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An economic reappraisal of the Melamchi water supply project – Kathmandu, Nepal*

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Abstract. This paper examines whether the benefits of the Melamchi water supply project in Nepal are likely to exceed its costs, assuming that high-quality municipal water services can be delivered to households and firms in the urbanized part of the Kathmandu Valley. Monte Carlo simulations are used to explore the sensitivity of the net present value and economic internal rate of return calculations to a wide range of assumptions and input parameters. We find that extreme assumptions are not required to generate large differences in economic feasibility; quite plausible differences in the values of some key parameters can lead to large differences in the economic attractiveness of the project. The results reveal that the three most important influences on net present value and economic internal rate of return are: (i) the discount rate and discounting procedure; (ii) the magnitude of monthly benefits for households connected to the new water system; and (iii) the annual growth rate in monthly benefits of connected households after the project comes on line. Our contribution lies in illustrating, with an actual case study in a developing country, the degree to which cost-benefit calculations of large infrastructure projects are influenced by key economic modeling assumptions and input parameters.

Keywords: Cost benefit analysis – Municipal water supply – Hyperbolic discounting – Monte Carlo simulations – Melamchi – Kathmandu – Nepal

JEL Classification Numbers: H42, H43, H54, Q25, Q56

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1 Introduction

In this paper, we use cost-benefit analysis to investigate the economic viability of the proposed Melamchi water supply project (MWSP) for supplying water to the urban populations of the Kathmandu Valley in Nepal. We assess the risks and benefits of the project and identify the factors that have greatest influence on its net present value (NPV) and economic internal rate of return (EIRR). The study was carried out in 2003 for the Asian Development Bank (ADB), which had already approved a major part of the MWSP in 2001. We were thus asked for a comprehensive review of whether this project would pass an ex-ante cost-benefit test when in fact the decision had already been made to move ahead. Although the MWSP has already begun, a few design and other aspects of the project are still unresolved.

The MWSP has four main components. The first is raw water supply that involves an inter-basin transfer of 170 million liters per day. Much of the water from the Melamchi River located northeast of the Kathmandu Valley will be diverted into a 26-kilometer long tunnel. The water will be delivered to a new water treatment plant, the second component of the MWSP. The third component is a bulk distribution system that includes primary transmission mains and ground storage reservoirs. The fourth component is rehabilitation of the water distribution network.

In many respects, the MWSP is a proposed solution to problems that are common to cities throughout the developing world (Whittington, 2003). Urban populations are growing rapidly, straining existing municipal water systems. Public sector water utilities have failed to provide customers with high-quality reliable service. Investment in both expansion and maintenance has been inadequate, and infrastructure has deteriorated to the point where many households only receive water a few hours a day. As a result, households and businesses have to struggle to provide themselves with the water they need. Households in Kathmandu that can afford to do so have installed private storage tanks and private treatment systems and have drilled their own private wells.

Furthermore, in many cities, including Kathmandu, farmers live near urban areas and use water for irrigation. The economic value of this water is typically low. Water supply planners have usually found, however, that the challenges of developing new sources and transferring water over long distances are less daunting than the political and institutional problems associated with reallocating water from agriculture to municipal uses. But as populations grow and nearby sources are exhausted, such new water sources are increasingly expensive.

All large inter-basin water supply projects are controversial and the MWSP is no exception. Throughout its long gestation period, there have been six main arguments against it. The first is that there were cheaper ways of obtaining raw water for Kathmandu Valley. The Melamchi diversion and tunnel are generally acknowledged as the best of the out-of-valley water supply alternatives, but there is controversy over whether in-valley sources are cheaper and sufficient to meet future demands (the only sizeable in-valley sources are those currently being used for agriculture).

The second argument against the MWSP is that the project is too expensive for the amount of water provided, which is essentially an argument that the shadow price of capital is very high in Nepal and that the opportunity costs of the MWSP have not been carefully considered. A third argument is that the project is financially unaffordable; its capital cost is about 7% of Nepal's 2001 gross domestic product. Fourth, opponents argue that it is inequitable to spend such a large portion of the government's development resources on a project to benefit the highest-income community in the country. Fifth, environmental groups have contended that communities in the Melamchi Valley need the water from the Melamchi tributary and that it should not be diverted to the Kathmandu Valley.

The sixth argument focuses on rehabilitation of the distribution network. Critics question whether the institutional arrangements are in place to achieve the needed improvements. ADB's current plan requires that a performance-based management contract be executed with a private management contractor before funds will be released for construction of the tunnel. Some critics doubt that the proposed plan goes far enough to restructure the current dysfunctional institutions and they question the commitment of government to effectively involve a management contractor. Others feel that involving the private sector is misguided and that the price of water will be too high.

Although an economic criterion is only one of several criteria that should be used to evaluate investment projects such as the MWSP, sound economic analysis can often contribute to a narrowing of the scope of such controversy. In truth, however, economic analysis of such complex investment programs is subject to a great deal of uncertainty and project economists too often offer false assurance about the finality of their results. Projects such as the MWSP require that decision makers balance the costs incurred in the near term against a stream of benefits that can be expected to last far into the future, and it is as difficult for economists as for anyone else to see clearly into the future.

This paper attempts to answer the specific question of whether the benefits of the MWSP are likely to exceed its costs, *assuming high-quality water services can be delivered to households and firms in the urbanized part of the Kathmandu Valley*. The qualification is important. Our cost-benefit analysis of the MWSP assumes that, technically and institutionally, the project can perform as intended, that is: (i) adequate raw water flow is available; (ii) the engineering design is sound; (iii) facilities will perform as planned; (iv) the proposed institutional reforms are a success; and (v) the water utility operator (with the management contractor) delivers potable water 24 hours a day to its customers. If these conditions are *not* achieved, then the estimated benefits will not materialize and worse economic consequences will follow.

