Future DAMS

Design and Assessment of water-energy-food-environment Mega-Systems

The *ex-ante* economic analysis of investments in large dams: a brief history

Dale Whittington[1] & V. Kerry Smith[2]

[1] University of North Carolina at Chapel Hill, USA; Global Development Institute, University of Manchester, UK. Dale_Whittington@unc.edu

[2] Wrigley Global Institute of Sustainability, Arizona State University, USA; NBER and Resources for the Future, USA. Kerry.Smith@cavecreekinstitute.com

FutureDAMS

Working Paper 009

February 2020

ISBN: 978-1-913093-08-2

Cite this paper as: Whittington, D. and Smith, V. K. (2020) The ex-ante economic analysis of investments in large dams: a brief history. FutureDAMS Working Paper 009. Manchester: The University of Manchester.

www. futuredams.org

Abstract

This paper summarizes highlights in the history of the *ex-ante* economic analysis of large dams. We argue that six key developments are especially important: 1) adding systems analysis; 2) incorporating multiple objectives; 3) introducing environmental and social gains and losses; 4) recognizing economy-wide linkages; 5) accounting for non-cooperative behavior; and 6) dealing with uncertainty. We conclude that current professional practice in the *ex-ante* assessment of large dams has not yet caught up with the scholarly literature on these six developments. After that discussion, we consider a small number of *ex-post* analyses of the economic effects of dams and discuss how their results align with what has been called for in *ex-ante* assessments.

Keywords

Large dams as water projects, public investments, cost-benefit analysis

Acknowledgements

We would like to thank Spencer Banzhaf, Ariel Dinar, Jim Hall, David Hulme, Jack Knetsch, Victor Nechifor and Kevin Wheeler for comments on an earlier draft of this paper.

FutureDAMS is a consortium of over 30 researchers developing the knowledge base, tools and approach for designing interventions in systems to support resilient and sustainable development in a warming world. This work was supported by UK Research and Innovation-Economic and Social Research Council [ES/P011373/1] as part of the Global Challenges Research Fund.

Contents

1 Introduction

The construction of large dams evokes strong passions. Proponents see a way to avoid the losses from catastrophic floods and droughts, to improve navigation and to provide hydropower and a controlled water supply for irrigation schemes. Critics see the destruction of ecosystems and indigenous cultures, the loss of free-flowing rivers and cost overruns (Ansar et al, 2014). Individuals from different disciplines line up on different sides of this debate. Engineers typically focus on the benefits; ecologists, sociologists and anthropologists focus on the costs. For decades economists have tried to find a reasoned approach to weighing the benefits and costs of large dams that would bridge this gap between proponents and critics. As described in this paper, this effort by economists has proved complex and challenging, and has achieved only limited success. Of course, the use of cost–benefit analysis to evaluate dam projects is not the first time economic analysis has been in the middle of contentious debates involving large, complex water projects. As Banzhaf (2009) documents, the origins of cost–benefit analysis can be traced to debates about how to inform policy decisions associated with multi-objective water projects. This history helps today's readers appreciate how the tools of cost–benefit analysis evolved and how their perceived shortcomings stimulated new research. We argue that the lessons from analyses of decisions related to building large, new dams are equally relevant for the evaluation of both the current decisions about removing dams (large and small) and large water projects generally.

Although the gap between the views of proponents and critics of large dams shows little signs of narrowing, the effort to improve the *ex-ante* economic analysis of investments in large dams continues. This is in large part because the problem of water scarcity is increasing as population and economic growth place rising demands on limited freshwater resources, especially in the Global South. In North America and Europe, economists' interest in the economic analysis of large dams peaked in the 1950s, when large investments were being made in water storage and related water infrastructure, but then waned as fewer investments were made. In that early research by Eckstein (1958), Krutilla and Eckstein (1958), Freeman (1966), Haveman (1965) and others, water projects served as a platform to consider how public investments designed for multiple objectives should be evaluated. The focus was on alternative methodologies. One school of thought argued that programming methods, with one objective maximised and the others used as constraints on that optimisation, should be used to inform policy. Another argued for cost–benefit analysis using individual willingness-to-pay measures to monetise the changes in all project-related outputs where estimates were available. Those that could not be measured were often gauged indirectly. That is, analysts would consider the rhetorical question – were the benefits (or costs) of the unmeasured outputs large enough to change the net benefits based on what could be measured?

A decade or so after these early contributions, US policy makers' interest in the analysis of dams picked up again, as provisions of a number of statutes – including the Wild and Scenic Rivers Act of 1968, the Endangered Species Act of 1973 and the Clean Water Act of 1972 – were used to consider dam removal as a basis for improving the environmental services associated with river systems. While only 3% of the more than 90,000 dams listed for the US as part of the National Inventory of Dams are owned by federal agencies, the US Federal

Emergency Management Agency's National Dam Safety programme is intended to facilitate collaboration among owners and stakeholders affected by dam removals.[1] Many of the same issues associated with dam construction arise in comparable ways with dam removal decisions. Among them is the need to consider the benefits and costs under 'with-and–without' situations for the dam and the water resource system it affects.[2]

However, in developing countries, where there is little water storage on a per capita basis, the problem of how best to assess the benefits and costs of large dams never really went away (Hall et al, 2014). Although many countries in the Global South were unable to mobilise the capital necessary to construct large dams, as economic growth and globalisation proceeds, opportunities for financing large dams have opened up. These new proposed dam projects in the Global South are being planned and built at a time when climate change is creating even more uncertainties about both future temperature and hydrology.

In this paper we explore the history of the *ex-ante* economic analysis of large dams through an analysis of six key developments that have occurred since the 1950s, in order to address the increasing recognition by economists of the complexity of this endeavour. We conclude that current professional practice in the *ex-ante* assessment of large dams has not yet caught up with the scholarly literature on these six developments. After that discussion, we consider a small number of *ex-post* analyses of the economic effects of dams and discuss how their results align with what has been called for in *ex-ante* assessments of the net benefits of these projects. Current best practice in the application of *ex-ante* cost–benefit methods tries to address a subset of these developments, but there are no case studies or guidelines that an analyst can reference to learn how best to incorporate all six developments in the *ex-ante* appraisal of a new dam. Our assessment of the *ex- post* record suggests a need to reconstruct the measures called for in *ex-ante* evaluations once the dam is built, and to evaluate whether what were anticipated as sources of benefits and costs were in fact realised.[3] This strategy is consistent with the call for designing regulatory policies in ways that assure the information needed for *ex-post* evaluation is available.[4] We thus highlight the need for a new era of engagement by scholars and practitioners with this 'old' challenging problem.

---

[1] See CRS (2019).

[2] Lane (2006) summarises the issues in the US surrounding dam removal, noting that the analyses must be considered case-specific.

[3] Jeuland (2020) makes a related point, noting that "In order to avoid mistakes and improve welfare, more work is needed to systematically understand the economics costs and benefits of dams *as implemented in the real world*, and what conditions tend to raise or lower these costs" (emphasis added).

[4] We need to acknowledge a parallel need in the evaluation of public investments. As Greenstone (2009) argued: "Our goal should be to rigorously evaluate every regulation in order to expand upon the ones that work and weed out the ones that fail to improve our well-being (or worse, harm it). At the heart of such reform is the recognition that we cannot know a regulation's benefits and costs until it has been tested." (p 112)

1.1 Background

About 12,000 years ago, humans gradually began to abandon their hunter-gatherer lifestyle and settle down, first in the Fertile Crescent and China. They domesticated wild grasses and two herbivores, sheep and goats, and started to live in larger, more permanent communities. Our species' interest in civil engineering works to control surface water soon followed. Early water engineers and communities presumably discussed and debated the advantages and disadvantages of dams to store water. The archaeological evidence suggests that many early dams could not withstand large flood events and were swept away (Biswas, 1970). But early societies learned by trial and error and ingenuity what worked and did not work in different hydrological and soil conditions, and made steady progress on the development of engineered solutions to providing water supplies for cities and irrigated agriculture.

In the 19th century British engineers planned and built large dams in both India and Egypt, and increasingly discussed the relationship between water infrastructure and economic development. They often argued about the consequences of what would ensue if dams were built, but there was no agreed methodology for quantifying the costs and benefits of water infrastructure investments. Verbal descriptions of the various outcomes from dam construction were common, and proponents of dams often referred to both financial gains and more intangible social benefits. Looking back at these discussions, there was typically no distinction made between economic and financial analysis of water investments. There was, however, often a qualitative discussion of the counterfactual: what would the future look like without new water infrastructure.

The beginnings of modern cost–benefit analysis can traced back to the writings of the French engineer and economist Jules Dupuit (1804–66) and his interest in the measurement of the 'utility' of public works projects (Ekelund, 1968). Dupuit was the first to identify the principle of marginal utility and the area under the demand curve as the total utility associated with consuming a specific quantity of the good (or service) associated with that demand.[5] Dupuit suggested that these insights could be used for *ex-ante* assessment of the costs and benefits of infrastructure projects such as a bridge and how the utility derived from the bridge varied with tolls of different magnitudes. While his focus was on infrastructure in fairly general terms, he did not specifically discuss the measurement of the costs and benefits of dams.

