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Should we build more large dams? The actual costs of hydropower megaproject development ☆

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H I G H L I G H T S

- We investigate *ex post* outcomes of schedule and cost estimates of hydropower dams.
- We use the "outside view" based on Kahneman and Tversky's research in psychology.
- Estimates are systematically and severely biased below actual values.
- Projects that take longer have greater cost overruns; bigger projects take longer.
- Uplift required to de-bias systematic cost underestimation for large dams is +99%.

A R T I C L E I N F O

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A B S T R A C T

A brisk building boom of hydropower mega-dams is underway from China to Brazil. Whether benefits of new dams will outweigh costs remains unresolved despite contentious debates. We investigate this question with the "outside view" or "reference class forecasting" based on literature on decision-making under uncertainty in psychology. We find overwhelming evidence that budgets are systematically biased below actual costs of large hydropower dams—excluding inflation, substantial debt servicing, environmental, and social costs. Using the largest and most reliable reference data of its kind and multilevel statistical techniques applied to large dams for the first time, we were successful in fitting parsimonious models to predict cost and schedule overruns. The outside view suggests that in most countries large hydropower dams will be too costly in absolute terms and take too long to build to deliver a positive risk-adjusted return unless suitable risk management measures outlined in this paper can be affordably provided. Policymakers, particularly in developing countries, are advised to prefer agile energy alternatives that can be built over shorter time horizons to energy megaprojects.

1. Large hydropower dam controversy

The 21st Century faces significant energy challenges on a global scale. Population and economic growth underpin increasing demand for energy from electricity to transport fuels. Social objectives of poverty alleviation, adaptation and mitigation of climate change, and energy security present policy makers and business leaders with difficult decisions and critical trade-offs in implementing sound energy policies. Demand for electricity is, for example, slated to almost double between 2010 and 2035 requiring global electricity capacity to increase from 5.2 terawatt (TW) to 9.3 TW over the same period (IEA, 2011). Currently, the de facto strategic response to these big energy challenges is "big solutions" such as large hydropower dams. Are such big solutions in general and large hydropower dams in particular the most effective strategy, on a risk-adjusted basis, to resolve global energy challenges? Might more numerous small interventions be more prudent from the perspective of risk management and maximizing net present value even when they entail somewhat higher per unit cost of production?

Proponents of large dams envisage multiple benefits. A big step-up in hydropower capacity along with a long and varied list of corollary benefits: reducing fossil fuel consumption, flood control, irrigation, urban water supply, inland water transport, technological progress, and job creation (Billington and Jackson, 2006; ICOLD, 2010). Inspired by the promise of prosperity, there is a robust

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pipeline of new mega-dams being developed globally after a two-decade lull. The Belo Monte dam in Brazil, the Diamer-Bhasha in Pakistan, Jinsha river dams in China, Myitsone dam in Myanmar, or the Gilgel Gibe III dam in Ethiopia, all in various stages of development, are unprecedented in scale.

Large dams are, however, controversial because they exert substantial financial costs (World Bank, 1996; World Commission on Dams, 2000). Beyond the financial calculus, large dams have profound environmental (McCully, 2001; Scudder, 2005; Stone, 2011), ecological (Nilsson et al., 2005; Ziv et al., 2012), and social (Bakker, 1999; Duflo and Pande, 2007; Richter et al., 2010; Sovacool and Bulan, 2011) impacts. Stone (2011, p. 817) reports in *Science* that the Three Gorges dam in China is an "environmental bane" that will cost over USD 26.45 billion over the next 10 years in environmental "mitigation efforts". Despite their outsized financial and environmental costs, the purported benefits of large hydropower dams prove uncertain. For example, the World Commission of Dams (2000, p. 30) reported that for large hydropower dams "average [hydropower] generation in the first year of commercial operation is 80% of the targeted value"—a trend of which the recently completed Bakun hydroelectric project in Borneo is an alarming example (Sovacool and Bulan, 2011). Similarly, Duflo and Pande (2007) find adverse distributional impacts of large irrigation dams in India. Winners downstream come with losers upstream yielding a more modest, if any, net economic benefit.

The scale of contemporary large dams is so vast that even for a large economy such as China's the negative economic ramifications "could likely hinder the economic viability of the country as a whole" if the risks inherent to these projects are not well managed (Salazar, 2000). Similarly, Merrow et al. (1988, pp. 2–3) warn that "such enormous sums of money ride on the success of megaprojects [such as large dams] that company balance sheets and even government balance-of-payments accounts can be affected for years by the outcomes". Such warnings are not idle alarmism. There is mounting evidence in civil society, academic research, and institutional accounts that large dams have strikingly poor performance records in terms of economy, social and environmental impact, and public support (McCully, 2001; Scudder, 2005; Singh, 2002; Sovacool and Bulan, 2011; WCD, 2000). There are acrimonious, and as yet inconclusive, debates in scientific literature and civil society about whether large dams are a boon or a curse. Should we build more large hydropower dams? How confident can planners be that a large bet on a large dam will pay-off handsomely?