Our approach to answering this question is to use Monte Carlo simulations to explore the sensitivity of the NPV and EIRR calculations to a wide range of assumptions and input parameters. Although the use of Monte Carlo methods in cost-benefit analysis is well described in cost-benefit texts (e.g. Boardman et al., 2001, pp. 173–176), there are surprisingly few published examples of its application to actual development projects in developing countries. Project analysts are not often encouraged to describe the full extent to which their results are influenced by tenuous, subjective assumptions, and discussions of specific cost-benefit case studies are rare in the academic literature (for exceptions, see Flowerdew, 1972; Mishan, 1972; Hanke and Walker, 1974; Whittington et al., 1989).

The contribution of this paper thus lies in illustrating, with an actual case study in a developing country, the degree to which cost-benefit calculations of large infrastructure projects are influenced by three key assumptions: (1) the procedure adopted to discount future costs and benefits, as well as the actual discount rate assumed; (2) the economic benefits current households derive from the infrastructure service (in this case piped water supply); and (3) the rate at which household benefits increase over the planning horizon.

The paper is organized as follows. The next, second, section describes the historical background of the MWSP and explains why it was chosen over other alternatives. The third section discusses the economic modeling approach, while the fourth section presents and discusses the results of the economic analyses. The fifth and final section offers concluding remarks.

2 Background: An overview of alternatives for increased raw water supply for Kathmandu

Historically, Kathmandu Valley has received water from 200–250 gravity-fed public taps called 'stone spouts' as well as from private wells. The stone spouts capture mountain springs and transport water to public squares where people come to bathe and collect water for their homes. Many of these stone spouts have strong flows and short queues. Although the water is often contaminated, it is perceived by most residents to be of good quality and safe to drink (Whittington et al., 2002).[1]

The late 19th and early 20th centuries witnessed construction of the first piped distribution networks in Kathmandu, which captured local springs and distributed water to a small number of households. During the second half of the 20th century, the water supply system evolved in a symbiotic relationship between a public water utility in various guises and the international donor community (Etherington et al., 2002). The first commercial water supply system was started in the 1960s, with support from the Government of India (SAPI, 2003), while the first water supply master plan for the Kathmandu Valley was completed in 1973. Subsequently, the World Bank played a major role in the municipal water sector, financing the first Kathmandu water supply project in 1975 and the second and third Kathmandu water supply projects.

Over the period 1975–1987, the first, second and third World Bank projects financed expansion of the distribution network, sewers and wastewater treatment plants, water metering, groundwater production wells, new surface water supplies and a variety of 'institutional strengthening' measures. However, the consensus among both the donors and the citizens is that much of this investment was poorly conceived and executed. Currently, it is estimated that about 70% of the residents of Kathmandu have a connection to the piped distribution network, but they typically

[1] This perception may well be true in a relative sense because the water from the piped distribution system is also contaminated.

receive poor quality water for only 1–2 hours per day. The majority of the wastewater treatment plants are not functioning and surface waters are heavily polluted.

Despite huge problems with existing infrastructure, the 1973 master plan shifted attention to the need for new out-of-valley raw water sources. It argued that in-valley water sources were inadequate to meet long-term needs and that out-of-valley sources should be studied. This process began in 1988 when a pre-feasibility study of alternative raw water sources was initiated (Binnie and Partners, 1988). In this study, a systematic examination of out-of-valley sources was carried out; almost two-dozen were evaluated using multiple criteria. Three main types of alternatives were considered: (i) surface water storage schemes; (ii) run-of-river gravity schemes; and (iii) run-of-river pumping schemes. From 1990 to 1992, a large feasibility study of the MWSP was conducted (Snowy Mountain Engineering Consultants, 1992), funded by the UNDP and executed by the World Bank. An influential environmental impact assessment in 1990 concluded that the environmental impacts of the MWSP would be lessened if its hydropower component was dropped and ADB and other donors accepted this recommendation (Stanley Associates Engineering, 1990).

What seems largely missing from the historical record is a thorough economic assessment of the costs and benefits of reallocating a portion of the water currently used for irrigation to municipal use, or how best to sequence investments in a reallocation of in-valley irrigation water and new out-of-valley sources such as the MWSP. Irrigation needs are currently supplied largely from springs and streams in the hills surrounding Kathmandu Valley. However, several studies have argued that the quantity of water available from these in-valley sources is inadequate to meet long-term demands and the quality of water is poor (e.g. JICA, 1990). In addition, it seems to be generally assumed that present irrigation use is fixed and that only the unused supplies are available to municipalities. It is also argued that reallocating irrigation water to urban uses is impractical because it would require complex negotiations with farmers. Moreover, in-valley surface water supplies are geographically dispersed making it difficult to capture economies of scale in water transmission and treatment.[2]

Table 1 lists the main decision criteria that government and consultants have used to assess the advantages and disadvantages of various raw water supply options and it shows how each 'scored' in terms of these criteria. The alternatives differ principally with regard to four criteria: (i) complexity of ongoing operations; (ii) capacity expansion potential; (iii) raw water quality; and (iv) environmental and resettlement impacts. In terms of all four criteria, the MWSP was judged to be better than or at least as good as the other alternatives. Hence, there were four main reasons why the MWSP was recommended: first, it would supply water by gravity while the other alternatives would all have high operation and maintenance costs; second, it has pristine high-quality water; third, it can be relatively easily expanded in the future at low cost; and fourth, it has few environmental and resettlement

[2] The Nippon Koei (2000) economic analysis puts an unusual twist to the social/political argument by pointing out that the transition from irrigated agriculture to urban land use is already occurring in the Kathmandu Valley, freeing up water used in agriculture for other purposes.