When the US Bureau of Reclamation began its efforts to build large dams in the arid western parts of the country in the early 20th century, there was still no formal approach for comparing the costs and benefits of large dams, but this began to change. The planning and financing of the Tennessee Valley Authority (TVA) fostered extensive discussion of the multiple benefits of water resources infrastructure (flood control, hydroelectric power generation and water supplies for irrigation). But the concern about the limits of quantification and intangible benefits remained. In 1934 the US Water Resources Committee of the Natural Resources Board wrote of the need to study, "the part played by intangible factors in assessing the costs and benefits of public works projects".

[5] Alfred Marshall later termed the difference between the total area under the demand curve and the amount paid by the consumer as 'consumer surplus'.

The 1936 Flood Control Act stated that the US Army Corps of Engineers was permitted to participate in projects, “if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and security of people are not otherwise adversely affected”. This push from the Us government to conduct *ex-ante* analysis of public investments resulted in the development of more formal methods to actually quantify the benefits and costs of water resources infrastructure.[6]

In 1950 the US Federal Interagency River Basin Committee appointed a Subcommittee on Benefits and Costs. Its report, *Proposed Practices for Economic Analysis of River Basin Projects* (1950), become known in the US as the ‘Green Book’ and it is arguably the first widely available statement on how to conduct *ex-ante* economic analysis of water infrastructure investment projects. The table of contents of the Green Book lays out many (but not all) of the issues and challenges of conducting *ex-ante* cost–benefit analysis of water projects.

The Green Book made three recommendations about how the outputs of water resources investments should be valued. First, the authors argued that market prices should be used when possible. Second, they stated: “Project effects which are ordinarily valued incompletely or not at all in actual exchange processes should be given an adjusted or estimated value in monetary terms”. Third, they discussed types of effect they called ‘intangibles’. These were “effects which it is considered impossible or undesirable to express in monetary terms”. The Green Book recommended that these effects “need to be described with care and should not be overlooked or minimized merely because they do not yield to dollar evaluation”.

Prompted in part by the Green Book’s recommendations, in the 1950s cost–benefit analysis and its application to water projects became an active area of academic research. One of the earliest and most influential academic contributions was *Water Resources Development: The Economics of Project Evaluation* (1958), a book resulting from Otto Eckstein’s PhD thesis in 1955. Eckstein elaborated on the distinction between economic and financial analysis of investments and introduced a clear definition of the concept of economic benefits as based on an individual’s willingness to pay. By summarising the assumptions required for the use of alternative cost as a measure of benefits, he helped link the practical compromises needed to implement cost–benefit methods to the economic logic required to assure that these methods offered a signal of whether investments represented changes consistent with a more efficient allocation of public resources. Krutilla and Eckstein (1958) also discussed the relationship between the conditions for an efficient allocation of resources and the cost–benefit criterion. This study reviewed a series of water resource projects demonstrating how the logic needed to be adjusted to meet the special circumstances of each application. While the Krutilla and Eckstein study is usually cited for its discussion of discounting, their treatment of the unstated assumptions in the cost–benefit logic offers continuing insights for current applications.

[6] See Banzhaf (2009) for a discussion of the debates associated with the use of programming methods versus benefit–cost analysis to consider multi-objective projects.

Eckstein followed the lead of the authors of the Green Book on how to handle 'intangible' consequences of water projects, noting that:

> There have been many attempts to measure the benefits of recreation. Since people actually hire the use of recreation facilities, one might expect that one could find prices that would measure willingness to pay. When a dam creates a lake, agencies look to the total expenditures which people make on swimming and fishing … But these expenditures are for travel, equipment, lodging, and so forth, and are not expenditures of the lake. A proper measure of benefits would be to indicate how much managers of the lake could collect in user charges; since there are no charges for the use of the reservoir … appropriate prices cannot be found … *Such purposes of water projects as recreation must be judged on other criteria, for the use of benefit-cost analysis for them not only is invalid, but casts doubt and suspicion on procedures which can effectively serve a high purpose where they are appropriate.* To assure proper consideration of such immeasurable outputs, an analysis of intangible benefits and costs should be part of every project report … *Verbal discussion of intangible benefits and costs will communicate the facts to Congress more clearly than invalid benefit estimates*. Relevant figures may be submitted without forcing them into the benefit–cost framework; for example, recreation benefits of a project can be described in terms of expected use. (Eckstein, p 41, emphasis added)[7]

It is not clear whether Eckstein was aware of Hotelling's (1947) proposal to the Director of the National Park Service that outlined the logic for using travel costs to estimate recreation demand some eight years before his thesis was completed. Equally importantly, shortly after *Water Resource Development* (1958) was published, Clawson (1959) independently developed the travel cost method and illustrated how it could be used in practice.[8] More generally, while Eckstein acknowledged that water projects produced both private and public goods, he did not appreciate the potential for using revealed preference methods to estimate individuals' willingness to pay for increases in public goods. Instead he argued that Samuelson's (1954) arguments precluded solving the valuation of public goods, and thus required that all intangibles be relegated to the status of unquantifiable changes that needed to be acknowledged outside the formal logic of a cost-benefit analysis. He observed that:

> P. A. Samuelson has shown that there is no general solution to this problem [measuring individuals' values for collective or public goods], and that no voting or interviewing scheme can be devised which will elicit truthful responses about the marginal utility of a collective good. (p 74)

He also highlighted the importance of how the treatment of the counterfactual, or what would happen if the dam was not built, a previously qualitative discussion as we noted earlier, had quantitative impacts. Eckstein labelled the issue the 'with-and–without' principle, where two

---

[7] Although Otto Eckstein was very sceptical of assigning monetary values to 'intangibles', two of his graduate students at Harvard (Robert Davis and Jack Knetsch) made seminal contributions to the field of nonmarket valuation. In his PhD dissertation, Robert Davis did the first application of the contingent valuation method, estimating the economic value of recreational hunting in Maine. For his PhD dissertation Jack Knetsch carried out the first hedonic property value study to estimate recreational benefits, and went on to make major contributions to the travel cost method, state preference techniques, and behavioral economics. Both Davis and Knetsch completed their dissertations in 1963 and published their research in 1964.

[8] Marion Clawson had not seen or heard about Hotelling's original letter before he and Jack Knetsch published *Economics of Outdoor Recreation* in 1966. (Jack Knetsch, personal communication.)

hypothetical situations were being compared. This comparison is not the same as a before versus after analysis. He made clear that it recognises that each action causes a reallocation of resources and should be analysed recognising these differences. While he and other authors at the time acknowledged that the counterfactual seemed clear enough at least for some project outcomes of interest to policy makers, they limited their analysis to the conceptual questions associated with when general equilibrium (GE) issues would arise. Their arguments assumed that the interventions being considered were small in relation to the overall economy. Formal analysis of the GE effects of an investment or a new policy was omitted. It was enough to suggest that, if the dam was built, hydropower would be generated for many years into the future; without the dam, hydropower would not be generated. If the dam was built, flood damage would be reduced; without the dam, flood losses would continue.

But a full recognition of the ‘with-and-without’ principle as part of the *ex-ante* cost–benefit analysis of water projects required that the analyst make assumptions about the counterfactual far into the future, and that alternative development paths without the proposed water resources investments be possible. Even within a static analysis for large projects, we now recognise that the difference between partial and GE measures of benefits and costs is simply an example of the cascading effects of different resource allocations. Equally importantly, many large water resource development projects require large infusions of capital that could have been invested in other economic development projects. Accounting for the opportunity cost of these public funds was a central concern for the creation of a proper counterfactual. Of course, depending on how we define these opportunity costs, consideration needs to be given to how the financing of public debt affects private investment.

Since these beginnings of the use of economic techniques for the evaluation of water investments in the 1950s, there have been six significant developments. We now briefly describe each of these methodological developments in order to bring us up to date on the ‘state of play’ and where advances in current practice are needed.

2 Development 1: adding systems analysis

The application of systems analysis techniques to the planning of water resources projects transformed the economic analysis of such investments by making the forecast of project outcomes much more accurate. Major insights into the application of a systems approach were described in a seminal contribution in this field published in 1962 and entitled *Design of Water-resource Systems : New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning* (Maass et al, 1962). In that volume the authors discussed how water resource investments, including dams, could be designed, built and operated to maximise net economic benefits. Systems techniques enabled economic analysts to much more accurately incorporate the interdependences between different infrastructure investments on a river, as well as the actual operation of dam managers who faced a stochastic hydrology. The problem framework developed by Maass et al has remained a focus of both researchers and practitioners for the last half century.

With the astonishing increases in computing power over the past five decades, both the simulation and optimisation modelling approaches described by Maass et al have been further developed and extended in many different directions, including geomorphology and sedimentation, fisheries and water quality. These various systems models are now essential tools deployed by managers of large rivers around the world for both planning and operation. Numerous developments in systems tools increased the ability of water resource planners to accurately portray the behaviour of the interactions between a river's hydrology and infrastructure, and thus indirectly improved economists' ability to estimate economic outcomes from dams.