We investigate these questions with the "outside view" or "reference class forecasting" based on the literature on decision-making under uncertainty that won Princeton psychologist Daniel Kahneman the Nobel Prize in economics in 2002 (Kahneman and Tversky, 1979a, 1979b; Kahneman, 1994) extended and applied by Bent Flyvbjerg and colleagues to infrastructure projects (Flyvbjerg et al., 2003; Flyvbjerg, 2009). We present statistical and comparative evidence from the largest reference class to-date of actual costs of large hydropower dam projects (hereafter large dams unless stated otherwise). We find that even before accounting for negative impacts on human society and environment, the actual construction costs of large dams are too high to yield a positive return. Large dams also take inordinately long periods of time to build, making them ineffective in resolving urgent energy crises. Our evidence pertains primarily to large dams and the results cannot be applied either to smaller dams or other large energy solutions such as nuclear power without first building a separate "reference class" for other types of power generation technologies. Our findings, however, point towards the generalizable policy proposition that policymakers should prefer energy alternatives that require less upfront outlays and that can be built very quickly.

There is no doubt that harnessing and managing the power of water is critical for economies but large dams are not the way to do so unless suitable risk management measures outlined in this paper can be affordably provided. Building on literature in decision making under uncertainty in management, psychology, and planning research, this paper further provides public agencies (e.g. national planning and finance ministries, power and water authorities), private entrepreneurs, investors, and civil society a framework to test the reliability of *ex ante* estimates for construction costs and schedules of power generation alternatives. An impartial and rigorous application of the reference class forecasting methods proposed here can improve the selection and implementation of new investments.

2. Delusion and deception in large hydropower dam planning?

Our approach to address the debates about whether or not to build dams is to incorporate an evidence-based perspective that reflects how decisions among alternative options are actually made and on what basis. Theoretical and empirical literature on decision-making under uncertainty proposes two explanations—psychological delusion and political deception—that suggest decision-makers' forecasts, and hence ex ante judgments, are often adversely biased (Tversky and Kahneman, 1974; Kahneman and Lovallo, 1993; Flyvbjerg, 2003; Lovallo and Kahneman, 2003; Kahneman, 2011).

First, experts (e.g., statisticians, engineers, or economists) and laypersons are systematically and predictably too optimistic about the time, costs, and benefits of a decision. This "planning fallacy" (Kahneman and Tversky, 1979b; Buehler et al., 1994) stems from actors taking an "inside view" focusing on the constituents of the specific planned action rather than on the outcomes of similar actions already completed (Kahneman and Lovallo, 1993). Thus, for example, the estimated costs put forward by cities competing to hold the Olympic Games have consistently been underestimated yet every four years these errors are repeated. Biases, such as overconfidence or overreliance on heuristics (rules-of-thumb), underpin these errors.

Second, optimistic judgments are often exacerbated by deception, i.e. strategic misrepresentation by project promoters (Wachs, 1989; Pickrell, 1992; Flyvbjerg et al., 2002, 2005, 2009). Recent literature on infrastructure delivery finds strong evidence that misplaced political incentives and agency problems lead to flawed decision-making (see Flyvbjerg et al., 2009). Flyvbjerg et al. (2009, p. 180) further discuss that delusion and deception are complementary rather than alternative explanations for why megaprojects typically face adverse outcomes. It is, however, "difficult to disentangle" delusion from deception in practice. Using quasi-experimental evidence from China, Ansar et al. (2013) suggest that while better incentive alignment can help to lower the frequency and, to a lesser extent, the magnitude of biases, it does not entirely cure biases.

Be it delusion or deception, is decision-making in large hydropower dams systematically biased by errors in cost, schedule, and benefit forecasts? What is the risk that costs might outweigh benefits for a proposed dam? While the future is unknowable, uncertain outcomes of large investments can still be empirically investigated using "reference class forecasting" (RCF) or the "outside view" techniques (Kahneman and Lovallo, 1993; Flyvbjerg, 2006, 2008). To take an outside view on the outcome of an action (or event) is to place it in the statistical distribution of the outcomes of comparable, already-concluded, actions (or events). The outside view has three advantages: First, it is evidence-based and requires no restrictive assumptions. Second, it helps to test and fit models to explain why the outcomes of a reference class of