Table 1. Criteria-by-alternatives decision matrix: Water supply alternatives for the Kathmandu Valley

Project type	Option	Cost	Environmental impact	Resettlement issues	Capacity expansion potential	Complexity/cost of on-going operations	Raw water quality
Run of river – Gravity	Melamchi diversion	High	Very Low	Low	High	Low	Excellent
	Modified Melamchi	High	Low	Low	High	Low	Excellent
Run of river – Pumping schemes	From Trisuli River	High	Low	Low	Medium	High	Medium
	From Indrawati River	High	Low	Low	Medium	High	Medium
Surface water storage	Rosi Khola – upper	High	Low	Low	Medium	High	Good
	Rosi Khola – lower	High	Low	Low	Medium	High	Good
	Kulekhani	High	Low	Low	Medium	High	Good
In-valley sources	Surface	Uncertain	Uncertain	Low	High	Uncertain	Medium
	Groundwater	Low	Low	Low	Low	Medium	Medium

impacts. In summary, the available literature suggests that the choice of MWSP over other out-of-valley water sources was not ill-considered.

3 Economic approach to the reappraisal of the Melamchi water supply project

3.1 Economic modeling approach

The evaluation of the MWSP presents a classic problem in cost-benefit analysis, i.e. how to compare a time stream of large capital costs in the early years with a time stream of benefits that commences after the project is completed and extends far into the future. Economists agree that a benefit or cost in the future should be worth less than one today. A procedure is thus needed to determine exactly how to calculate the weights for discounting future benefits and costs so that they can be compared with benefits and costs in earlier periods. The conventional procedure used by most economists (and adopted by the ADB) is to assume that these weights, or discount factors, can be calculated using the following constant exponential discount function:

$$w_t = 1/(1 + r)^t \quad (1)$$

where w_t is the weight attached to costs or benefits t years from when the project begins, and r is the (constant) rate of time preference.

Although this constant exponential function is commonly used for project appraisal, there is not universal agreement on its appropriateness, particularly for capital investments that produce benefits that extend far into the future such as the MWSP (Weitzman, 1998; Frederick et al., 2002). There are at least two fundamental reservations about the constant exponential function (Portney and Weyant, 1999; Poulos and Whittington, 2000).

First, if a cost-benefit analyst employs a 'high' discount rate in the range recommended by most development banks (e.g. 10–12%), the underlying assumption is that the funds used to finance the project are drawn from private sector investment and that the returns from this private sector investment would have all been reinvested in other attractive private sector investments throughout the life of the project. This assumption implies that there are very high opportunity costs associated with the investment project, i.e. that the shadow price of capital is high because both donors and government have many other very attractive opportunities that will be displaced if the project is undertaken. This assumption may or may not be true.

An alternative approach is to directly assign a shadow price of capital and then discount the cost and benefit streams by a social rate of time preference, typically 2–4% (Dasgupta et al., 1972). This procedure increases both the capital costs (because these would be multiplied by a shadow price of capital greater than one) and the present value of the benefit stream (because the benefits in the future would be discounted by 2–4% instead of 10–12%). The end result of this shadow pricing capital approach (SPCA) on NPV depends on the project's particular time stream of costs and benefits, the magnitude of the shadow price of capital, the social rate of time preference and the original discount rate used. This approach is in fact difficult to implement because to our knowledge there are no estimates of the shadow price of capital in Nepal (nor guidance from the ADB on what value might be used).

Second, the use of a constant exponential discount function and a high discount rate implies that the weight assigned to a benefit produced by the project far in the future approaches zero. This is in fact contrary to how many people think about distant benefits (Loewenstein and Prelec, 1992): arguably, many would put a low weight on benefits far in the future, but not as small as that obtained by the constant exponential discount function.

Many people's rates of time preference are probably better characterized by a non-exponential 'hyperbolic' discount function of the following form:

$$w_t = 1/(1 + \alpha t)^{\rho/\alpha} \qquad (2)$$

where w_t is the discount factor in year t and α and ρ are parameters with values greater than zero (Henderson and Bateman, 1995). Figure 1 compares the weights (or discount factors) resulting from a constant exponential discount function with r equal to 0.10 and a hyperbolic discount function with α and ρ both equal to 0.20. It is illustrative to consider the discount factors far into the future that result from these two discount functions: the constant exponential function yields a discount factor in year 50 of 0.01, i.e. \$1 of benefits in year 50 is equivalent to \$0.01 today; while the hyperbolic discount function yields a discount factor in year 50 of 0.1,

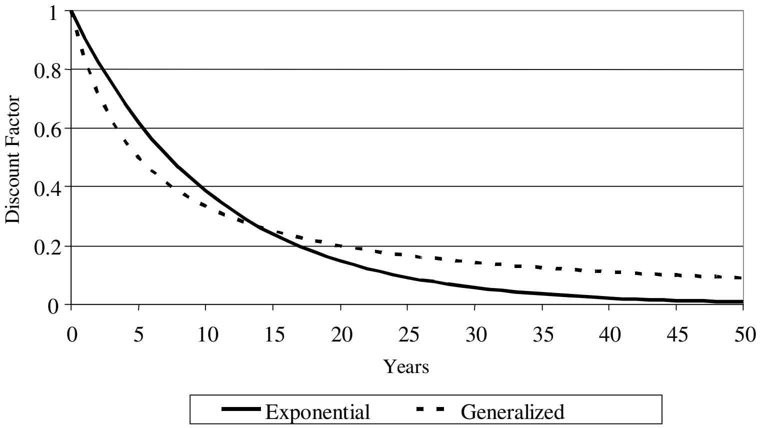

Fig. 1. Constant exponential and generalized hyperbolic discount functions

i.e. $1 of benefits in year 50 is equivalent to $0.10 today. The hyperbolic discount function assigns a small value to a benefit 50 years in the future, but it is ten times larger than that assigned by the constant exponential discount function.

