits of hydropower dams

The discrepancy between the appraisal and the actual rates of return of dams in this study is analyzed based on the ‘avoided cost’ methodology for the generation of electricity. Here, the economic benefits of the hydro dams are measured as the cost savings that would have been incurred to generate an equivalent amount of electricity with a similar load factor with a configuration of single-cycle or combined-cycle thermal technologies. The rates of return of this portfolio of electricity dams are estimated twice. First, we estimate the ex-ante rates of return, which are based on the estimated construction costs of the dams at the time of appraisal. Second, the rates of return are calculated based on the actual construction costs of the dams. The results are presented in Table 8 by the region in which the dam is located, and also in Table 9 by the installed capacity (MW).

This method of estimating the benefits of hydro dams ignores all the other benefits that some of the multipurpose hydro dams might also be providing, such as irrigation, flood control, and recreational services. In some instances, these benefits are quite substantial (World Bank

OED, 1996). Perhaps even more importantly, this analysis does not attempt to evaluate the economic value of the reduction in GHG emissions as a consequence of the implementation of these projects[8]. Considering the above factors alone, the estimates made here will tend to be minimum estimates of the benefits associated with these projects. Conversely, there are ongoing environmental costs associated with some of the dams that are not included in this analysis of the economic costs of the dam.

In the context of this study, the internal rates of return are the discount rates at which the benefits estimated for the dams over the operating life of the projects are equal to the actual costs of the dams. The difference between the estimated ex-ante and ex-post rates of return is directly associated with the magnitude of the cost overruns that are included in the estimated ex-post rates of return. Intuitively, the systematic pattern of errors in cost projections identified in the study would suggests that the ex-post rates of returns are more likely to deviate significantly below their estimated ex-ante values.

The quantities and load factor of the electricity generated by each hydro dam are those projected at the appraisal stage[9]. Any loss of output that is due to delays in the dam completion is accounted for in the analysis. When the dam is delayed, the benefit projected profile is shifted to the period when the dam actually starts operation. Hence, the benefits of the dam will have a lower PV. To better understand the impact of possible shortfalls in actual power generation on the outcome of our analysis, we perform a sensitivity analysis for the level of energy output. The benefits of the individual dams – that is, the cost savings from not employing the replacement plant – are estimated using actual data for HFO price that

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[8] The analysis does not include additional benefits that are due to the alleviation of unplanned outages or an increase in new connections, since those benefits could potentially be realized from the additional electricity generated by either the dam facility or the thermal plants.

[9] Evidence from the World Commission on Dams Case Studies has shown that the power outputs of dams have performed close to what was planned for stations where the designed plant capacity is not altered at completion, and in some cases, the annual power generated surpassed expectations (see Aylward and Berkhoff, 2001, p. 31).

correspond to each of the years the hydro power plants have been operating to date. For periods beyond 2014 to the end of the hydro dams' life cycle (40 years), the HFO price is assumed to be fixed in real terms at US$ 89 per barrel; results are then simulated for different future fuel price scenarios[10].

For the range of dams examined in this study, the average ex-ante rate of return estimated at the time of appraisal for the whole portfolio of 58 dams is 20.1 percent, while the ex-post average rate of return is 14.3 percent (Table 8, row 6, columns 6 and 7, respectively). This reduction of 5.8 percentage points reflects the 27 percent average cost overrun. The PV of the net benefits evaluated as of 2014 (expressed in terms of the 2014 price level) amounts to US$ 505 billion. This value of net benefits represents a very substantial contribution to the wellbeing of the countries in which these dams are located.

Table 8. Estimated vs. actual Economic Internal Rate of Return (EIRR) according to region

Region	Number of dams	Total capacity installed (MW)	PV of estimated costs @ 10% (US$ million, 2014)	PV of actual cost (US$ million, 2014)	PV of benefits @ 10% (US$ million, 2014)	Net PV of hydro @ 10% (US$ million, 2014)	Ex-ante EIRR (%)	Ex-post EIRR (%)	Number of projects with projected negative NPVs	Number of projects with actual negative NPVs
Africa	13	1,468	91,594	115,365	126,881	11,516	14.40	11.08	7	10
Latin America	15	13,092	351,804	578,200	832,454	254,253	24.30	14.39	1	6
Asia	22	16,500	228,245	258,907	441,715	182,808	16.70	14.95	6	8
Europe	5	3,088	83,343	93,186	152,220	59,034	17.72	16.26	0	1
Oceania	3	116	7,878	9,828	8,053	-1,775	10.26	7.86	2	3
Total	58	34,264	762,865	1,055,486	1,561,323	505,837	20.10	14.28	16	28

The distribution of the results by region is shown in Table 8 in terms of rates of return and PVs expressed in 2014 dollar prices. The 13 dams constructed in Africa, representing about 1.5 GW of installed capacity, have produced an economic net benefit of about US$ 11.5 billion for the region. The ex-post EIRR for the subgroup is 11.1 percent, falling slightly below the rate of return at the time of the appraisal, which was estimated to be 14.4

