Uncertainty in the Economic Appraisal of Water Quality Improvement Investments:

The Case for Project Risk Analysis

William J. Vaughan
Arthur H. Darling
Diego J. Rodriguez

Inter-American Development Bank

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William J. Vaughan is a Senior Economist in the Environment Division of the Sustainable Development Department. Arthur H. Darling is a Principal Economist in the Environment and Natural Resources Management Division of Regional Operations Department I. Diego J. Rodriguez is an Economist in the Environment Division of the Sustainable Development Department.

The application explained in this paper was originally performed as part of the economic feasibility analysis of an investment lending operation approved by the Bank in 1999 (BR-2265, Tietê River Decontamination, Stage II). Comments were received from a number of IDB staff during the approval process. A condensed version of the paper was accepted in April 2000 for forthcoming publication in a special issue of *The Journal of Water Resources Planning and Management*, with the addition of Professor Clifford S. Russell of Vanderbilt University as coauthor. We are grateful to him, Professor John Braden of the University of Illinois (editor of the special issue) and three anonymous reviewers for their comments and suggestions. Dr. Thomas J. Lutton, Deputy Director of Financial and Statistical Analysis at the Comptroller of the Currency and Adjunct Professor of Economics at Virginia Polytechnic Institute and State University also provided suggestions and guidance as an advisor to D. J. Rodríguez, who fulfilled the master's degree requirement in economics with the thesis *Cost-Benefit Analysis of Environmental Quality Improvement Projects: Uncertain Benefits of Willingness to Pay from Referendum Contingent Valuation*.

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E-mail: mariak@iadb.org
Fax: 202-623-1786
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FOREWORD

This is the last in a quartet of papers by SDS/ENV about the economic analysis of environmental quality improvement projects in the water sector, and completes the series. The first paper (ENV-126) reviewed the state-of-the art in economic analysis practice at the Inter-American Development Bank (IDB) and found that a majority of the economic analyses of ambient water quality improvement projects undertaken since 1989 have used the contingent valuation (CV) method to estimate environmental benefits. Paper ENV-130 discovered that with referendum CV survey data there are nearly a score of alternative ways to measure the mean or median of willingness to pay (WTP) for environmental improvements, and that past IDB practice had been using an approach that systematically understated project benefits. The optimal sample size needed to get an accurate estimate of benefits from such surveys was discussed in paper ENV-136.

The studies noted above emphasize that uncertainty is inherent in project analyses that are based on CV benefit estimates. This paper explains how to take uncertainty fully into account in economic cost-benefit analysis by using Monte Carlo simulation rather than conventional sensitivity analysis, which provides a great deal less information about project risk. The paper argues that when benefits and costs are uncertain, decision makers in the Bank’s borrowing member countries would be well-served by a full economic evaluation of the risks associated with prospective investments.

Walter Arnsberg
Environment Division
Sustainable Development Department
Inter-American Development Bank

ABSTRACT

The value of the services provided by environmental quality improvement projects are subject to large margins of error. These services are not sold in markets and have no established prices, and often have to be valued through stated preference surveys (i.e. contingent valuation). These uncertainties are necessarily transmitted into uncertainties about the net present value (NPV) of environmental investments. The NPV distribution can and, we argue, should, be quantified and evaluated during the project design and approval process.

The statistical techniques for imputing benefits using referendum contingent valuation data are sensitive to the analyst's assumptions. Equally justifiable parametric and nonparametric evaluation routes to average benefits may produce very different mean estimates, estimates that are outside the 99.5% statistical confidence intervals generated by any given route. In short, average (and, by implication, total) benefit estimates based on contingent valuation are fraught with *statistical* uncertainty. This source of uncertainty can be measured by the standard error of the mean, computed using any particular approach. However, the more important *methodological* uncertainty about which approach to extracting mean benefits is best has no such easy resolution, and both types of uncertainty about benefits matter.

In addition, environmental investments often are accompanied by uncertainties about execution timing provoked by institutional obstacles, divergent interests of stakeholders, and the behavior of the natural world the project operates on and in, as well as the more familiar uncertainties about costs and economic prices. To reflect all of these uncertainties, the economic cost-benefit analysis demonstrated in this paper employs Monte Carlo simulation, which permits their effect on the distribution of project net present value to be quantified.

The paper argues that Monte Carlo risk analysis offers a more comprehensive and informative way to look at project risk ex-ante than the traditional (and often arbitrary), one-influence-at-a-time sensitivity analysis approach customarily used in IDB analyses of economic feasibility. The case for probabilistic risk analysis is made using data from a project for cleaning up the Tietê river in São Paulo, Brazil. A number of ways to handle uncertainty about benefits are proposed, and their implications for the project acceptance decision and the consequent degree of presumed project risk are explained and illustrated.