As we noted at the outset, in the early days of developing the research associated with project evaluation, the programming or systems approach was viewed as an alternative to cost–benefit analysis. Banzhaf (2009, p 8) explained the issues raised by some of the economists from the Harvard Water Program who contributed to the Maass et al systems approach, noting that they argued: "economists simply are not in the position to collapse multiple objectives into a scalar function. Together with engineers, they can only make the tradeoffs known to decision makers." However, economists were active in the development of one class of systems models: hydro-economic models (Whittington et al, 2005; Harou et al, 2009). Building upon the early work of Maass et al (1962), these optimisation models combined economic objective functions with constraints imposed by infrastructure and hydrology. Solutions were often presented in terms of economic benefits that could be obtained from the construction and operation of water infrastructure investments. Hydro-economic models also extended the systems representation to include the actions of economic agents, notably farmers.

Systems analysis made another important contribution to the economic analysis of water projects. The modelling approach of defining a river basin as a unit of analysis enabled economic analysts to better conceptualise the counterfactual. Systems models enabled analysts to simulate the behaviour of the water resources system with and without the project, and to compare the outcomes in each 'state of the world'. This difference was the change brought about by the project. Of course, many determinants of the 'state of the world' with and without the project were unknown, and thus the change could not be known with certainty.

3 Development 2: incorporating multiple objectives

Despite the detailed discussion of multiple 'outputs' from water projects in Eckstein, and Krutilla and Eckstein, a number of economists (including Eckstein himself, as we noted), as well as the non-economists and decision makers, were not convinced that the economists' approach to valuing the benefits and costs of water resources investments fully captured all the issues that were of most concern for public sector decisions. They maintained that the analysis and evaluation needed to reflect more dimensions of the public's interests. In the late 1960s and 1970s, the water resources community turned to multi-criteria or multi-objective approaches to policy evaluation. This shift from the single cost–benefit criterion of maximising changes in human wellbeing to a multi-criteria approach also occurred in the international development field. In 1972 the United Nations Development Programme published a handbook with guidelines for the appraisal of development projects in low-income countries that explicitly advocated a multi-objective approach (Dasgupta et al, 1972).

By 1977 the American Geophysical Union had published a monograph by David J Major entitled *Multiobjective Water Resource Planning* that laid out the arguments for adding other, noneconomic metrics to an *ex-ante* evaluation of water resources investments (Major, 1977). The following year, Jared Cohon (1978) published a textbook, *Multiobjective Programming and Planning*, which introduced a generation of engineers, economists and planners to multi-objective optimisation methods and planning techniques. An early, seminal application of multi-objective planning in the water resources sector was a project undertaken at the Rand Corporation in Santa Monica, CA on water resources investments in The Netherlands (Goeller et al, 1983).[9]

Proponents of multi-objective analysis typically did not argue to exclude the economist's welfare-theoretic objective of economic efficiency. Rather, they simply wanted other objectives, such as social justice, distributional equity, health and environmental quality included as stand-alone objectives important in their own right. From one perspective, the argument for the use of multi-objective planning methods to evaluate water resources investments was a continuation of Otto Eckstein's argument that important intangibles could not be quantified and were best incorporated with other metrics (eg his proposal for verbal descriptions). But a different line of argument came from decision theorists: that real-world policy makers thought in terms of tradeoffs between multiple objectives, and would make better decisions if a framework presented this information on water resources projects in quantitative terms to them (Zelleny, 1982). Of course, as Banzhaf (2009) observed, the tradeoffs displayed in the solutions to these large-scale programming problems simply reflected how the constraints introduced to accommodate these other concerns reduced the region of feasible choices, or how 'soft constraints' were introduced as modifications to the objective function. This reduction in the space for feasible solutions then affects the realised value of the objective function. So, to interpret the tradeoff measures, we need to consider both how the weights of the various criteria are defined in the overall objective function and how the added criteria are represented in each specific constraint.

Multi-attribute utility theory tried to bridge the gap between proponents of multi-objective (or multi-criteria) analysis and benefit–cost analysis (Keeney & Raifa, 1993), but the debate between the two approaches continues to the present. Many systems analysts, decision theorists, planners and engineers find multi-objective frameworks intuitively appealing. Increasing computation power has made the depiction of tradeoffs between multiple objectives in the design and operation of complex systems much easier than was the case in the past. Somewhat ironically, today many development and behavioural economists themselves focus on other outcome indicators when evaluating public investments (eg measures of the effects on the distribution of household income, effects on the pace or pattern of regional economic growth, health effects measured as physical outcome such as

---

[9] The Goeller et al work was intended to be a summary of a project initiated by the Rand Corporation with the agency in The Netherlands responsible for water projects and public works. This effort, designated the Policy Analysis for Water Management in The Netherlands (PAWN), began in August 1976 and led to a number of reports; it was recognised well before the Goeller summary became available.

changes in mortality or morbidity for the elderly or young children) rather than on benefit measures consistent with the basic welfare-theoretic logic that seems to have started the systematic analysis in the first place. Indeed, proponents of cost–benefit analysis approaches working on the *ex-ante* evaluation of water investments often find themselves arguing for the inclusion of an economic efficiency objective in part because no one else is.

4 Development 3: incorporating environmental and social losses

Early economic analyses of multipurpose dams typically focused on five main benefits: 1) hydroelectric power generation; 2) water supply for irrigation, industry and cities; 3) flood control (usually described in terms of reducing flood losses); 4) improved navigation; and 5) recreational benefits associated with reservoirs. Rarely were the environmental and social losses associated with dam projects treated with the seriousness they deserved. The development of the field of modern environmental economics changed the playing field for the economic analysis of water infrastructure projects by developing methods for measuring (and later 'transferring' from existing studies) monetary values for the environmental and social losses previously considered to be 'intangibles'. One of the single most important changes, highlighted by Krutilla (1967), was the recognition that preserved environments had an economic value. Indeed, a simple change in the vocabulary used in describing the status of water resources, from 'developed versus undeveloped' to 'developed versus preserved' captures the implicit bias in the earlier perspective.

Before 'environmental and resource economics' became recognised as a field of study in economics, there was a field called 'recreational economics', where practitioners attempted to measure monetary values for fishing, hunting, sightseeing and boating activities. The travel cost and contingent valuation methods were all first developed to measure recreational benefits. Early applications of these nonmarket valuation techniques often focused on the recreational benefits of water resources development projects. At the same time that Eckstein was arguing that 'proper prices could not be found', Marion Clawson and Jack Knetsch were demonstrating how the travel cost method could solve some of the problems that Eckstein had posed (Clawson & Knetsch, 1966).

The travel cost method is now taught in environmental economics and management courses throughout the world, and there have now been hundreds of applications (Phaneuf & Smith, 2005). Of course, when we consider a new reservoir, the recreational benefits that the site is likely to generate are unknown. They must be estimated from the information available about the use of existing sites. When considering a new site, the research question must recognise that benefit measures need to be 'transferred' or adapted using the existing benefit estimates for other comparable sites so that they fit the specific features of the proposed project. Most of the literature has focused on adapting the estimates for a typical user's willingness to pay for a trip to the new site, and the assignment of these monetary values as a potential user's recreational benefits from that reservoir is now relatively uncontroversial.

There are important issues associated with cross-country transfers. Many of the available benefit estimates are based on applications in developed economies. Studies for developing economies have tended to focus on public health issues related to environmental quality and not on recreation. Those studies that have been done caution that improvements in surface water quality may have only modest economic value for recreational users in developing countries (Choe et al, 1996). As a result, the process of cross-country transfer of benefit measures requires recognition of the context for the services to be valued. In a developed economy setting, the baseline of environmental quality may already meet public health concerns and further improvements would be motivated by their contributions to the quality of the resources associated with recreation. This distinction is important when using a benefit measure estimated in a developed economy setting for a developing economy application. Another potentially important question arises in judging how many users to expect –or 'the extent of the market'- for each new reservoir. This issue has received much less attention and can be a key factor determining whether the estimated benefits exceed the costs.

The development of other nonmarket valuation methods by environmental economists has added to the economists' toolkit for converting Eckstein's verbal descriptions of intangibles into estimates of monetary gains and losses of dam projects. For example, in many locations a key benefit of dam projects is the reduction in risks posed by floods.[10] We now have a choice of strategies – do we adapt the measures of reductions in housing prices resulting from the prospect of flood or storm risks or do we consider the expected reductions in flood-related deaths and in direct damage and repair costs? Both strategies involve what we labelled 'benefit transfers' earlier. The mortality risk approach assumes that estimates of the economic value of reductions in mortality risks (Value of Statistical Life" – VSLs) can be applied to convert estimates of lives saved from reduced flood events into monetary benefit estimates (Viscusi, 1993; Cropper et al, 1994; Hammitt & Robinson, 2011). These estimates of VSLs are based on both stated and revealed preference methods (eg contingent valuation and hedonic wage models) that have been developed since the 1950s.

The wage studies involve risks of death from on-the-job-related hazards, not flooding risk. The surveys used in this context often involve some type of environmental contaminant and a situation where survey respondents are asked to decide about a policy proposed to address it. The hedonic property value studies may involve risks that are assumed to be attributed to properties based on past events, or from information disclosures about locations in a flood plain, or other spatially delineated source of risk that lead to differences in what each homeowner is assumed to recognise when buying a house (see Bin et al, 2008; Gallagher, 2014).