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[10] The results of sensitivity analysis for future fuel price are not included in this paper because the findings from this study are not particularly affected by the volatile fuel price, since most of the benefits that are affected come at very late periods in the operating cycle of the dams, which, when discounted, become quite insignificant. For instance, at the worst-case fuel price scenario of US$ 66/bbl (25 percent less than the 2014 price of US$ 89/bbl), the actual EIRR is only reduced to 14.21 from the 14.28 percent estimated for the base case. The best-case future price of fuel is set at US$ 110/bbl (25 percent above base price), and the result for actual EIRR increase to 14.34 percent.

percent. After incorporating the cost overruns, none of the dam projects built in Oceania seem economically justified by their electricity-generation benefits alone[11].

For other regions, the 15 dams built in Latin America represent about 13 GW of installed capacity. For this sub-sample, the ex-ante EIRR was estimated at 24.3 percent, but the ex-post results show that the actual EIRR generated by the projects is 14.4 percent on average. The large deviation between the ex-ante and ex-post EIRR for the region is explained by the high magnitude of real cost overruns. Notwithstanding the high level of overruns, overall, the dam investments have contributed a net economic gain of US$ 254 billion to the region. The deviations between the ex-ante and ex-post EIRR were moderate for Asia and Europe regions. The 16.7 percent ex-ante EIRR estimated for Asia turned out to be 15 percent ex post, and a total of US$ 183 billion worth of net gains are expected to be realized in the region by the end of the operating life cycle of the dams.

Of the 22 hydropower dams financed in Asia by the World Bank over the period of this study, 8 were built in China. They will have contributed, by the end of their economic life, up to US$ 160 billion of net surplus to the economy of China (in 2014 PV terms). Most of these dams constructed in China have faced major resettlement challenges and the cost overruns are mainly due to increases in the population resettlement budgets. The magnitude of the overall cost overruns have been reduced substantially by cost underruns in other components of the construction cost estimates. The dams implemented in China performed well in terms of both cost containment and net benefits. The average rate of return that was predicted at appraisal to be 24 percent was in fact an actual rate of return of 22.7 percent.

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[11] For some of the countries, like those in Oceania and some landlocked African countries, the margin on imported fuel above the international spot prices is likely to be significantly more than the 20 percent used for the estimation of the benefits. For instance, the refining and transportation margins for imported fuel in Cape Verde have been estimated to be about 50 percent above the price of crude oil (Salci, 2014).

Table 9. Estimated vs. actual EIRR according to size of installed capacity (MW)

Size: installed capacity (MW)	**Number of dams**	**Total capacity installed (MW)**	**PV of estimated costs (US$ million, 2014)**	**PV of actual cost (US$ million, 2014)**	**PV of benefits (US$ million, 2014)**	**Net PV hydro (US$ million, 2014)**	**Ex-ante ERR (%)**	**Ex-post ERR (%)**	**Number of projects with projected negative NPVs**	**Number of projects with actual negative NPVs**
		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
0–99	17	926	76,263	96,430	61,301	−35,129	7.9	6.24	12	17
100–299	12	2,231	107,587	128,920	151,746	22,826	14.2	11.80	3	5
300–699	14	5,914	177,414	232,120	278,238	46,118	15.9	12.04	1	5
700–1,499	8	8,850	124,632	175,441	290,269	114,829	20.3	15.62	0	1
1,500 and above	7	16,342	276,969	422,575	779,768	357,193	25.2	17.68	0	0
Total	58	34,264	762,865	1,055,486	1,561,323	505,837	20.1	14.28	16	28

The PVs of the net benefits are reported in Table 9, column 5, according to the size of the installed capacity of the dams. The results show that the internal rates of return of the dams (column 6) increases by the size of generating capacity of the dam. Larger dams produce the bulk of the benefits and have relatively higher rates of return on their investment outlays[12].

3.3.1 Sensitivity of net benefits of the dams to choice of discount rates

Given that hydro dams are capital intensive, with the majority of their costs coming as up-front capital outlays, while the benefits are to be realized in later periods of the project's life cycle, the net benefits are quite sensitive to choice of discount rates. Table 10 shows that the cumulated net benefits of the dams covered by this study increase from US$ 505 billion to US$ 535 billion when the 8 percent rate of discount is applied, and are significantly reduced to US$ 386 billion when the 12 percent rate is applied. Even at the 12 percent rate of discount, a value of US$ 386 billion is still a substantial net economic gain from this portfolio of dams.

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[12] The cross-effect of regional distribution and size of dams in our dataset is not considered in the distribution of the net benefits calculated in this study.