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THE RATIONALE FOR PROBABILISTIC RISK ANALYSIS

In the terminology of decision analysis, a decision based on a Cost-Benefit (CB) rule is a two-action problem with infinite states of nature (Pfaffenberger 1987). An investment proposal can either be accepted if in expectation it will yield a positive discounted net cash flow above the break-even point of Net Present Value (NPV) equal to zero, or rejected if it does not. Because the many influences on NPV are random variables, so is NPV. Therefore, at least conceptually, there are an infinite number of possible net discounted cash flow outcomes from a prospective investment, each with its own probability of occurrence.

The risk-neutral investment decision rule (Brent 1996, Harberger 1996) is to proceed with a capital investment project if the *expected value* of its discounted stream of net benefits, E(NPV), is non-negative. If the expectation of discounted net benefits is negative the project proposal is economically infeasible. The conceptually correct way to obtain E(NPV) is not through a deterministic analysis that inconsistently combines extreme value guesses for some variables driving benefits or costs with an assortment of empirically-based measures of central tendency (i.e. a mixture of means, medians and “most likely” modes) for others. Rather, in principle, the “best” estimate of NPV (in the sense of being unbiased, not most likely), is obtained by weighting each possible value of every variable that determines NPV by the probability of its occurrence (Squire and van der Tak 1975, Chapter 5). That is exactly what probabilistic risk analysis based on Monte Carlo simulation does.[1]

In addition to the mean of NPV, if we want to talk about risk, we also need to ask about spread or dispersion. Risk can be viewed rigorously as either the probability of occurrence of an undesirable outcome (Evans and Olson 1998) or the variance of the expected value of NPV (Squire and van der Tak 1975). Probability is the best-known formalism for quantifying uncertainty (Morgan and Henrion 1990), and probabilistic risk analysis gets a firm handle on it (Sang 1988). Alternatively, risk can be defined more loosely by asking whether an undesirable outcome (negative NPV) might occur over a range of circumstances that are deemed plausible a-priori. Although this notion of risk is computationally simple to assess using sensitivity analysis, it is not probabilistic.

Sensitivity Versus Risk Analysis

Sensitivity analysis only gives a rough indication of how the net present value (NPV) or internal rate of return (IRR) of a project might react to changes in the most crucial input variables. In its most familiar form, the technique deterministically modifies the values of selected cost and benefit input variables one at a time by making up and down adjustments (e.g. ±10%, ±20%, etc.) and then calculating the effect on the outcome indicator (NPV or IRR). Unfortunately, sensitivity analysis does not provide any information on the statistical dispersion of the NPV’s (Sang 1988). Even a sensitivity analysis that improves on arbitrary percentage increases and decreases in input values by postulating what-if scenarios that employ, for example, three sets of values for each input variable (minimum, best guess, and maximum) are not fully probabilistic because the

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[1] Standard deterministic CB analysis uses an expected value criterion for the outcome, E(NPV), so strictly speaking the variables influencing NPV should be specified as averages and not medians or modes. However, because this approach does not force the analyst to think about probability distributions, in practice it is usually impossible to determine whether favorable tail values or central tendency measures were employed for the key variables, let alone which kind of central tendency measure was used. The use of favorable tail values disguised *as if* they were means is a trick that responsible IDB project economists recognize and strongly disapprove of, according to a survey performed by two of the authors in collaboration with other IDB staff (see Vaughan *et al.* 1993).

collection of variables can, in fact, take on any number of values. Although sensitivity analysis incorporates some of the uncertainty in the input variables it is not adequate for very sensitive or complex projects, such as those in environmental quality improvement or natural resources management. A great deal of uncertainty about outcomes is likely to be present in these projects because of the necessarily imprecise way we measure benefits (Vaughan *et al.*1999, 2000b) and the randomness of the natural world setting on and in which the project operates.

Unlike sensitivity analysis, in probabilistic risk analysis a probability distribution is assigned to each input variable that has a relevant influence on the economics of the project. Then, through repeated brute force simulation, an empirical approximation to the probability distribution of the outcome of interest (e.g. NPV) is obtained. The probability distributions assigned to each input variable can be subjective or objective. Subjective probability distributions are used when empirical information is unavailable and the analyst must form a judgement or draw on expert opinion. Objective probability distributions are often preferable to subjective ones because they replace speculative guesswork with variability that has been observed in the real world, but of course they depend on the quality and availability of empirical data.[2]

In the probabilistic context of risk analysis, following an expected value decision rule has a quantifiable cost called the *cost of uncertainty*. It can be extracted from the empirical probability distribution for NPV that the Monte Carlo simulation produces. The *cost of uncertainty* is the expected opportunity loss of making the decision determined by the decision rule. That is, if the expectation, E(NPV), taken over the entire NPV distribution is non-negative, the investment will be made. But if some portion of the NPV distribution falls below zero, actual losses in specific instances are still possible. The cost of uncertainty can therefore be measured as the mean of that portion of the NPV distribution truncated from above at zero (the average loss, given that a loss might indeed occur), multiplied by the probability of a negative NPV occurring. If the project is not undertaken because the expected value of NPV is negative, the investment will not be made, thus foregoing any possibility of positive net returns. Symmetrically, the prospective loss in this situation is the mean of that portion of the NPV distribution truncated from below at zero (the average net gain foregone, given that a net gain might occur), multiplied by the probability of a positive NPV occurring.[3]