Both of the alternatives to current discounting practice (SPCA and hyperbolic discounting) are important for the evaluation of capital-intensive projects with long economic lives because they place greater weight on benefits generated far into the future. Hence, in this paper, cost-benefit calculations are presented using the conventional discounting procedure (constant exponential discounting), as well as the alternative approaches of SPCA and hyperbolic discounting.

Just as with conventional discounting, the results of using the SPCA and hyperbolic discounting are sensitive to the values of the parameters chosen. We assume a shadow price of capital of 2 based on our judgment that this estimate is a plausible order of magnitude, although we have no empirical evidence to support it. Our assumed social rate of time preference (3%) is likewise not supported by empirical evidence from Nepal, but most economists would probably agree that the social rate of time preference should be in the range of 2–4% (Weitzman, 2001), much lower than the assumed 10–12% opportunity cost of capital. The assumed values of α and ρ for hyperbolic discounting are also arbitrary, but we chose them so that the difference between the discount factors generated by the hyperbolic discount function and a constant exponential function with a 10% annual discount rate would be relatively minor over most of the planning horizon (see Fig. 1).

3.2 Decision rules used for economic evaluation

Results of cost-benefit calculations are presented in terms of both NPV and EIRR. A positive net present value indicates that the present value of the benefit stream is greater than the present value of the cost stream; it says that on balance, ‘people’ would be better off if the project were implemented. Two points are worth noting when using this criterion. First, there may be other projects with higher returns per unit of capital expenditure. A comprehensive capital budgeting exercise would compare the NPV per unit of capital of the MWSP with the NPV per unit of capital of all other possible investments and allocate the available capital to the investment program that would yield the highest total NPV. Thus, there is no assurance that just because the MWSP might have a positive NPV it would be included in such an investment program.

Second, the reference to 'people' does not necessarily mean only the 'people of Nepal.' ADB's project appraisal methodology implies that benefits accrue to the people of Nepal, but the costs of the project are incurred by people both in and outside Nepal (Whittington and MacRae, 1986). This point bears elaboration. ADB and other donors are providing the people of Nepal with grants and concessional financing to undertake the MWSP. The benefits of this project are largely confined to the residents of Kathmandu Valley; however, not all of the costs are borne by them or even by the citizens of Nepal. Some of the costs are incurred by the people who provide the grants and concessional financing living outside Nepal. Hence, in making economic appraisals of their projects, ADB requires that they pass a cost-benefit test, taking full account of all the benefits, regardless of who receives them, and all the costs, regardless of who pays them.

Naturally, the people of Nepal see the problem differently: they are not overly concerned about the costs imposed on people outside Nepal. It should thus not be a surprise if His Majesty's Government of Nepal does not find the results of this cost-benefit analysis about the pros and cons of the MWSP persuasive. An example can help clarify this point. Consider a project whose cost stream has a present value of $100. Assume donors offer a package of grants that amount to $50 and government has to pay the remaining $50 of the cost. Suppose the present value of the benefit stream is $80, all of which accrue to people in Nepal. From the perspective of the government, this project appears to have positive NPV of $30 ($80 − $50). However, based on ADB's appraisal methodology, the NPV is negative $20 ($80 − $100). Hence, the project would fail ADB's economic test even though it would pass a cost-benefit test from the perspective of government.

3.3 Quantifying project costs

The financial cost estimates provided in project preparation reports typically require adjustment in order to better reflect their real opportunity costs. For example, import duties and other taxes are actually transfer payments and not economic costs. Contingency cost estimates are also removed, not because unforeseen events may not occur, but because it is preferable to address risk explicitly in the cost-benefit analysis. Ideally, one would shadow price the inputs required for construction of the project, but estimates of shadow prices were not available; it is thus assumed that the financial cost estimates adjusted for transfers are reflections of real opportunity costs in Nepal.

Table 2 presents the magnitude and time profile of the costs for the different components of the MWSP after making these adjustments. As shown, the raw water supply component of the project (intake weir, tunnel and access roads) only accounts for about one-third of total project cost. The bulk distribution system, treatment system and rehabilitation of the existing pipe network represent the majority of project cost (and would need to be incurred whatever raw water supply source were chosen).

The time profile of costs in Table 2 reflects the most optimistic construction schedule. In fact, the MWSP is already over a decade behind its original schedule, so it seems prudent to explore scenarios in which construction delays continue to occur. To show how construction delays affect the economic attractiveness of the project, NPV is calculated assuming that the project is completed on schedule and, alternatively, that commissioning is delayed until 2013 instead of 2010. The cost estimates in Table 2 also include modest mitigation costs for resettlement.

3.4 Quantifying project benefits

Private households with connections will receive the majority of the MWSP benefits. Other important beneficiaries include firms connected to the improved system and households not connected but who still collect their water from it (e.g. purchase or obtain water free from neighbors with connections). The main task on the benefit side of the ledger is to estimate what these private household benefits will be.

Estimates of household benefits are based on a contingent valuation (CV) survey of a random sample of 1,500 households conducted in Kathmandu in 2001 (Whittington et al., 2002). Respondents were asked whether they would vote for a program that would deliver reliable water supply to their household if it resulted in a monthly water bill of a specific amount. They were told that their monthly bill would entitle them to about 15 cubic meters per month (about 70 liters per capita per day). Respondents were then told to assume that the program was adopted and were asked what their household would do (e.g. for connected households, whether they would stay connected or would choose to disconnect from the piped distribution system). From the responses to these hypothetical questions, we derived a range of estimates of households' mean willingness to pay (WTP) for improved water services similar to those from the MWSP. These mean WTP estimates are quite high, on the order of US$14 per month per household, which is the 'gross' WTP for improved service. Current household water bills in Kathmandu are about US$2 per month, so the estimate of net benefits is approximately US$12 per month per household.