The so-called 'credibility revolution' in applied econometrics has raised expectations of data quality and information used in isolating the effects attributed to these proxy measures. Recently, Bishop et al (2019) have taken stock of the differences between measuring the effects of exogenous events in detailed quasi-experiments and being able to develop a welfare interpretation for the resulting estimates. Overall their assessment is optimistic. Hedonic methods can reveal marginal values for small changes in spatially delineated

[10] However, a side-effect of infrastructure investments that reduce flood risk can also be to induce development closer to a river, thus increasing flood risks of catastrophic damages if levees or flood embankments fail. These types of responses are another type of general equilibrium response to a public investment or regulatory policy. Incorporating them into the *ex-ante* analysis of the investment or policy would require a model that described how locational choices respond to the characteristics of different locations and how these locations might be affected by the intervention. See Kuminoff et al (2013) for a review of the structural models used in the context of modelling residential housing markets.

amenities or dis-amenities. The policy analysis task is how to use them in evaluating proposed water projects. This remains an important area for research. As for the VSL literature, similar questions can be raised about these hedonic studies. Nonetheless, governments routinely publish and use estimates of VSLs in the evaluation of a wide range of government regulations and investments (including water resources investments). Thus, estimates from all three areas – travel cost recreation models, hedonic property and wage models, and contingent valuation – provide examples of how the realm of intangible effects of dam projects has increasingly narrowed as nonmarket valuation methods have been ever more refined and accepted (see the review chapters on each method in Maler and Vincent (2005), and a new graduate text on environmental economics, Phaneuf and Requate (2017)).

The authors of the Green Book recommended incorporating estimates of economic losses into the economic analysis of dam projects:

> Consequential damages are uncompensated losses resulting directly from the development of a project. Even though no compensation may be required or possible, such losses are nonetheless a real part of the project development cost. For example, when lands are flooded to develop a reservoir, there are costs for relocation and reestablishment of the persons and enterprises which are displaced, and local enterprises which do business with people in the project area may have their volume of business and net incomes reduced if people move from the area. (p 32)

Today, psychologists, environmental economists and behavioural economists are developing a much better understanding of how people value losses and gains differently. Specifically, people dislike (suffer from) losses more than they value corresponding gains. When policy interventions impose losses on people, these analysts have found that the individuals involved value these losses more than what a simple expected utility framework would suggest (Kahneman & Tversky, 1979). Others have argued that the discrepancies can be reconciled within a more nuanced model of how people form risk perceptions and how the events at risk are specified to affect an individual's preferences (see Smith and Moore (2010) for a review of the other possibilities). Nonetheless, at this stage the profession seems to have been more accepting of the behavioural economists' arguments. Richard Thaler's 2017 Nobel award for contributions to behavioural economics is one tangible signal. Regardless of who one sides with – the 'behaviouralists' or more nuanced conventional models – this research has definitely raised awareness of the importance of how people perceive their entitlements to open access resources or resources with poorly defined property rights. These issues are especially relevant for the economic analysis of dam projects because they imply an understanding of the conditions affecting whether the economic losses of households that are displaced (and the compensation required to make them whole) are actually much larger than economists initially imagined. This improved understanding of the perceived rights and the sources of discrepancies in what conventional economic models would imply for the values associated with gains and losses means that investments in dam projects may have a much higher economic bar to overcome than Eckstein and others initially envisioned.

As we noted earlier, environmental economists have also advanced our understanding of what should be treated as an 'economic resource' and why people would be willing to pay for its services. Krutilla's (1967) seminal paper in the *American Economic Review*, 'Conservation reconsidered', introduced the concept of 'existence value' of a natural resource such as a wilderness area. This concept refers to the value that an individual may place on assuring the continued existence of the resource in its preserved state, even if the individual never intends to visit the area or make use of its services, even if just for recreational purposes. Most environmental economists today accept that existence value is one component of the total economic value of a resource. Once this point is recognised, the implicit assumption that *undeveloped* resources have no economic value must be questioned. A *preserved* natural resource yields valuable services; some of these may be recreational uses but they need not be. Computing the aggregate amount of these existence or non-use values requires that we address the issue of determining the extent of the market for the preserved resource when there may be no behavioural trail to follow.

Thus, if a natural area or free-flowing river were to be lost thanks to the construction of a water resources project, the *ex-ante* economic analysis of the dam project would require that the economist measure not only the lost use value to households of the natural area, but also its existence value. The Fisher et al (1972) analysis of the hydro project proposed for the Hells Canyon has become a signature example of this point.

Another area in which the work of environmental economists is relevant to the *ex-ante* economic evaluation of dam projects is the social value of carbon. The economic analysis of a large dam necessitates a careful consideration of its contribution to both hydroelectric power generation and CO_2 emissions. On the one hand, hydroelectric power generation from dams is a renewable energy source (at least as long as reservoir storage lasts before being filled by silt from the upstream watershed). Unlike fossil fuel power generation, the release of reservoir water through the turbines does not generate CO_2. In a cost–benefit comparison between fossil fuel generation and hydropower generation, the fossil fuel plant should incur the costs of the negative externality associated with its CO_2 emissions. But although the release of reservoir water through the dam's turbines does not release CO_2 emissions, there is a negative CO_2 externality that needs to be assigned to the dam. If biomass is left in a reservoir site, when the site is flooded, this biomass is submerged and then decomposes. This process releases CO_2 into the atmosphere. The amount of CO_2 released by this decomposition of organic matter depends on numerous factors, including the extent of the efforts made to clear the reservoir site before it is filled. The proper accounting for the social cost of carbon is a development that was neglected in the early *ex-ante* economic analysis of dam projects.[11]

[11] There are many issues when considering how large water projects can have GE effects and the ability of existing models to capture responses that would influence these results, especially for very long-term effects. In the next section we discuss some literature on GE modelling but do not attempt to deal with the important role of uncertainty in how any model's results should be used for informing policy. Some authors, notably Wagner and Weitzman (2015), have argued for action, suggesting: "The evidence is overwhelming: the levels of greenhouse gases in the atmosphere are rising" (p 148). As they acknowledge, the effects of these changes are uncertain, but in their view policy needs to "Stick it to Carbon". By contrast, others, such as a distinguished economic theorist, Levine (2019), acknowledge the problem but expect more modest effects and have confidence in the ability of markets to respond, concluding that: "the best science indicates that if we do nothing the effect of global warming on our children will be modest and despite global warming our descendants will likely

5 Development 4: economy-wide linkages

To understand the consequences that result from building a dam, an obvious place to begin is to estimate the magnitude of the direct changes that result from the new pattern of water releases from the dam. Releases through the turbines generate electricity. Water may now be available downstream for more irrigation withdrawal. The smoothing of river flows may reduce floods and flood damage downstream. As a first step in an *ex ante* cost–benefit analysis, economists typically seek to estimate the welfare changes that occur as a result of these direct effects in primary markets. But these direct changes may also result in changes in prices in secondary markets that cause additional, indirect welfare changes. The magnitude of these secondary, indirect effects and how best to include them in the cost–benefit analysis, has long been a contentious issue in the economic analysis of dam projects. In fact, there is still a divide in practice between cost–benefit analysts, who prefer to use a partial equilibrium approach (to measure the 'direct' effects), and those favouring a GE approach (to capture the 'indirect' effects) (Farrow & Rose, 2018).

One of the first efforts to consider the role of GE effects for benefit measurement can be found in Harberger's (1971) early summary of the treatment of multi-market effects. He used a Taylor series approximation for consumer surplus to argue that all consumer effects of a policy intervention –whether public investment, tax or new rule, including multi-market effects – could be captured within a single market, provided that there were no pre-existing distortions in those markets. This analysis amounts to using what Just et al. (2004) have labelled general equilibrium demand functions, as we discuss in more detail below. These authors went further and outlined in conceptual terms how one would undertake the applied welfare analysis with one or more market distortions. They concluded that GE effects (defined as multi-market responses) can be included in applied welfare analysis. More specifically, they observed in these cases that:

> a general equilibrium welfare methodology emerges *for which the major limitation is simply the ability to measure equilibrium relationships empirically*. (p 462, emphasis added)

In other words, we need to be able to compute the GE effects on the prices of other goods and services and then include these effects in the associated GE demand functions. Just et al's analysis describes the logic connecting partial and GE benefit measures when the focus is on interactions through markets. Within a static, multi-market setting their GE demand function acknowledges that a policy affecting one market should take account of the repercussions in all other markets. It evaluates that policy using the demand function that reflects equilibrium outcomes in these other markets *with* the policy in comparison to old equilibrium price in the affected market since it reflects the *without* situation. Of course, the central issue in moving from concept to practice is how we actually consistently track these repercussions. Kokoski and Smith (1987) and Hazilla and Kopp (1990) demonstrated how computable general equilibrium (CGE) models could be used when the issue was a policy or project affecting the costs of producing market goods and services. Once it is acknowledged that large-scale projects can have effects outside markets – on nonmarket environmental

---

be considerably better off than we are. Moreover, the growth effect is so much stronger than the damage effect that this conclusion is robust to substantial errors in either the rate of warming or the level of economic damages" (p 6).

services – the method used to compute the equilibrium outcomes must incorporate nonmarket effects as influences to that equilibrium.