A number of authors support the use of risk analysis in project appraisal. Clarke and Low (1993, p. 142) conclude that "...while sensitivity testing is useful to highlight the most critical parameters, risk analysis provides an estimate of project worth variability that is both more realistic and easier to interpret than that from the more standard sensitivity analysis." Jenkins (1997, p. 41) in his review of the World Bank's economic analysis methodology recommends that "...when possible, a Monte Carlo analysis should be undertaken to assess the key variables affecting the riskiness of the project and to assess the probabilities of the project's potential for success or failure." Squire and van der Tak (1975, p. 46) recommend that "Risk analysis should be considered for larger more complex projects or projects having exceptional risks that cannot be adequately appreciated by means of simple sensitivity analysis. The advantages of further study of certain project features or variables and of a more flexible design to cope better with future uncertainties should be part of the normal process of project preparation and appraisal."

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[2] On assigning probability distributions to random variables in risk analysis Vose (1996, p. 51) observes that "The precision of a risk analysis relies very heavily on the appropriate use of probability distributions to accurately represent the uncertainties of the problem." Empirically obtained probability distributions, perhaps tempered by some judgement, may provide a more accurate picture than purely subjective distributions in many situations.

[3] Only if the probability distribution of NPV lies entirely in either the positive or negative domains will there be no cost of uncertainty because you literally can't go wrong; either an unattractive investment is unambiguously bad over the entire range of NPV outcomes or no losses are possible because there is zero probability that NPV will fall below zero.

To sum up, risk analysis is not new. Rather, it is a venerable decision analysis technique that is enjoying a latter day revival in both government and the private sector. Its initial promise was hampered by computational limitations, not conceptual flaws (Poulinquen 1970, Reutlinger 1970). With modern software packages like Crystal Ball (Decisioneering Inc. 1998, Hulett 1999) and the power of the personal computer, a simulation of tens of thousands of trials can be run in a few minutes, while in 1970 a small simulation of 1000 trials took from 3 to 5 days on a mainframe (Poulinquen 1970). In short, a strong case can no longer be made against systematically quantifying project risk.[4] Why, then, is the approach not standard practice at institutions like the IDB?

One can only speculate, but Johnson (1985, p. 19) clearly states the source of the reluctance of multilateral development banks to use risk analysis: "The adoption of any technique that slows operational performance is bound to attract the criticism of both conservative line staff and output-oriented managers." Nowadays, lack of knowledge and understanding of the method in some echelons of management may still hinder its application. It may also remain true that, as Johnson suggests, output oriented managers in lending institutions may be reluctant to learn about the ex-ante probability of failure of a proposed project investment if that information might dampen a prospective borrower's enthusiasm, preferring to focus instead on a single (positive) point estimate of NPV.

Irrespective of the viewpoint of the lender, borrowers in developing countries should be concerned about the consequences of having too many risky projects in the public sector portfolio, especially if that portfolio is dominated by a small number of mega-projects whose risks and impacts cannot be pooled or spread widely across space or population (Squire and van der Tak 1975). They, if no one else, should insist on a proper comparison of all of the risks associated with proposed projects in comparison with other, potentially less risky alternatives. The risk neutrality rule used by multilateral development banks to approve projects (Harberger 1996) should perhaps not be imposed on borrowers de facto by ignoring information. Spending a few more months in ex-ante analysis to set up and carry out a risk analysis may pay off in the long run in terms of the quality of the investment decisions developing countries make.

The Specific Issue of Uncertain Benefits

Wattage *et al.* (2000) argue persuasively that contingent valuation (CV) is the most all-encompassing way to measure the (largely non-market) benefits of water quality improvement investments in order to apply the CB test. The Inter-American Development Bank (IDB) has been a leader among multilateral development institutions in implementing this approach (Ardila *et al.* 1998, Travers 1999), having performed over a score of water quality project CB appraisals since 1989 that have been based on CV benefit estimates. However, with a few notable exceptions (Ardila 1993, Ardila *et al.* 1998) these CB analyses have not attempted to quantify the uncertainty surrounding the benefits that have been obtained via CV, and how it transmits into uncertainty about NPV.

There are a number of plausible techniques for extracting benefit estimates from referendum contingent valuation data.[5] The resulting measures of central tendency span a wide range, and economic theory provides no criterion that can be used to unambiguously choose a correct (or best) estimate (Vaughan *et al.* 1999). All we have are plausible bounds (Boman *et al.* 1999). Even if there were a

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[4] Admittedly, the setup of a spreadsheet CB model can be more complex and time consuming if it has to be structured to work under a risk analysis add-in like @Risk or Crystal Ball. In the case study discussed subsequently, to accommodate delays in project execution, phasing delays between project stages, and alternative energy benefit scenarios, the spreadsheet design was definitely made more intricate than it otherwise would have been for a deterministic analysis, adding more than 1 person-months of effort.