Most economists and water resources policy analysts will likely be surprised by estimates of household benefits this large. CV surveys are routinely criticized because the answers that respondents give are not tempered by their actual budget constraints and many economists would probably argue that these CV estimates are unrealistically high. However, these values are not implausible given the high coping costs and inconvenience experienced by households in Kathmandu. Moreover, one can argue that households probably do not perceive all of the health benefits of improved water supplies and that these CV estimates may actually underestimate benefits from an improved system. Also, to the extent that positive externalities are associated with households' use of the improved water supply (i.e. that household

Table 2. Economic cost estimates of the Melamchi water supply project (US$ millions)

Project component	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total costs through 2015
Melamchi diversion scheme	0	0	15.92	21.22	31.83	21.22	15.92	0	0	0	0	0	0	106.1
Access roads	6.85	6.85	0	0	0	0	0	0	0	0	0	0	0	13.70
Water treatment plant	–	–	4.88	9.76	12.20	12.20	9.76	0	0	0	0	0	0	48.80
Bulk distribution system	0	0	4.50	9.00	11.25	11.25	9.00	0	0	0	0	0	0	45.00
Initial distribution improvements	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distribution network improvements	0	0	4.05	4.05	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	1.62	81
In-valley water source improvements	5.35	5.35	5.51	0	0	0	0	0	0	0	0	0	0	16.20
Physical capital	12.20	12.20	34.85	44.03	64.19	53.58	43.59	8.91	8.91	8.91	8.91	8.91	1.62	310.80
Other	3.50	3.50	11.48	11.48	11.48	7.98	7.98	0	0	0	0	0	0	57.40
Total capital	15.70	15.70	46.33	55.51	75.67	61.56	51.57	8.91	8.91	8.91	8.91	8.91	1.62	368.20
Annual O&M and replacement costs	1.88	1.88	1.88	1.88	1.88	1.88	1.88	4.92	5.10	5.44	5.74	6.04	6.10	46.50
Expected earthquake risk	0	0	0	0	0	0	0	0.10	0.10	0.10	0.10	0.10	0.10	0.60
Total economic costs	17.60	17.60	48.20	57.40	77.50	63.40	53.40	13.80	14.00	14.40	14.60	15.00	7.70	414.60

B benefits from household A's use of better quality water), these would not likely be reflected in the CV estimates. In our benefit-cost analysis, estimates of household benefits derived from the CV survey by Whittington et al. (2002) are used, and sensitivity analyses are made by varying household size, liters per capita per day, monthly household benefits and other parameters.

An important assumption pertains to how the estimated benefits of improved water supply will increase over the planning horizon. If the Nepalese economy grows strongly over the next fifty years, the per-household benefits of the MWSP will grow as well. If the Nepalese economy grows more slowly or stagnates, the per-household benefits will stagnate. In the cost-benefit analysis, we assume a range of values for the annual rate of growth in household benefits.

3.5 Other assumptions

The four components of the Melamchi project have different economic lives and their excess capacity may run out at different times. The diversion scheme and tunnel, for example, may last over 100 years. The water treatment plant, transmission mains, storage reservoirs and the distribution network will also last for many years, but will need to be replaced sooner than the tunnel. The economic life of these components of the MWSP varies from about 15 to 40 years. Furthermore, the capacity of these components will enable the provision of more water than that supplied from the tunnel. If the raw water supplies from the MWSP are fully utilized before the end of the planning horizon, additional raw water will be needed. In this case one needs to be careful not to assign the total benefits of supplying water to the Kathmandu Valley to the MWSP. However, if there is excess capacity in the water treatment plant, transmission mains, storage reservoirs and the rehabilitated distribution network when the raw water supplies from the MWSP run out, then some of the total benefits should be ascribed to the MSWP. In the cost-benefit analysis, checks are made of when the raw water supply from the MWSP is fully utilized. If additional raw water supplies are needed, the costs and benefits of this capacity expansion are not included in the analysis.

Kathmandu is an earthquake-prone region and one important project risk is that a severe earthquake could cause the Melamchi diversion tunnel to collapse (Metier Scandinavia, 2000). Estimating the likelihood of such a catastrophe is a difficult, subjective process. We have attempted to approximate the economic cost of the annual risk of total tunnel destruction from an earthquake by assuming an annual probability of catastrophic failure of 1 in a 1000 and assigning the project an expected annual loss of US$100,000; we have also conducted some sensitivity analyses using different values (Mark and Stuart-Alexander, 1977).

3.6 Probabilistic analysis

In the next section, we offer our best judgment of the most likely NPV and EIRR of the MWSP. There are, however, many uncertainties in how this investment program will play out. A better approach is to use Monte Carlo analysis to assess the likelihood that the NPV and the EIRR of the MWSP will exceed (or fall below) specified values. The output of the Monte Carlo simulations is a cumulative distribution function (CDF) rather than a single value for the different economic evaluation criteria.

Table 3 lists 30 input parameters used in the economic model. All of these parameters are to some extent uncertain. A subset of 11 of the 30 main model parameters (listed at the bottom of Table 3) was identified that had the greatest effect on the economic evaluation criteria. A range of possible values and a uniform probability density function was assumed for each of these 11 parameters and they were varied simultaneously in Monte Carlo simulations. For example, based on judgment, we assumed that the constant exponential discount rate could have a value anywhere from 6% to 12%; a uniform probability density function was chosen for this range, which implies that all values in the range are equally likely.

4 Results and discussion

The economic model shows that the NPV of the MWSP can be positive or negative (and the EIRR can be high or low) depending upon the combination of assumptions one makes about the input parameters. Extreme assumptions are not required to generate large differences in NPV and EIRR; quite plausible differences in the values of some key parameters can lead to large differences in the economic attractiveness of the MWSP. The challenge is to show how NPV and EIRR change with different assumptions about parameter values.