Table 10. Sensitivity of net benefits to choice of discount rates (US$ million, 2014)

Discount rate	**PV of estimated costs**	**PV of actual costs**	**PV of benefits**	**Net PV of hydro**
8%	437,812	599,927	1,135,644	535,716
*10%	762,865	1,055,486	1,561,323	505,837
12%	1,330,683	1,856,622	2,243,257	386,635

*base rate

4.0 Conclusions and policy implications

While there is much evidence to show that the construction costs and time scheduled for the completion of dam projects are commonly underestimated at the time of appraisal, the results of this study support the view that this portfolio of dam investments is, as a whole, economically worthwhile. This study finds that about 78 percent of the dams incurred construction costs above their initial estimates. Weighted according to the capacity of the project (MW), the real cost overruns for this portfolio of dams are estimated to be 27 percent. These results are entirely consistent with the previous studies of the real cost overruns of dams.

This study also provides some evidence that, despite the World Bank's long history of concern and research into this issue, its ability to forecast the escalation of real costs has not greatly improved. Given the high standard deviation of the rates of real cost overruns across the dams, it would appear that there are many unknown elements of cost at the time of appraisal which might require considerable expenditures to be incurred in order to obtain more accurate information. While contingencies for real cost escalation are made by the World Bank project appraisers, there does not seem to be sufficient information available at the time of appraisal to link the value of the contingencies closely to the likely incidence of the real cost overruns.

In this study the cost of time overruns is estimated in terms of the alternative generation costs of the electricity not supplied by the project owing to the delay in completion of the dams.

Although these costs are positive, at 3.5 percent of the initial real estimated cost of the dams, they are not nearly as significant as the underestimation of the real costs of construction. In fact, there were no time overruns in 41 percent of the dams, while 78 percent of the projects had real cost overruns.

Nevertheless, the magnitude of failure in cost projections has not prevented these dams, in the vast majority of cases, from being economically beneficial investments. Aggregated over the portfolio of 58 dams, the economic NPV of the set is at least US$ 505 billion.

If the dams had not been constructed, the economic cost of generating and supplying an equivalent amount of electricity to these societies would have been much greater than the actual cost of the hydropower dam projects. Thus, the notion put forward in the literature that hydro dams should not be built because they suffer from cost overruns (Ansar et al., 2014; Sovacool et al., 2014) does not necessarily hold when the benefits of the dams are also brought into the assessment. For example, the Itumbiara Power Project in Brazil had an actual cost that was almost double the estimated cost at the time of appraisal. The estimated benefit for this project turned out to be twice as much as the actual cost, and four times that of its biased cost estimate. Even if the actual project cost had been estimated correctly at the time of appraisal, it would still have been the preferred choice over an alternative thermal technology.

Enhanced professionalism at the appraisal phase may reduce the errors in projection that are caused by strategic deception, but the reduction of technical difficulties caused by geological and environmental mitigation uncertainties is likely to involve a trade-off between the extra front-end investments that would be required to obtain more accurate information and the possible overruns that will show up during the construction of the dam. Eliminating the artificial bias caused by political interest/strategic deception may not eliminate the inaccuracies in the projected cost of dams.

4.1 Policy implications

The high degree of variability and uncertainty of costs in dam construction raises the question of what improvements in the appraisal and project selection methodology would contribute to better investment decision making. The proposal made by Ansar et al. (2014) using reference class forecasting (RCF) is certainly a promising methodological advancement. The probabilities and magnitude of the cost overruns that are likely to arise with dams of specific types in particular countries should become a central part of a modern project appraisal in such investments.

At the same time, the analyst should also take into consideration the nature of the benefits that a particular dam site is likely to produce. Considering this set of 58 dams as a portfolio, the ex-ante benefit–cost ratio was about 2, but ex post ended up at about 1.5. One could question whether the solar and wind projects that the World Bank has been financing over the past 15 years will, even without cost overruns, prove on an ex-post basis to have as good a track record.

Because the benefits and the costs of every dam differ, and many dams are far from being marginal investments, the analysts and decision makers should also consider what the risks are, on the side of both benefits and costs, before coming to a decision on whether a particular dam is an investment that should be supported.

The few exceptional high-NPV hydro dam projects should not deter investment analysts and decision makers from remaining vigilant in conducting the most realistic assessment of costs and from trying to quantify the risks of both the costs and the benefits. Again following the recommendation of Ansar et al. (2014), small countries can be fiscally destroyed by unexpected cost overruns of large hydro dams unless the expected benefits of the project are so large that they can absorb significant cost overruns. Alternatively, as in the case of Bhutan and Ghana, countries may be able to spread their risks through joint-venture relationships with either neighboring governments or strong commercial partners.

The policy recommendation to be drawn from this analysis is that one should not view all hydro dams as being too risky to undertake. A critical variable is the value of the benefits they will produce, and at what range of costs. If the benefits are large enough relative to the expected costs, such investments can very well be worth the risk. In the case of hydro dams, in addition to the problems of delusion and deception common to many public sector investments, there is the very real technical uncertainty associated with the geophysical nature of the sites. Hence, a realistic assessment of the future benefits of a project is critical in order to assess the magnitude of construction cost risks that can be accommodated.

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