[5] The direct revelation approach to CV question design is not discussed here. A non-trivial discrepancy between the expected values of WTP produced via referendum or direct revelation can exist for the same problem setting (e.g. Wattage *et al.* 2000).

way to find a unique point estimate of benefit, uncertainties would not disappear because, being random variables, each of the estimates has a statistical confidence interval associated with it. This phenomena of statistical uncertainty was first recognized explicitly in IDB project applications by Ardila (1993). In short, subjective and statistical uncertainty always exists about the magnitude of nonmarket benefits, and usually exists for market-based benefits estimates as well. This uncertainty may or may not affect the decision to undertake a project.

If a project is economically feasible (or infeasible) irrespective of the benefit estimate used, the decision maker can be confident in undertaking (or rejecting) it. For example, if a project's NPV is positive using one of the low estimates of average WTP, it will pass the test with an upper bound estimate as well, and can therefore be accepted with a reasonable degree of confidence. Likewise, if a project fails the cost-benefit test using one of the high estimates of mean WTP, it probably is not a good investment, signaling that changes in designs and objectives are needed before any commitment can be made. These are clear and fairly safe choices, but unfortunately many prospective investment projects fall in the grey area where the project is feasible using some benefit estimates but not others, as when it fails the positive NPV test using a lower bound benefit estimate but passes the test when a high benefit estimate is used instead. In these common situations the decision maker should be told: (1) the probability that the project is feasible, (2) the expected losses if it turns out badly, (3) and the value of obtaining additional information to clarify the decision.

This paper examines the issue of uncertainty in the context of the case study for the Tietê river clean-up project introduced in Vaughan *et al.* (1999). It builds upon the original economic analysis performed as part of the IDB's formal loan approval process, and uses the Monte Carlo technique to simulate the economic results of the project and analyze its risk.[6] The paper analyzes both the uncertainty with respect to measures of willingness to pay (WTP) developed in Vaughan *et al.* (1999, 2000a, 2000b) and Vaughan and Rodriguez (2000) and the uncertainty with respect to other estimates used in the calculation of feasibility (e.g. project costs, execution period, shadow prices, and future political decisions that affect use of project outputs). It concludes that the analysis of risk provides the decision maker with important information about the possible consequences of his or her decision and the degree of confidence s/he can have in making it. It also concludes that the conventional sensitivity analysis commonly provided in many CBAs is a poor substitute for risk analysis and can sometimes be misleading.

The paper begins by presenting the problem being addressed in the case study. It then describes the multi-stage project designed to resolve the problem. At the time of analysis of the second stage of the project, the first stage had already been completed and, for that reason, the analysis concentrates mainly on the economic feasibility of the works yet to be built (the incremental project). The uncertainties about the factors that potentially determine the project's outcome, and how they are captured in the risk analysis are explained. Finally, the results and conclusions of the risk analysis are contrasted with those produced by a conventional sensitivity analysis, and conclusions are drawn.

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[6] For didactic purposes, the analysis described herein explores a broader range of assumptions about costs and benefits than the original analysis did, and differs from it in several ways that will be touched upon below. Our conclusions in no way reflect the official position of the Bank or the borrower.

CASE STUDY: THE TIETÊ RIVER POLLUTION PROBLEM

The parts of the Tietê river and its tributaries that flow through the São Paulo Metropolitan Area (SPMA) in Brazil are the most polluted bodies of water in the state. The Tietê enters the metropolitan area with acceptable water characteristics but in Guarulhos, at the confluence of the Jacu, it becomes anaerobic. Downstream from the Jacu, the large volume of domestic and industrial waste dumped into the relatively small volume of river flow has made the river an open sewer that supports no aquatic life, smells most of the year, and is used only as a sewer canal for more than 80 kilometers.

The city of São Paulo has developed around the Tietê in a way that adjusts for the river's extreme pollution. On either side of the river, there are large expressways, which impede access. Land adjacent to the expressways is used predominantly for industry or commercial storage and wholesale activities. Land use has adjusted so that the population's exposure to the river is limited, but the problem remains. Surveys indicate that people who drive the expressways and work in the areas are aware of the stench of the river. Sections of the expressways frequently flood in rainy season, exposing people to health risks. The water is too contaminated even for industrial use.

The contamination of the Tietê caused the government of the state of São Paulo to prohibit the pumping of Tietê water to the Billings reservoir in another river basin where it had previously been used to generate hydroelectric power.[7] The loss of power production costs the power generating company about R$75.2 million per year in foregone revenue.

In 1985, the State sanitation company, Saneamento Básico de São Paulo (SABESP), began to address the two problems of low sewerage coverage (64%) in its metropolitan service area and river pollution caused by not treating 81% of the sewage that was collected. It contracted a master plan to study the least costly way to clean up the river. The study focused on the Tietê basin within the SPMA rather than the whole basin.[8] This appears to be a reasonable simplification since the headwaters of the Tietê are 95 km to the east of São Paulo and the majority of the contaminants enter in the SPMA. The river extends another 1,000 km after the SPMA but the contaminants that enter thereafter are minor in comparison to those that enter in the SPMA.