Table 4 presents the NPV and EIRR for four combinations ('scenarios') of assumed parameter values under the three different approaches for discounting: (i) conventional; (ii) shadow pricing capital with a social rate of time preference; and (iii) hyperbolic. The assumed parameter values in our base case scenario are shown in the column labeled 'Scenario 1 (Base Case).' They are as follows: (i) ADB's official discount rate of 12%; (ii) the official capital cost estimates and construction schedule of the MWSP; and (iii) monthly benefits per connected household of

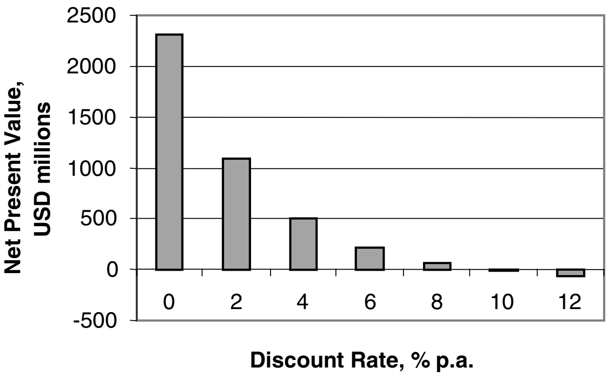

Fig. 2. Effect of discount rate on Net Prevent Value for base case (conventional discounting approach)

Table 3. Key parameters of economic model

Parameters	Base case	Fixed in Monte Carlo?	Type of distribution	Low limit	High limit
Base year	2003	Yes	None	–	–
Planning horizon for cost benefit analysis, years	50	Yes	None	–	–
Year capacity of planned project comes online (commission year)	2010	Yes	None	–	–
Year capacity of delayed project comes online (commission year)	2013	Yes	None	–	–
Existing capacity in 2003, million liters per day (MLD)	110	Yes	None	–	–
Capacity added by JICA project by 2004, MLD	20	Yes	None	–	–
Capacity added in commission year by Melamchi project, MLD	170	Yes	None	–	–
Unaccounted for water in base year, %	40	Yes	None	–	–
Year distribution network improvements start	2005	Yes	None	–	–
Annual reduction in unaccounted for water starting 2005, % per annum (p.a.)	2	Yes	None	–	–
Population connected to network in 2003, %	70	Yes	None	–	–
Population connected to network in commission year, %	70	Yes	None	–	–
Unconnected population in 2003 not using water from network, %	10	Yes	None	–	–
Unconnected population in 2053 not using water from network, %	10	Yes	None	–	–
Unconnected population in 2003 using water from network, %	20	Yes	None	–	–
Unconnected population in 2053 using water from network, %	20	Yes	None	–	–
Commercial/industrial sales in 2003, MLD	6	Yes	None	–	–
Commercial/industrial sales in commission year, MLD	15	Yes	None	–	–
Growth in commercial sales after commissioning, % p.a.	1	Yes	None	–	–
Consumption for HH without connections using water from network, liters per capita per day (LCD)	50	Yes	None	–	–
Benefits to commercial/ industrial users, US$ per m3	1	Yes	None	–	–
Multiplier for shadow price of capital	2	Yes	None	–	–
Hyperbolic discount rate parameter	0.2	Yes	None	–	–

Table 3 (continued)

Parameters	Base case	Fixed in Monte Carlo?	Type of distribution	Low limit	High limit
Discount rate, % p.a.	8	No	Uniform	6	12
Persons per household (HH)	7	No	Uniform	6	8
Consumption for HH with connections, LCD	70	No	Uniform	70	120
Benefits for HH with connections in commission year, US$/month per HH	12	No	Uniform	6	18
Benefits for HH without connections using water from network, US$/month per HH	4	No	Uniform	1	7
Annual growth in benefits for HH with connects starting commission year, % p.a.	0	No	Uniform	-1	2
Annual growth in benefits for HH without connects starting commission year, % p.a.	0	No	Uniform	-1	2
Annual growth in benefits for commercial starting commission year, % p.a.	0	No	Uniform	-1	2
Salvage value of tunnel in 2053, US$ millions	70	No	Uniform	20	120
Growth in HH connections first 3 years post commissioning, % p.a.	2.0	No	Uniform	1	3
Growth in HH connections starting 4th year post commissioning, % p.a.	0.8	No	Uniform	1	3

US$12 per month that do not increase or decrease in real terms over the 50-year planning horizon.

Under baseline assumptions, the conventional discounting approach yields a negative NPV of US$65 million for the MWSP. On the other hand, the NPV using a hyperbolic discounting function (α and ρ =0.20) is positive at US$207 million. Assuming a shadow price of capital of 2 and a social rate of time preference of 3%, the NPV of the project is also positive at US$487 million.

In Scenario 2, the only change in the parameter values is that the discount rate for the conventional discounting approach is reduced from 12% to 8%. This single change increases the NPV of the MWSP from −US$65 million to +US$63 million. Figure 2 shows the effect of different discount rates on NPV for the Base Case; NPV switches from positive to negative at a discount rate above 9%. In Scenario 3 the assumed annual growth in real monthly household benefits is increased from 0% to 2% and the discount rate stays at 8% as in Scenario 2. In this case, the NPVs associated with all three of the discounting approaches are strongly positive. The shadow pricing capital approach yields a very high NPV (+US$1,177 million) because the future benefit stream is growing in real terms (at 2% per year) and the low social rate of time preference (3%) implies that these future benefits are valued quite highly.