Introducing non-market resources into a GE setting and allowing them to both influence and be influenced by choices of market goods and services requires a description of the mechanism creating those linkages. For example, in the case of air quality this mechanism is through an air diffusion model that links emissions at one or more locations to ambient air quality at other locations. For the water quality associated with freshwater bodies, it would be a description of how emissions affect water quality in rivers and lakes. The role of air or water quality measures within the specification of a household's preference function determines how these affect decisions about market goods and services. The combination of these two modifications to the preference and production functions in conventional CGE models is what establishes non-market feedbacks within a GE framework.

To our knowledge, the first model to include both was the Espinosa–Smith (1995) generalisation of the Harrison, Rutherford, and Wooten (HRW) (1989) model. The HRW analysis was intended to evaluate trade policy, considering a framework with eight members of the European Community –Germany, France, Italy, The Netherlands, Belgium, the UK, Denmark and Ireland –as well as the US, Japan and an aggregate region that included all other countries. The Espinosa–Smith generalisation allowed for a non-separable effect of air pollution on households by adopting a Stone–Geary preference function and assuming some market goods and services provided perfect substitutes to offset or mitigate the impacts of air pollution.

Later, Carbone and Smith (2008, 2013) relaxed the assumption of perfect substitution in small CGE models used and demonstrated the importance of complementarity or substitution relationships between these nonmarket services and the market goods for feedback effects that are outside the market, and in turn for GE welfare measures.

Early proponents of dam projects (including the US Army Corps of Engineers) argued for the use of a Keynesian multiplier to increase the direct benefits in primary markets by a factor of, say, 1.5 or 2 in order to estimate the direct and indirect benefits of the project. In the 1960s economists debated the assumptions underpinning such a simplistic adjustment to benefits. As noted by Harberger (1971) in general terms, advocates of partial equilibrium analysis have long understood that, when distortions exist in secondary markets, market interactions between the change in the primary market and distorted secondary market need to be incorporated in the cost–benefit analysis. Cost–benefit textbooks that presented partial equilibrium methods described the circumstances in which welfare effects would occur in secondary markets and when to include these welfare changes in the benefit estimates (see, for example, Boardman et al 2011). The conventional wisdom of economists practising partial equilibrium analysis has been that welfare changes in secondary markets for most government investment projects are usually small enough that GE effects are unlikely to change the outcome. This conventional wisdom is codified in the US in the Office of Management and Budget (OMB) guidelines for conducting cost–benefit analysis, which advise analysts not to include secondary markets or use simplified multiplier gauges of their effect.

Over the past two plus decades our understanding of GE effects has advanced to the point where the OMB advice needs to be updated. Advocates of the use of GE analysis for *ex-ante* evaluation of dam projects have argued that large investments in water resources infrastructure do cause price changes in secondary markets that are large enough to warrant the GE approach and that there are CGE models capable of measuring these effects (Robinson et al, 2008; Strzepek et al, 2008, 2006; Kahsay et al, 2015, 2019). The last two of these papers discuss CGE models linked with simulation models for the river system with and without the proposed project. While significant innovations, it is important to consider two features of these models. The first of these considerations is the scale of the project in relation to the overall economy represented in the CGE. In both applications they use 'world' models because there is a readily available framework that allows the region of Africa to be handled in detail and the rest of the world to be taken into account as an aggregate. While the regional detail is impressive, scale in this case means the project is likely to have little effect on relative prices, given that the model represents all the resources in the 'world' as defined by the Global Trade Analysis Project (GTAP) database underlying the model.

The second issue concerns the prospect for feedback effects. The model design has the hydrologic model taking the economic effects (changes in relative prices) as given. Ideally one would want to evaluate whether the project has feedback effects in other sectors. This issue was implicit in the with-and-without perspective discussed in Eckstein. In these applications the selection of a world model implies that scale will be small and feedback effects are likely to be small as well. Hydrologic effects are larger than GE market effects in their results, and this should not be surprising. It follows from the scale selected in describing the economy in relation to the project.

There are several challenges that need to be addressed before these recommendations can become a part of routine practice. First, most CGE models are large-scale, economy-wide models with limited or no geography, so the introduction of large regional water projects may require an array of adjustments to 'fit' the policy into the description of the model. In the Kahsay et al (2019) model, regions are introduced through disaggregation of the output mix and pre-specified transportation costs and taxes. The sectoral resolution in these models must fit the available social accounting matrix (SAM) describing resource flows in the economy. Often water infrastructure is not adequately captured.

Second, environmental services are completely left out. In the Kahsay et al (2015, 2019) model, recreation is commercial recreation aggregated into the services sector. There is no recognition or link to nonmarket services produced by the water project. Even in the cases where models have been developed to deal with the social costs of carbon, most of the applications treat environmental services as making separable contributions from preference and production functions. These specifications imply that the feedback effects demonstrated to be important in the Carbone–Smith analyses are precluded by assumption.

Finally, a key issue in determining the importance of these non-market GE effects for welfare measures is the estimated economic importance of environmental services to the households in the economy. The parameters in CGE models are selected in two ways. Some are specified based on consensus results from the empirical literature. The remainder of the parameters are calibrated using these assumed values along with the model's solutions for the baseline (or *without* condition of the economy), which relies on a given

SAM. Nonmarket environmental services are not commonly available in SAMs. So, a share of virtual income (market expenditures on goods and services plus the value attributed to environmental services) must be selected for environmental services. The size of this share matters and the literature on nonmarket valuation has not given this concept adequate attention (Smith & Zhao, 2019)

As a result of these challenges, how best to deploy partial and CGE models for the *ex-ante* evaluation of dams remains a question to be answered. And neither approach addresses the possibility that large dams are planned to assist with the creation of large structural changes in the economy.

6 Development 5: modelling non-cooperative behaviour

The early systems analysis work on how to optimise the economic benefits of water resources infrastructure assumed that the state would seek to design, build and operate infrastructure that was in the best interests of all parties involved. However, economic production decisions were conceived as separate from distribution decisions. First, social planners would maximise the size of the economic pie, and afterwards they would decide how to divide it.

It quickly became clear to water resources practitioners that this was not how political actors made decisions in the real world, especially on transboundary rivers. Upstream and downstream riparians typically pursued their own national interests, perhaps constrained by potential retaliatory measures that other stakeholders might undertake. Economists recognised early on that transboundary river basins shared many characteristics of non-cooperative games, and soon applied game theory techniques to model the behaviour of state actors sharing water resources (Rogers, 1969; Dufournaud, 1982). Investments in dams on large rivers were a particularly popular focus of the application of game theory to water resources management (Dinar & Hogarth, 2015).

In important respects the application of game theory to water resource systems paralleled the development of multi-objective evaluation approaches. Instead of multiple objectives for a single decision maker, game theorists asked how the outcome realised by multiple decision makers, each potentially motivated by different goals or at least different weights for the multi-objectives, would compare with the efficient choice. Analytically the two problems are similar.

Despite the enthusiasm of many water resources economists for the application of game theory to the problem of managing transboundary water resources, these models have not been used much in practice. This is in stark contrast to the application of simulation models of water resource systems, which are now widely adopted. We believe there are two main reasons why policy makers and practitioners have been unable to make much use of game theory models in the water resources sector. The first is because these models have been unable to capture policy makers' actual political motivations for investing in water resources infrastructure; they have also been unable to characterise the full range of retaliatory actions that policy makers may undertake in response to undesirable actions by other actors on a river.

Second, the analytical task of evaluating all the possible coalitions of actors, the investment decisions these potential coalitions might make, and the different ways that these potential coalitions might operate the various infrastructure to achieve each actor's objective, all in a dynamic context, is very complex (Wu & Whittington, 2006). Even if modern computation tools can characterise and evaluate some of the actors' possible strategies, these solutions may not be closely related to what the actors themselves are planning. The solutions of these game-theoretic models are thus rarely of much interest to policy makers.

7 Development 6: dealing with uncertainty

Uncertainty affects *ex-ante* cost–benefit analyses of dams in at least two ways. First, as the scope of these analyses has expanded to include many additional direct and indirect consequences of dams, the uncertainty in the results of the analyses has become more apparent. Even simple cost–benefit calculations require dozens of parameter estimates. Some of these parameters relate to epistemic uncertainties about the physical world, such as the risk of dam failure (Baecher et al, 1980). Others are questions about contested social values, eg the discount rate. Forecasting both the state of the world with and without any particular water resources investment programme far into the future introduces uncertainty. Second, our models now acknowledge that people are making their choices under uncertainty and thus their values for policies should reflect the fact that the outcomes are not guaranteed (Schlee & Smith, 2019).

Climate change introduces uncertainty into both the counterfactual and treatment scenarios. In a future in which climate change unfolds, the hydrology of rivers may become non-stationary (Milly et al, 2008). If this non-stationarity is unknown, it is especially challenging to incorporate this source of uncertainty into a cost–benefit analysis. At first glance it might appear that dams would become more valuable as the variability of surface flows increased. But a countervailing influence is that the risk of building dams with capacity that will not be needed (because surface water flows turn out to be lower than expected) may also increase, and building new dams that represent unused capital is an especially heavy penalty in a cost–benefit analysis.