The impact on river quality caused by reducing the inflow of contaminants at different points was simulated using the QUAL2E Stream Water Quality Model developed by the U.S. Environmental Protection Agency. The model is deterministic and relatively simple. Hydrological variations are determined outside the quality model and the quality is calculated on the basis of a particular river flow and the contaminant loads that enter. The model separately accounts for contaminant loads coming in above the SPMA, point discharges of industrial and sewerage outfalls, contaminant loads from tributaries, non-point discharges from surface runoff, and river reflows from underground lenses.

Two dams on the river, Ponte Nova and Edgard de Souza, can control the flow of water in the basin. The dams affect volume and velocity and therefore quality. If the flow control system is operated exclusively for carrying wastes away from the SPMA, all rivers run in their natural direction. If, however, water is to be diverted to Billings reservoir, the gates at the Edgard de Souza dam are partially closed to

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[7] Pumping is allowed to lessen flood problems in periods of very high flows.

[8] The study is no longer in the IDB's files, so this characterization comes from the Project Report for Stage I.

raise the level of water and cause the Pinheiros river to flow in the reverse direction. The water quality model simulates two different operating regimes that are relevant to the economic analysis: operation exclusively to carry away wastes, and operation in which 60% of the water goes to Billings and 40% continues downstream for other uses.[9]

With the water quality model, the master plan used a Regional Least-Cost Mixed Integer Programming model to choose the treatment plant capacities, locations and construction timing. The objective, subject to budget constraints, was to minimize the cost[10] of meeting water quality constraints at three points: (1) just above the confluence with Tamanduatei, (2) at the Pinheiros pumping station, and (3) at the discharge of Edgar Souza dam (see Table 1 below).

The resulting program included connections, collection networks, interceptors, treatment plants, and disposal of residual solids. In addition, it included a program of control of industrial contamination, which was managed by the Companhia de Tecnologia de Saneamento Ambiental (CETESB).

Because the pollution problem was enormous, both SABESP and the Bank knew that the solution would be expensive and would require many years to achieve. Taking the technical and financial resources of SABESP into consideration, SABESP and the Bank agreed to divide the project into three stages.

The impact on water quality of implementing the works in the master plan appear in Table 1. It shows the quality of water at "minimum flow" on various segments of the river system at the end of each of the stages. Water quality will be better than the level shown 90% of the time (329 days of the year). The results indicate that, by the end of the second stage in 2003, dissolved oxygen will exceed the critical level of 0.5 mg/l from the confluence of the Pinheiros downstream (with the exception of the confluence itself, which does not quite reach 0.5 mg/l if the project is operated for hydroelectric generation). By the completion of the third stage in 2010, there will be significant levels of dissolved oxygen in all segments of the Tietê and Pinheiros whether the system is operated exclusively for carrying wastes or for combined waste disposal and generation of electricity.

The investments in Stage I, which has been completed and is in operation, increased the proportion of wastewater treated from 19% in 1992 to 45% by 1998. The works included interceptors to carry wastes from collection points to treatment plants and three treatment plants. The proposed Stages II and III include the expansion of CETESB's industrial pollution control program, and the construction and operation of more interceptors and treatment plants.

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[9] This 60-40 division of water is a suggestion of the consulting firm that developed the master plan for state water use. This division of water does not imply optimal operation. It appears to reflect a judgement of what might be politically feasible. Before the Constitutional restriction, water volumes were divided 50-50 between the Tietê and Billings.

[10] Investment, operation and maintenance costs.

Table 1. Water Quality in the Tietê Basin at Minimum Flow at the Conclusion of Each Project Stage

	Operation to Carry Away Wastes			**Operation to Carry Away Wastes and Generate Electricity**		
Point Where Quality is Measured	Dissolved Oxygen [mg/l]	Bio-chemical Oxygen Demand [mg/l]	Fecal Coliforms [no/100 ml]	Dissolved Oxygen [mg/l]	Bio-chemical Oxygen Demand [mg/l]	Fecal Coliforms [no/100 ml]
Tietê confluence Tamanduatei						
1998	0	33.49	850,200	0	33.49	850,200
2003	0	23.19	547,800	0	23.19	547,800
2010	1.46	13.64	233,300	1.46	13.64	233,300
Tietê confluence Pinheiros						
1998	0	15.22	150,200	0	28.89	777,700
2003	1.33	3.73	20,400	0.43	22.27	563,600
2010	1.14[a]	3.70[a]	22,000	1.98[a]	12.55[a]	246,900
Pinheiros Pumping Station						
1998	0	18.47	156,500	0	32.22	587,300
2003	1.99	7.21	10,500	0.55	16.66	292,800
2010	2.07[a]	7.20[a]	10,900	2.18[a]	11.62[a]	148,500
Edgard de Souza Dam						
1998	0.29[a]	29.16[a]	664,000	0.98[a]	31.95[a]	651,200
2003	1.34[a]	22.88[a]	505,400	2.95[a]	26.10[a]	460,500
2010	2.48[a]	12.65[a]	216,000	4.01[a]	13.09[a]	174,900
Pirapora						
1998	2.24	20.6	8,400	4.35	14.27	2,200
2003	2.6	17.59	10,200	4.5	13.41	2,400
2010	3.03	10.97	3,700	4.27	8.35	800

a. The two different modes of operation, to carry away waste and to carry away waste and generate electricity, are associated with different flows (volume, depth, velocity, and direction) that result in different dilution and reaeration rates. In dual purpose operation, the velocity of water is greater at the location indicated, and since the Barueri waste treatment plant is located between the confluence of the Pinheiros and Edgard de Souza dam, there is less water to dilute Barueri's effluent. For this reason, the levels of both BOD and DO are higher with joint waste/hydroelectric operation, than they are for waste operation alone.