Table 4. Estimates of net present values and economic internal rates of return of the Melamchi water supply project using three discounting approaches (4 scenarios)

Input Parameter	Scenario 1 (Base)	Scenario 2	Scenario 3	Scenario 4
Conventional (real) discount rate, % p.a.	12	8	8	12
Monthly benefits per connected household, US$	12	12	12	8
Annual growth in monthly benefits, connected households , % p.a.	0%	0%	2%	0%
Construction schedule	As planned	As planned	As planned	Delayed
Hyperbolic discount function parameter ($\propto$)	0.20	0.20	0.20	0.20
Shadow price of capital	2	2	2	2
Social rate time preference, % p.a.	3	3	3	3
NPV – Conventional discounting, US$ M	−65	63	233	−108
NPV – Hyperbolic discounting, US$ M	207	207	459	93
NPV – Shadow pricing capital, US$ M	487	487	1177	168
EIRR – Conventional discounting, % p.a.	9.4	9.4	12.1	7.1
EIRR – Hyperbolic discounting, % p.a.	n.a..	n.a.	n.a.	n.a.
EIRR – Shadow pricing capital, % p.a.	5.9	5.9	8.3	4.1

Notes:
The estimates assume fixed parameter values, i.e. not based on Monte Carlo simulation
NPV: net present value
EIRR: economic internal rate of return
M: millions
p.a.: per annum
n.a.: not applicable

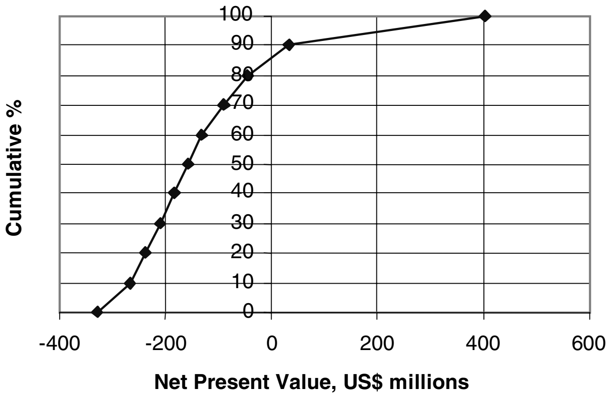

Fig. 3. Monte Carlo simulation results: cumulative distribution function of NPV of MWSP using conventional (constant exponential) discounting

On the other hand, Scenario 4 shows what happens to the economic viability of the MWSP if: (i) monthly household benefits turn out to be $8 per month instead of US$12; (ii) household benefits do not increase in real terms over the planning horizon; (iii) the construction schedule slips by 3 years; and (iv) the ADB's official discount rate of 12% is used for conventional discounting. In this scenario, NPV of the MWSP using conventional discounting is strongly negative (−US$108 million) and the EIRR is 7.1%. If either the hyperbolic discounting approach or the SPCA is used, however, NPV remains positive.

The results in Table 4 illustrate differences in the three different discounting approaches to valuing future costs and benefits. First, the conventional discounting approach results in lower NPVs than both the hyperbolic discounting function and the SPCA and the hyperbolic discounting approach results in lower NPVs than the SPCA (given the parameter values we have assumed). Second, the EIRR using the SPCA is always lower than the EIRR associated with the conventional approach because the SPCA raises the costs in the early years and a lower discount rate is required to increase the present value of the benefit stream to counteract the higher NPV of the costs. The EIRR is not a particularly intuitive or useful concept to associate with a hyperbolic discount function.

Figure 3 shows the CDF for net present value from the Monte Carlo simulations using conventional discounting; it corresponds to Scenario 1 (the Base Case in Table 4) except that now 11 parameters are assumed to be uncertain and values for them are drawn randomly from the assumed uniform probability density functions. The CDF shows that the calculated NPVs based on 500 randomly selected trial values of the parameters ranged from about −US$330 million to +US$400 million. The probability that the NPV is greater than zero (i.e. positive) is only about 15%, which means there is roughly an 85% chance that the MWSP has negative NPV.

The pertinent statistics for the CDF in Figure 3 are presented in Table 5, which shows the mean and median NPV of the MWSP to be −US$130 million and −US$157 million, respectively (column 1, 'NPV Conventional discounting'). Half the calculated NPV values were less than −US$157 million, and 70% were less

Table 5. Cumulative distributions of economic evaluation criteria

	(1)	(2)	(3)	(4)	(5)	(6)
Evaluation criterion:	NPV Conventional discounting	NPV Hyperbolic discounting	NPV SPCA	NPV Delay	EIRR Conventional discounting	EIRR SPCA
	US$ (Millions)				% per year	
Mean NPV	−130	86	588	−94	6.4%	6.6%
Median NPV	−157	64	524	−125	6.4%	6.5%
Percentile						
0%	−331	−190	−175	−300	2.6	3.6
10%	−267	−114	83	−238	4.2	4.4
20%	−238	−67	212	−211	4.8	4.9
30%	−209	−26	320	−179	5.3	5.5
40%	−184	17	437	−153	5.8	6.2
50%	−157	64	524	−125	6.4	6.6
60%	−131	108	633	−92	6.9	7.1
70%	−90	162	777	−54	7.4	7.6
80%	−44	230	961	5	8.0	8.2
90%	33	316	1169	81	8.7	9.1
100%	402	619	1832	619	10.7	10.9

Notes:
NPV: net present value
SPCA: shadow pricing capital approach
EIRR: economic internal rate of return

than −US$90 million. As depicted in column 4, it is interesting to note that the NPV actually improves slightly if the MWSP is delayed. Column 2 shows that mean and median NPVs using the hyperbolic discounting function were positive, US$86 million and US$64 million respectively. Column 3 shows the mean and median NPVs using the SPCA were US$588 million and US$524 million, respectively. The last two columns in Table 5 show the EIRR based on conventional discounting and the SPCA.

One of the strengths of Monte Carlo simulation is that it enables probability statements about economic evaluation of the project. For example, column 2 in Table 5 suggests that the chance is about 1 in 3 of the NPV being negative if the hyperbolic discounting approach and the assumed parameter values for α and ρ are used; column 3 shows that the chance of a negative NPV decreases to about 5% with the SPCA discounting approach. On the other hand, columns 1 and 4 in Table 5 indicate that there is high probability (at least 70%) that NPV will be negative if a conventional discounting approach is utilized. Columns 5 and 6 suggest that the EIRR of the project has about a 50% chance of exceeding 6%, whether conventional discounting or SPCA is used.