Technological innovation over the forecast planning period will probably affect the magnitude of the streams of benefits. For example, the ongoing revolution in solar energy technology will make hydropower generation from dams much more valuable in the future in many locations. This is because hydropower and solar generation are good technological complements for each other (hydropower power can be generated when solar power is not available).

These multiple sources of uncertainty introduce several related challenges for the analyst. The first is simply how to conduct sensitivity analyses to effectively illustrate the extent of the uncertainty in the estimates used to measure costs and benefits, and the relative importance of different assumptions that the analyst has made. Monte Carlo analyses that incorporate distributions of parameter estimates used in the cost–benefit analysis are now routinely used to test the robustness of the results for investments in dams. The results of the analysis are typically sensitive to the old culprit, the discount rate (Whittington et al, 2009). Real options is another probabilistic technique that may be useful (Wang & de Neufville, 2006, Steinschneider & Brown, 2012; Jeuland & Whittington, 2014).

The second challenge is how to address ‘deep certainty’ and ‘ambiguity’ (Morgan, 1999; Whittington & Wu, 2006). Monte Carlo analysis is again often used, in this case as a tool in ‘decision making under deep uncertainty’ (DMDU) methods to project interval uncertainties without make probabilistic commitments about the sample distribution.

People’s responses to risk depend on how they perceive the extent of the risk and what they believe they are responsible for. Their reactions can be displayed in measures of the values of losses and gains that are dramatically different, even when simple theories would imply they should be close.

Many people in both industrialised and developing countries perceive that the environmental and social impacts of large dams will not be adequately considered in governmental decision making about large dams. When reservoirs will inundate entire communities and people are displaced from their homes, the public mistrusts economists’ attempts to assign monetary values to such negative consequences. People also doubt government promises that displaced households will be adequately compensated.

Finally, simply incorporating uncertainty into the cost–benefit analysis is not sufficient; it is also necessary to find better ways to communicate these results to policy makers and civil society. Analysts studying the costs and benefits of climate change have made important advances in both incorporating uncertainty into their work and displaying the results to better communicate with policy makers. Analysts evaluating dam investments can learn from these climate change analyses.

8 What effects do water resources and investments in them have on regional economic outcomes?

As Jeuland (2020) suggested in his closing comments, there have been few *ex-post* assessments of the economic effects of water resource investments. To fully appreciate the relevance of his comments, we need to distinguish at least two types of *ex-post* evaluation. The first considers the ingredients of an *ex-ante* cost–benefit analysis and asks: how did the benefits attributed to the project’s outputs and the costs align with what was estimated *ex ante*? His comments are most relevant for this type of *ex-post* assessment.

The second type of *ex-post* analysis considers the effects of these projects on overall economic activity at a regional level. While these impacts are often a motivation for the water resource investments, their treatment in the *ex-ante* benefit–cost analysis has been controversial. The logic underlying the omission of project effects on the level or the growth of economic activity in an area is that, with full employment, each new project simply reallocates resources. It does generate net additions to overall output.

Haveman’s (1972) early *ex-post* evaluation of water resource investments offers a direct example of this first category and should be viewed as anticipating the calls for evaluation research (Greenstone, 2009) in today’s literature on policy evaluation with benefit–cost methods. His assessment of the *ex-ante* benefit–cost studies concluded agency practices were seriously flawed, in that the anticipated outputs were often not realised. He also found that the uneven quality of the *ex-ante* cost estimates “erodes any serious reliance on benefit cost calculations as a basis for project choice” (p 109). This work was clearly a motivation for the focus on improving the benefit–cost methods used in assessing water resource projects.

To our knowledge, consistent with Jeuland's observation, there has been no comparable effort to look at today's analyses of water projects and gauge their status –comparing *ex ante* estimates and *ex post* outcomes for comparable variables.[12] As a result, there is little evidence available to use for improving the ability of current *ex-ante* appraisals.

The second type of *ex-post* evaluation has seen more activity. There are two sets of contributions –one group initiated over 50 years ago anticipated many of the issues raised in the current literature by Duflo and Pande (2007), Kline and Moretti (2014) and Severnini (2014). This early research was largely focused on the US and considered the effects of water resources on economic activity and growth at a regional level. Howe (1968), for example, considered the influence of water availability for regional economic activity. In his analysis, availability was measured by three physical variables – availability of water transportation, streamflow and an average annual runoff. He used employment growth as a proxy measure for economic activity His focus was on activity at the county level between 1950 and 1960. Based on the analysis he concluded:

> water did not constitute a path to rapid economic growth in water deficit areas of this country, nor did its presence in large quantities in other regions guarantee rapid economic growth of these regions. (p 488)

His study was routinely cited in this early research as consistent with concluding that new water investments would not have an effect on economic activity. The first study in the US to more specifically consider water projects was Cox et al (1971). It focused on the northeastern US and used a composite index of economic activity as the dependent variable. The index was constructed using principal component analysis to distil a set of 15 variables intended to measure economic growth. The authors concluded that water resource projects were not a stimulus to growth in rural counties in the northeastern US. The last of these early studies was by Cicchetti et al (1975), who found results that contrasted with the prior work. They concluded that:

> water resource investments have an impact on regional economic growth … The extent of the effect depends on the nature of the water investment, the state of the region, and the amount and nature of other investments. (p 5)

There are some important differences in the strategies used in these early studies.[13] The first of these distinctions is the unit of analysis for measuring effects of water projects on economic activity. As with the current studies, the unit of analysis for Howe and Cox et al

---

[12] The Morgenstern (1997) volume provides a detailed *ex-post* assessment of benefit–cost analyses for a variety of the Environmental Protection Agency's (EPA) regulatory programmes in specific sectors, including water pollution from the organic chemical industry, municipal wastewater and the Great Lakes water quality programme.

[13] We should acknowledge that some readers interpret the Cicchetti et al results as being less supportive of a relationship. Hanemann (2006), for example, acknowledges that the study provides some evidence of a link but argues that the instability in the magnitude and statistical significance of the estimated parameters across models and measure of economic activity raises a question about the causation: do the water investments cause the economic growth or is the absence of regional growth a motivation for the investments? We would argue that the results for the change in sub-regional income between 1960 and 1970 do provide reasonably clear support for a link when the region is consistent with an economic definition and investments in other important forms of infrastructure are taken into account.

was a political unit, a county. Cicchetti et al argued that counties did not necessarily conform to economic units or to the areas that best captured where the Bureau of Reclamation's water projects were concentrated. This point is potentially important, because a key issue in the current literature comes down to the distinction between treatment and control counties in the US for Kline and Moretti and Severnini, and instruments exploiting measures of geographical attributes of districts in India for Duflo and Pande. All these current studies use political units to define treatment and control observations.[14] Cicchetti et al used composite mapping to define their sub-regions, based on population density, irrigated croplands and highway accessibility. Twenty-one sub-regions were defined over five southwestern states.

The current literature largely assumes that a political unit can proxy an economic region and focuses instead on controlling the composition of the sample of counties (or districts) to approximate cases that are treated or controlled. The objective is to isolate comparable situations, aside from the dam (or water resource investment). Kline and Moretti consider a single, regional initiative TVA (which involved more than dams) and compared TVA and non-TVA counties. TVA counties were contrasted with those in the south of the US that were not in the TVA system and with a set proposed for alternative, comparable to TVA authorities that were never acted upon, but presumably where the counties involved were intended to be comparable to those selected for a TVA initiative.[15] Thus, their controls are either based on similar economic circumstances – depressed regions in the south –or defined by a process comparable to the TVA initiative to identify comparable regions to those in the TVA. Duflo and Pande use the physical attributes of districts. More specifically, their instrument is based a first stage model that predicts the distribution of dams built in a state across districts using the overall gradient of a district, the river length and elevation measure in a district, along with differences in the river gradient. This instrument for their measures of dams in the area is then used to evaluate how the inputs and outputs in agriculture, along with poverty indexes, were affected by these water resource projects between 1971 and 1999. Severnini follows Duflo and Pande and uses physical criteria, namely an assessment of the hydropower capacity based on site characteristics, streamflow data and hydraulic heads, in his assessment of large hydro dams in the US.[16]

---

[14] Duflo and Pande argue that, while districts are administrative units, they are also relevant markets and social units.

[15] They also compared the TVA counties to all other counties in the US overall.

[16] A study conducted in the interval between the early and later periods by Aleseyed et al (1998) has largely been overlooked in this literature. It considered dams in the US over the period 1958 to 1984 using a quasi-experimental logic. Using county-level data and information from the Bureau of Economic Analysis on regional economic activity, the authors screened counties to select treatment and control locations. Treatment counties were selected to reflect large dams that were completed between 1975 and 1984. Forty-eight counties were identified with dams for flood control, water supply, hydroelectric objectives, irrigation, navigation, recreation and other outcomes listed as the primary purposes. Several different criteria were used to select the control counties. An equal number of control counties was selected based on ranking a statistical index of the correspondence between the weighted average of descriptive variables for the treatment counties. Considering county income and employment, the study found that large dams had positive effects on the counties where they were located but that the findings varied based on the purpose of the dam and the variables describing the spatial context. However, the authors concluded that rural areas were not as positively impacted by these in projects, and dams for flood control had a limited effect in stimulating economic activity.

This later logic is similar to Howe's use of physical measures to characterise water resources.