OVERVIEW OF THE ECONOMIC ANALYSIS

The economic analysis of the works separates the appraisal of the sewerage connections, collection networks, and collectors from the analysis of the river clean-up (interceptors, treatment plants, and disposition of sludge). Investments that connect users to the public system and carry the wastes out of local areas have benefits in those areas that are not related to the benefits from cleaning up the river. Thus the connection and collection systems can be treated as independent projects.[11] The original analysis done by the Bank and SABESP did treat these investments separately and that analysis is not discussed here.

The investment in cleaning up the river (interceptors, treatment plants, disposal of sludge, and industrial pollution control) will produce benefits only when water quality improves enough to affect human behavior. For this reason, from the economist's point of view, the three stages are interrelated, not independent. All are needed to attain any benefits (improvement in water quality that will affect human perceptions and behavior).

SABESP and the Bank did not do a cost-benefit analysis for Stage I of the river clean-up project, presumably because the first stage, by itself, would not bring about a perceptible change in water quality that would change human behavior. Stage I removed 25% of organic material of domestic and industrial origin discharged into the Tietê river, and a similar percentage of other pollutants such as inorganic material, toxic compounds, and fecal coliforms. However, despite biochemical oxygen demand (BOD) reductions from a "without project" level of 86 mg/l to 40 mg/l, the recovery of dissolved oxygen (DO) was insignificant, since absolute BOD levels remained well above the 5 mg/l of BOD that defines a "clean" river. With the first stage, levels of DO reach between 0.5 to 1.0 mg/l in some months of the year in segments just before and after a long anaerobic stretch. The only benefit is a minor reduction in odors over a short stretch of the river in those months. Under Stage I dissolved oxygen does not reach levels that support aquatic life.

The analysis that follows develops two CB analyses: one for the project as a whole (Stages I, II, and III) and one for the incremental project (Stages II and III), that has yet to be built. The analysis of the incremental project is the only one relevant to the decision of whether to continue. To analyze the incremental project, it is necessary to calculate the NPV for Stages II and III together because Stage II by itself is not sufficient to bring any lasting improvement in the quality of the Tietê. The investment costs and benefits of Stage I are not relevant to the investment decision about Stages II and III because the capital costs have already been incurred and cannot be recovered (they are sunk costs) and the benefits are insignificant. The decision to continue depends only on the avoidable costs and attainable incremental benefits of the incremental project. The paper does, however, present the calculation of the NPV for the whole project for reasons of transpar-

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[11] Connection and collection are closely related to the river clean-up project only if one considers the cost of the clean-up project as the cost of mitigation. At the time this project was developed, the need for mitigation was moot. The receptor body was dead; direct dumping of additional effluent would not make it deader. This poses a paradox for economic analysis. Connection programs usually generate large benefits sufficient to cover the cost of mitigation (i.e. treatment). However, in the initial stages of sewage collection projects, the discharge of wastes directly into receptor bodies may cause no significant deterioration in water quality and are not economically justified. Expansions of sewer collection may finally start to degrade the water, but the surplus of the marginal population (often the poorest) may not be sufficient to cover the cost of cleaning-up everything. The willingness to pay for clean-up of the whole population may not be sufficient to justify the clean-up project, but economists do not use the net benefits from connection to sewer systems carried out in the past to justify the cost of clean-up once mitigation (environmental quality) becomes an issue.

ency and to demonstrate the well-known weakness of using cost-effectiveness analysis to justify a project.

Project Costs and Shadow Pricing Adjustments

SABESP provided the costs of the investment in the river clean-up and industrial pollution control program for the first and subsequent stages. The costs of investment for the first stage are known with certainty since they have already been incurred. The investment costs in the second and third stages are estimates and are subject to a margin of error. Because the works of the second and third stages are similar to those of the first stage, and because there are no major construction risks (such as geological risks when digging tunnels, etc.), it was assumed that the uncertainty about the estimates was relatively small. The cost estimates were assigned a margin of error of 15% in either direction under a symmetric triangular probability distribution.[12] This distributional assumption implies that the mid-point estimate is the most likely, small variations are more likely than large ones, and the maximum possible over ! or under ! run in costs is 15%. [13]

SABESP provided estimates of the operating costs of all stages, which were also assigned a symmetric 15% margin of error and a triangular distribution. The original economic analysis of the incremental project (Stages II and III) did not charge the operating costs or the industrial compliance costs of the first stage operation against the benefits of Stages II and III. Rather, these costs were ignored (treated as sunk) in the analysis of the incremental project because it did not seem realistic to assume that the first stage would be shut down if the incremental project were not built.