Another of the strengths of Monte Carlo simulation is that it provides a basis for identifying which of the uncertain parameters have the greatest effect on the economic evaluation. The analyses of variance are based on rank correlation coefficients between each parameter and model output. Column 1 in Table 6 shows the effect of different parameters on NPV calculated using the conventional discounting approach; note that the percentage contributions to variance in each column of Table 6 sum to 100%. The parameter that had the greatest effect on NPV was the monthly benefit per household connected to the network; it accounted for 60% of the total variation in NPV (recall from Table 3 that net benefit/HH was assumed to range uniformly from US$6 to US$18 per month). The second most influential parameter was the discount rate, which varied from 6% to 12% (Table 3) and accounted for 19% of the total variation in NPV. A third parameter that had nearly the same magnitude of effect on the NPV as the discount rate was the annual growth in net benefits for households connected to the network (the growth rate ranged from -1% to $+2\%$ per annum). The remaining eight parameters had relatively small effects on NPV. For example, the salvage value of the tunnel at the end of the planning horizon was assumed to range from US$20 million to US$120 million (Table 3). Despite such a large range of uncertainty, this parameter had negligible effect on the project's NPV. Similarly, the benefits to commercial users and the rate at which households are connected to the network following commissioning of the MWSP had little effect on the final results.

The results in Table 6 indicate which of the uncertain parameters are most important and deserve special attention during project implementation to ensure that the project is economically successful. For each of the eleven parameters listed in Table 6, three of them are consistently shown to have the greatest effect on uncertainty: the discount rate (assuming the conventional discounting approach), monthly benefits per household and the rate at which household benefits change over time. Hence, in judging the economic worthiness of the MWSP, these are the parameters that merit most consideration by decision makers. For example, between 15% and 30% of the variation in economic evaluation decision rules is due to uncertainty in how the benefits of MWSP will change over time. While this is an important finding, there is little that any of the MWSP planners can do about this parameter since it depends to a large extent on how the economic prosperity of Nepal changes in the future. Results also show that the approach adopted for discounting future benefits is central to judging the economic attractiveness of the MWSP.

5 Concluding remarks

Because our probabilistic cost-benefit analysis showed such a wide range of plausible NPV and EIRR, one might be tempted to conclude that nothing much was learned from this economic reappraisal of the MWSP. However, in our view such a conclusion would be incorrect. The analysis highlights the inherent well-known difficulties in trying to carry out a systematic cost-benefit analysis of large infrastructure projects that provide benefits far into the future. If one feels justified in using either the hyperbolic discounting approach or the SPCA, the probabilistic cost-benefit analysis indicates that the MWSP has an excellent chance of delivering benefits that exceed the costs if the project is properly designed and constructed, there are no significant capital cost overruns and the institutional reform process succeeds. Particularly for the Nepalese people this project looks very beneficial

Table 6. Contributions of parameters to variation in net present value using different discounting approaches

	(1)	(2)	(3)	(4)
	NPV Conventional discounting	NPV Hyperbolic discounting	NPV SPCA	NPV Delay
Discount rate, % per annum (p.a.)	19	0	0	23
Persons per household (HH)	2	1	1	1
Consumption for HH with connections, LCD	2	2	2	2
Benefits for HH with connections in commission year, US$/mo per HH	60	71	66	58
Benefits for HH without connections using water from network, US$/mo per HH	1	0	0	0
Annual growth in benefits for HH with connects starting commission year, % p.a.	15	25	30	17
Annual growth in benefits for HH without connects starting commission year, % p.a.	0	0	0	0
Annual growth in benefits for commercial starting commission year, % p.a.	1	0	0	0
Salvage value of tunnel in 2053, US$ millions	0	0	0	0
Growth in HH connections first 3 years post commissioning, % p.a.	0	0	0	0
Growth in HH connections starting 4^{th} year post commissioning, % p.a.	0	0	0	0

Notes:
The entries in the table are % of total variation in NPV due to each parameter. The percentage contributions to variance in each column sum to 100% (subject to rounding error)
NPV: net present value
SPCA: shadow pricing capital approach
p.a.: per annum
mo: month
HH: household
LCD: liters per capita per day

if all of the above conditions are met: Nepal stands to gain essentially all of the benefits and in addition will receive much of the financing in the form of grants and concessional loans.

But these are big 'ifs.' As noted earlier, the cost-benefit analysis performed is contingent on a number of key assumptions, namely, on the ability to supply potable water to households 24 hours a day. The engineering and political challenges ahead for the water utility/management contractors, government and the donors to achieve this high level of service appear to be formidable.

Our results also reveal that the three most important influences on NPV and EIRR are: (i) the discount rate; (ii) the magnitude of monthly benefits for connected households; and (iii) the annual growth rate in monthly benefits of connected households after the project comes on line. There is substantial controversy and uncertainty surrounding all three. For example, if one foresees a Nepalese economy that is growing strongly and steadily over the next fifty years, there is little doubt that the discounted value of the benefit stream from the MWSP will exceed the costs of an efficiently executed project. But if the Nepalese economy stagnates or declines, the economics of the MWSP look much worse.

The choice is complicated by the fact that improved infrastructure such as the MWSP is to some extent a prerequisite for strong, sustained economic growth, so there is always a chicken-and-egg type of problem in assessing the economic attractiveness of large infrastructure projects, i.e. strong economic growth is needed to justify the project, but the project is needed to sustain strong economic growth. In the case of the MWSP, the ADB and other donors must in effect place a bet on the future of the Nepalese people and their economy, giving large subsidies now in the form of grants and concessional financing in the hope that the benefits to future generations in Nepal are far more valuable than the costs today 'to whomsoever they may accrue.' It is indeed the kind of bet that developers of large infrastructure projects have always made.

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