An important reason for considering the criteria for defining controls is the ability to account for other public investments that might contribute to or substitute for the role of the water investments.[17]

Given the diversity of research designs, measures of economic outcomes and characteristics of the two economies considered in this second group of *ex-post* studies, it is hardly surprising that we conclude that any overall judgment on the regional growth effects of water projects would not be warranted based on this evidence. Nonetheless, a few general observations can be made. While much of the current work is based on reduced-form models that adopt a modern quasi-experimental logic, this advance in statistical methods does not imply that the logic of matching treatment and control observations removes the need to evaluate whether the unit of analysis defining each record authentically captures the economic process being studied. This is especially true when the analysis relies on aggregate measures of economic outcomes. Political units need not match the economic units defining markets. Controls defined based on geographic characteristics of spatially delineated records do not assure that economic investment in other forms of public capital will be taken into account as part of the research design. Impacts on regional growth may well be different over different intervals and the initial conditions may be important. Kline and Moretti's findings and those of Severnini illustrate this point. Overall, then, the current research record would not support changing current cost–benefit practice in omitting consideration of claims that water projects can advance regional economic growth.

9 Concluding remarks

Over the past 70 years the analytical tasks involved in conducting a state-of-the art *ex-ante* analysis of a proposed dam project have grown in both number and complexity. There are to our knowledge no published or unpublished analyses of actual dam investments that incorporate all the six developments described in this paper. There is thus nowhere analysts can turn to see examples of best practice. Nor are there any guidelines for conducting *ex-ante* cost–benefit analyses of dam projects that show analysts how to navigate the multiple analytical and theoretical challenges. This lack of guidance is in part to the result of insufficient demand for such analyses on the part of policy makers. It is also probably the result of the low status that such work receives in the academic community and of the poor publishing prospects academics face when they work on these problems.

In addition to the lack of examples of best practice and guidelines, analysts face an further challenge: how should an analyst allocate a limited budget for analysis among the various tasks required to conduct an *ex-ante* cost–benefit analysis of a dam? Is the estimation of the economic value of losses from displacement and resettlement of communities in the area

---

[17] Cicchetti et al included different subsets of seven measures for public investments, including: education, highways, sanitation, housing and urban renewal, health, fire and police, and parks and recreation, along with the Bureau of Reclamation water investment categories.

flooded by the dam more or less important than the incorporation of GE effects? Are time and money better spent on estimating the economic value of environmental losses, or on better ways to display and communicate the uncertainty in the results to policy makers? Different analysts will make different subjective judgments on where to put their effort. We have made progress. Certainly, a comparison of what was known when Eckstein's influential book was published over 60 years ago with today's understanding of best practice easily confirms that judgment. Resources will never be sufficient to tackle all the issues described in this paper. We do feel with all that has been learned in these six decades that the state of the art for *ex-ante* analysis of a proposed water investment stands on the cusp of a major advance. It remains to be seen if the next generation of scholars will see the opportunity as we do.

The six developments associated with *ex-ante* analysis that we have discussed in this paper are not just relevant to the economic analysis of large dams. The lessons apply to other water-related infrastructure projects, including flood management, wetland remediation and dam removal. Indeed, these six developments in *ex-ante* economic analysis deserve careful attention in the economic analysis of most large infrastructure projects.

Finally, our closing section on *ex-post* assessments of water resource projects documents that recent research has advanced our understanding of the method required to undertake economic assessment of the impacts of 'place based' public investments in water resources. Nonetheless, it would not cause us to revisit the early conclusion that regional economic growth cannot be treated as another 'benefit' in *ex-ante* cost–benefit analyses.

References

Aleseyed, M., Rephann, T. and Isserman, A. (1998). 'The local effects of large dam reservoirs: US experience'. *Review of Urban and Regional Development Studies 10*, 91–108.

Ansar, A., Flyvbjerg, B., Budzier, A. and Lunn, D. (2014). 'Should we build more large dams? The actual costs of hydropower megaproject development'. *Energy Policy 69*, 43–56.

Baecher, G.B., Pate, M.E. and De Neufville, R. (1980). 'Risk of dam failure in benefit–cost analysis'. *Water Resources Research 3*, 449–456.

Banzhaf, H.S. (2009). 'Objective or multi-objective? Two historically competing visions for benefit cost analysis'. *Land Economics 85*, 3–23.

Bin, O., Crawford, T.W., Kruse, J.B. and Landry, C.E. (2008). 'Viewscapes and flood hazards: coastal housing market responses to amenities and risk'. *Land Economics 84*, 434–448.

Bishop, K.C., Kuminoff, N.V., Banzhaf, H.S., Boyle, K.J., von Gravenitz, K., Pope, J.C., Smith, V.K. and Timmins, C.D. (2019). 'Best practices in using hedonic property value models for welfare measurement'. *Review of Environmental Economics and Policy,* forthcoming.

Biswas, A. (1970). *History of Hydrology*. Amsterdam: Elsevier.

Boardman, A., Vining, A., and Weimer, D. (2011). *Cost–Benefit Analysis: Concepts and Practice.* Fourth Edn. Upper Saddle River NJ: Prentice Hall.

Carbone, J.C. and Smith, V.K. (2008). 'Evaluating policy interventions with equilibrium externalities'. *Journal of Public Economics 92*, 1254–1274.

Carbone, J.C. and Smith, V.K. (2013). 'Valuing nature in a general equilibrium'. *Journal of Environmental Economics and Management 66*, 72–89.

Choe, K.A., Whittington, D. and Lauria, D.T. (1996). 'The economic benefits of surface water quality improvements in developing countries: a case study of Davao, Philippines'. *Land Economics 72*, 519–537.

Cicchetti, C.J., Smith, V.K. and Carson, J. (1975). 'An economic analysis of water resource investments and regional economic growth'. *Water Resources Research 11*, 1–6.

Clawson, M. (1959). *Methods for Measuring the Demand for and Value of Outdoor Recreation*. Report No. 10. Washington DC: Resources for the Future.

Clawson M. and Knetsch, J.L. (1966). *Economics of Outdoor Recreation*. Baltimore MD: Johns Hopkins Press for Resources for the Future.

Cohon, J.L. (1978). *Multiobjective Programming and Planning*. Cambridge MA: Academic Press.

Cox, P.T., Grower, W. and Seskin, B. (1971). 'Effect of water resource investment on economic growth'. *Water Resources Research 8*, 32–39.

Congressional Research Service (CRS) (2019). *Dam Safety Overview and the Federal Role*. Report R45981, 24 October. Washington DC: CRS.

Cropper, ML., Aydede, S.K. and Portney. P. (1994). 'Preferences for life saving programs: how the public values time and age'. *Journal of Risk and Uncertainty 8*, 243–265.

Dasgupta, P., Sen, A. and Marglin, S. (1972). *Guidelines for Project Evaluation*. New York: United Nations Development Programme.

Dinar, A. and Hogarth, M. (2015). 'Game theory and water resources: critical review of its contributions, progress and remaining challenges'. *Foundations & Trends in Microeconomics 11*, 1–139.

Duflo, E. and Pande, R. (2007). 'Dams'. *Quarterly Journal of Economics 122*, 601–646.

Dufournaud, C.M. (1982). ‘On the mutually beneficial cooperative scheme: dynamic change in the payoff matrix of international river basin schemes’. *Water Resources Research 18*, 764–772.

Eckstein, O. (1958). Water Resources Development: The Economics of Project Evaluation. Cambridge MA: Harvard University Press.

Ekelund, R.B, Jr (1968). ‘Jules Dupuit and the early theory of marginal cost pricing’. *Journal of Political Economy 76*, 462–471.

Espinosa, J.A. and Smith, V.K. (1995). ‘Measuring the environmental consequences of trade policy: a non-market CGE analysis’. *American Journal of Agricultural Economics 77*, 772–777.

Farrow, S. and Rose, A. (2018). ‘Welfare analysis: bridging the partial and general equilibrium divide for policy analysis’. *Journal of Benefit Cost Analysis 9*, 67–83.

Fisher, A.C., Krutilla, J.V. and Cicchetti, C.J. (1972). ‘The economics of environmental preservation: a theoretical and empirical analysis’. *American Economic Review 62*, 605–619.

Freeman, A.M., III. (1966). ‘Adjusted benefit–cost ratios for six recent reclamation projects’. *Journal of Farm Economics 48*, 1002–1012.

Gallagher, J. (2014). ‘Learning about an infrequent event: evidence from flood insurance take-up in the United States’. *American Economic Journal: Applied Economics 6*, 206–233.

Goeller, B.F., Abraham, S.C., Abrahamse, A., Bigelow, J.H., Bolten, J., DeHaven, J.C., Jaquette, D.L. et al. (1983). *Policy Analysis of Water Management for the Netherlands*. Vol. 1, Summary Report. Santa Monica, CA: RAND Corporation.

Greenstone, M. (2009). ‘Toward a culture of persistent regulatory experimentation and evaluation’. In Moss, D. and Cisternino, J. (eds), *New Perspectives on Regulation* (pp. 11–126). Cambridge MA: The Tobin Project.

Hall, J.W., Grey, D., Garrick, D., Fung, F., Brown, C., Dadson, S.J. and Sadoff, C.W. (2014). ‘Coping with the curse of freshwater variability’. *Science 346*, 429–430. doi: 10.1126/science.1257890.