The appropriateness of omission of first stage operating costs is open to discussion, since the costs are, in principle, avoidable. The treatment plants could be shut down and the industries could be allowed to suspend operation of their treatment facilities. While it is possible to argue that it would not be politically feasible to admit error and stop these operations, this is not an economic argument. Therefore, to maintain consistency with familiar cost-benefit conventions, our analysis assumes the first stage operating costs are avoidable, not sunk, which means that they must appear in the cost stream of the incremental project.[14]

The investment and operating costs correspond to different types of works including interceptors, treatment plants, and systems to pre-treat industrial effluents. Some of the factors that cause actual costs to deviate from estimated costs are common to all types of works (e.g. the price of cement or steel), while others differ in their effect across types (e.g. change in designs, troubles with a single contractor). Thus, the risks of variation in costs are somewhat, but not perfectly, correlated. The degree of correlation is important in risk analysis simulation. If categories of costs (or benefits) are perfectly correlated, they all take on extreme values at the same time. This tends to increase the variability of the economic results simulated. If they are uncorrelated, a high value in one cost category often offsets a low value in others and the degree of variability is dampened or even averages out. It is important to take this into account. By lumping all investment and operating costs together, the analysis here implicitly as-

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[12] The use of a 15% margin of error in either direction (symmetric) is neither necessary nor usual. Investment costs are typically underestimated (human optimism or intentional bias to influence decision makers). Usually, an asymmetric distribution is used with the “best estimate” of cost placed toward the lower end.

[13] In the original Bank analysis, a larger margin of error was assigned to estimates of cost of the third stage, since the final designs have not been prepared and conditions may change.

[14] Our choice of how operating costs are treated has been made largely for didactic reasons. Treating them as sunk produces an NPV distribution for the incremental project which displays no probability of a loss, which is not a very interesting or typical case. Our simplifying assumption of avoidable first stage costs analysis overlooks the possibility that the abandonment of Stage I would lead to additional deterioration of the river below its current poor quality, with economic consequences caused by the build-up of sludge, more frequent flooding, and an increased risk of episodic threats to human health. In short, the benefits (damages avoided) of the incremental project may be understated by assuming avoidable Stage I operating costs.

sumes that they are perfectly correlated. This may overstate the variance of the results.

A CB analysis must take into account all costs necessary to obtain the benefits, not just the costs financed for the project. One of the costs not financed by the project is the cost of industrial compliance with pollution control, which involved 1168 industries in Stage I and 350 in Stages II and III. The analysis of the first stage did not include private compliance costs.

Before the first stage was carried out, CETESB estimated that it would cost an average of R$342,464 per firm to carry out the investment necessary to control effluents. In retrospect, it estimates R$171,000 per firm. There is little empirical basis for either estimate.[15]

The analysis in this paper combines the mid-point of the range in estimated private industrial pollution control investment costs, R$256,848, with the public sanitation investment costs discussed previously and uses the same triangular distribution and 15% variation to reflect uncertainty. Annual operating costs for the private pollution control effort are approximated as 10% of capital costs. This significantly underestimates the possible variation of an important cost. [16]

The investment and operating costs of all works relevant to project benefits were subdivided into four categories: traded goods, non-traded goods, skilled labor and unskilled labor. These costs were adjusted to economic opportunity costs (shadow priced) using a study done for a prior project. That study estimated conversion factors for skilled labor and unskilled labor of 0.79 and 0.48 respectively. The research for the prior study used the reciprocal of the weighted average tariff to estimate a standard conversion factor of 0.91 for non-traded goods, but it did not take into account the impact of high interest rates (tight monetary policy) in maintaining the level of the exchange rate.

Therefore, this analysis uses 0.91 the estimate from the other study as an upper bound estimate, 0.75 as a modal (most likely) estimate, and 0.67 as a lower bound for the conversion factor for non-tradeables. The analysis used a triangular distribution to set the maximum variation. The distribution is slightly asymmetric; the mean is 0.78. This implies that simulations will generate a value less than 0.78 less than half of the time. The three shadow price factors are not correlated.

Table 2 reports the expected value of total capital and operating costs for each year of the project's life before the application of shadow price factors and discounting (i.e. these are financial costs). Table 7 summarizes the probability distributions used for each cost adjustment factor.

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[15] A World Bank study of pollution control by 22 industries in a nearby watershed estimated that the average cost of compliance for those industries was R$ 717,000, but the variance was enormous and it is difficult to extrapolate from this study without knowing the composition and size of industries regulated.

[16] Alternatively, the private compliance costs could have been treated in more detail by using a uniform distribution with a range from R$171,000 (CETESB's ex-post estimate) to R$342,000 The uniform distribution implies much greater uncertainty than our simplification.