Hammitt, J.K. and Robinson, L.A. (2011). ‘The income elasticity of the value per statistical life: transferring estimates between high and low-income populations’. *Journal of Benefit–Cost Analysis 2*, 1–27.

Hanemann, W. M. (2006). ‘The economic conception of water’. In Roger, P.O., Llamas, M.R. and Martinez-Cortina, I. (eds), *Water Crisis: Myth or Reality?* (pp. 61–91). London: Taylor & Francis.

Harberger, A.C. (1971). "Three Postulates for Applied Welfare Economics" *Journal of Economic Literature*. 9:3, 777-785.

Harou, J.J., Pulido, M.A., Rosenberg, D.E., Medellín-Azuara, J., Lund, J.R., and Howitt, R.E. (2009). ‘Hydro-economic models: concepts, design, applications, and future prospects’. *Journal of Hydrology*, *375*, 627-643.

Harrison, G.W., Rutherford, T.F. and Wooton, I. (1989). ‘The economic impact of the European Community’. *American Economic Association Papers and Proceedings 79*, 288–294.

Haveman, R.H. (1965). Water Resource Investment and the Public Interest: An Analysis of Federal Expenditures in Ten Southern States. Nashville TN: Vanderbilt University Press.

Haveman, R.H. (1972). The Economic Performance of Public Investments: An Ex Post Evaluation of Water Resource Investments. Baltimore MD: Johns Hopkins University Press.

Hazilla, M., and Kopp, R.J. (1990). ‘Social cost of environmental quality regulations: a general equilibrium analysis’. *Journal of Political Economy 98*, 853–873.

Hotelling, H. (1947). ‘Letter to the National Park Service’. Reprinted in *An Economic Study of the Monetary Evaluation of Recreation in the National Parks* (1949). Washington DC: US Department of the Interior, National Park Service and Recreational Planning Division.

Howe, C.W. (1968). ‘Water resources and regional economic growth in the United States, 1950–1960’. *Southern Economic Journal 34*, 477–499.

Jeuland, M. (forthcoming 2020). ‘Economics of dams’. *Oxford Review of Economic Policy*. *36*.

Jeuland, M. and Whittington, D. (2014). ‘Water resources planning under climate change: assessing the robustness of real options for the Blue Nile’. *Water Resources Research 50,* 2086–2107.

Just, R.E., Hueth, D.L. and Schmitz, D.A. (2004). The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation. Cheltenham: Edward Elgar.

Kahsay, T.N., Kuik, O., Brouwer, R. and van der Zaag, P. (2015). ‘Estimation of the transboundary economic impacts of the Grand Ethiopia Renaissance Dam: a computable general equilibrium analysis’. *Water Resources and Economics 10*, 14–30.

Kahsay, T.N., Arjoon, D., Kuik, O., Brouwer, R., Tilmant, A. and van der Zaag, P. (2019). ‘A hybrid partial and general equilibrium modeling approach to assess the hydro-economic impacts of large dams – the case of the Grand Ethiopian Renaissance Dam in the Eastern Nile River basin’. *Environmental Modelling and Software 117*, 76–88.

Kahneman, D. and Tversky, A. (1979). ‘Prospect theory: an analysis of decision under risk’. *Econometrica 47*, 263–292.

Keeney, R.L. and Raiffa, H. (1993). *Decisions with Multiple Objectives*. Cambridge : Cambridge University Press.

Kline, P. and Moretti, E. (2014). ‘Local economic development, agglomeration economies, and the big push: 100 years of evidence from the Tennessee Valley Authority’. *Quarterly Journal of Economics 129*, 275–332.

Kokoski, M.F. and Smith, V.K. (1987). ‘A general equilibrium analysis of partial-equilibrium welfare measures: the case of climate change’. *American Economic Review 77*, 331–341.

Krutilla, J. (1967). ‘Conservation reconsidered’. *American Economic Review 57*, 777–786.

Krutilla, J.V. and Eckstein, O. (1958). *Multiple Purpose River Development: Studies in Applied Economic Analysis*. Baltimore MD: Johns Hopkins Press for Resources for the Future.

Lane, N. (2006). *Dam Removal: Issues, Considerations and Controversies*. CRS Report for Congress RL33480, 20 November. Washington DC: CRS.

Levine, D.K. (2019). "Global Warming: What Sort of Mess Have We Made?", unpublished paper, Washington University, St. Louis Mo. October.

Maass, A., Hufschmidt, M.M., Dorfman, R., Thomas, H.A., Jr, Marglin, S.A. and Maskew Fair, G. (1962). Design of Water-resource Systems: New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning. Cambridge, MA: Harvard University Press.

Major, D.J. (1977). *Multiobjective Water Resources Planning*. American Geophysical Union (AGU). Water Resources Monograph 4. Washington DC: AGU.

Maler, K.G. and Vincent, J.R. (eds) (2005). *Handbook of Environmental Economics*. 3 vols. Amsterdam: Elsevier.

Milly, P., Betancourt, J., Falkenmark, M., Hirsch, R., Kundzewicz, Z., Lettenmaier, D. and Stouffer, R. (2008). ‘Stationarity is dead: whither water management?’. *Science 319*, 573–574.

Morgan, M.G., Kandilar, M., Risbey, J., and Dowlatabadi, H.(1999). ‘Why conventional tools for policy analysis are often inadequate for problems of global change’. *Climate Change 41*, 271–281.

Morgenstern, R.D. (ed.) (1997). *Economic Analyses at EPA: Assessing Regulatory Impact*. Washington DC: Resources for the Future.

Phaneuf, D.J. and Requate. T. (2017). *A Course in Environmental Economics: Theory, Policy and Practice*. New York: Cambridge University Press.

Phaneuf, D.J. and Smith, V.K. (2005). 'Recreation demand models'. In Maler, K.G. and Vincent, J.R. (eds), *Handbook of Environmental Economics,* Vol 2 (pp. 672–761). Amsterdam: Elsevier.

Robinson, S., Strzepek, K., El-Said, M. and Lofgren, H. (2008). 'The High Dam at Aswan'. In Bhatia, R., Cestti, R., Scatasta, M. and Malik, R.P.S. (eds), *Indirect Impact of Dams: Case Studies from India, Egypt, and Brazil* (pp. 227–273).Washington DC/New Delhi: World Bank/Academic Foundation.

Rogers, P. (1969). 'A game theory approach to the problems of international river basins'. *Water Resources Research 5*, 749–760.

Samuelson, P.A. (1954). 'The pure theory of public expenditure'. *Review of Economics and Statistics 36*, 387–389.

Schlee, E.E and Smith V. K. (2019) "The welfare cost of uncertainty in policy outcomes" *Journal of Environmental Economics and Management ,98,1-12*

Severnini, E.R. (2014). *The Power of Hydroelectric Dams: Agglomeration Spillovers*. Institute for Labour Research (IZA) Discussion Paper 8082. Bonn: IZA.

Smith, V.K. and Moore, E.M. (2010). 'Behavioral economics and benefit cost analysis'. *Environmental and Resource Economics* June, 217–234.

Smith, V.K. and Zhao, M.Q. (2019). 'Economy wide modeling, environmental macro-economics, and benefit cost analysis'. *Land Economics* (forthcoming).

Steinschneider, S. and Brown, C. (2012). 'Dynamic reservoir management with real-option risk hedging as a robust adaptation to nonstationary climate'. *Water Resources Research 48*, W05524.

Strzepek, K.M., Yohe, G.W., Tol, R.S J. and Rosegrant, M.W. (2008). 'The value of the High Aswan Dam to the Egyptian economy'. *Ecological Economics 66*, 117–126.

US Federal Interagency River Basin Committee, Subcommittee on Benefits and Costs (1950). *Proposed Practices for Economic Analysis of River Basin Projects*. Washington DC: US Government Printing Office.

Viscusi, K. (1993). 'The value of risks to life and health'. *Journal of Economic Literature 31*, 1912–1946.

Wang, T. and de Neufville, R. (2006). 'Identification of real options "in" projects'. Paper presented at the 16th Annual International Symposium of the International Council on Systems Engineering (INCOSE), Orlando, FL.

Wagner, G and Weitzman, M.L. *Climate Shock: The Economic Consequences of a Hotter Planet.* Princeton, N.J.: Princeton University Press.

Whittington, D., Wu, X. and Sadoff, C. (2005). 'Water resources management in the Nile Basin: the economic value of cooperation'. *Water Policy 7*, 227–252.

Whittington, D., Hanemann, W.M., Sadoff, C. and Jeuland, M. (2009). 'The challenge of improving water and sanitation services in less developed countries'. *Foundations and Trends in Microeconomics 4*, 469–609.

Whittington, D. and Wu, X. (2013). 'Water resources development on the Ganges: moving beyond ambiguity'. *Water Policy 15*, 1–8.

Wu, X. and Whittington, D. (2006). 'Incentive compatibility and conflict resolution in international river basins: a case study of the Nile Basin'. *Water Resources Research 42*, W02417, doi:10.1029/2005WR004238.

Zeleny, M. (1982). *Multiple Criteria Decision Making*. New York: McGraw-Hill.