Table 2. Project (Stages I, II and III) Capital and Operating Costs for Wastewater Treatment

(Undiscounted Thousand 1998 Reals)

Time Period and Stage (Year 1=1992)	Total Investment Costs	Total Operating Costs	Total Costs
BEGIN STAGE I Construction 1	18,304	0	18,304
2	33,559	0	33,559
3	333,948	0	333,948
4	60,864	30,000	90,864
5	72,549	30,001	102,550
END STAGE I Construction 6	87,370	30,001	117,371
STAGE I SUB-TOTAL	**606,594**	**90,002**	**696,596**
BEGIN STAGE II Construction 7	42,333	65,716	108,049
8	54,339	66,124	120,463
9	97,432	66,727	164,160
10	200,685	67,845	268,529
END STAGE II Construction 11	72,633	79,190	151,822
STAGE II SUB-TOTAL	**467,421**	**345,602**	**813,023**
BEGIN STAGE III Construction 12	42,761	104,349	147,110
13	38,090	104,864	142,954
14	60,182	105,100	165,282
15	60,333	105,392	165,725
16	59,667	105,627	165,294
17	59,666	105,916	165,582
END STAGE III Construction 18	57,563	106,100	163,662
STAGE III SUB-TOTAL	**378,262**	**737,347**	**1,115,610**
BEGIN Full Operation 19	0	135,288	135,288
20	0	137,415	137,415
21	0	137,592	137,592
22	0	137,769	137,769
23	0	137,947	137,947
24	0	138,036	138,036
25	0	138,127	138,127
26	0	138,216	138,216
27	0	138,306	138,306
28	0	138,306	138,306
29	0	138,306	138,306
END ANALYSIS PERIOD 30	0	138,306	138,306
YEARS 19 to 30 SUB-TOTAL	**0**	**1,653,612**	**1,653,612**
GRAND TOTAL	**1,452,277**	**2,826,563**	**4,278,840**

Note: Costs exclude household sewer connections, the collection system, and the cost of collectors sufficient to carry untreated effluent to the nearest dumping point in the river. These costs were balanced against local household sewering benefits in a separate CB exercise not reported here. The costs above are related to pollution control and include interceptors, wastewater treatment and the industrial environmental cleanup program. The costs in the table are not shadow priced or discounted because of the uncertainties about timing and pricing that are handled in the risk and sensitivity analyses discussed subsequently.

Project Benefits

There are two principal benefits of the Tietê project: the public good benefits stemming from a reduction in odors and aesthetic blight that had to be estimated by a contingent valuation approach, and the private benefits from increased hydroelectric power generation that could be valued through the market for energy.[17]

Improvement in River Water Quality

To calculate total gross project benefits of better water quality, the average benefit per household has to be multiplied by the number of beneficiary households, distinguishing households that are in districts contiguous to the river from those that are not. According to census data there are 2.46 million households in districts contiguous to the major tributaries and 1.6 million in non-contiguous districts.

The present population of São Paulo is known with certainty, but the rate of growth, which affects total benefits, is not. São Paulo is heavily built up and its expected population growth rate is low: 0.75% in contiguous districts and 1.00% in non-contiguous areas. The analysis specified a symmetric triangular distribution for each with possible ranges of growth of 0.5% to 1.0% for contiguous districts and of 0.75% to 1.25% for non-contiguous districts (see summary Table 7). Because the contingent valuation question limited the payment period to ten years starting with the construction period, these benefits were projected for ten years beginning with the construction of the second stage.[18]

Finding a reasonable average measure of per-household benefit is more problematic, and ultimately much more important, than specifying the size of the future population in this case. Population growth can be confidently confined to rather narrow bounds because population density in the areas of the city affected by the project is already high and there is not much room left for absorbing additional inhabitants.

Vaughan *et al.* (1999) provide a detailed discussion of how twelve different measures of mean and median water quality benefits could be extracted from a single referendum CV exercise.[19] Now, how can one or more of these measures be used in the cost benefit analysis of the project? Table 3 below recapitulates nine estimates of the mean and the standard error of the mean (where computable) from Vaughan *et al.* (1999).

There are two kinds of uncertainty associated with these measures. The first is *statistical* uncertainty *within any given measure* since each mean is a random variable with its own distribution and standard error.[20] The second is *methodological* or *subjective* uncertainty *across measures*, since none of them can be ruled out a-priori, with the possible exceptions of the untruncated parametric and bounded probit means.

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[17] In addition, there are other benefits that have not been quantified which include increased recreation benefits at Pirapora do Bom Jesus and further downstream, the retardation of saline intrusion in the Cubatão river in the Baixada Santista, and the provision of a more economic source of potable water for the Baixada.

[18] The payment period stipulated in the contingent valuation survey was ten years. Because the principal benefits accrue for 10 years, but operating costs continue beyond that, the net benefit flow eventually turns negative. Just when or how often negative net benefits appear depends partly on the length of execution delays and the timing of energy benefits. These complexities mean that over the 30 year analysis period, there can be multiple sign changes in net benefits so there may be multiple internal rates of return. For this reason, the analysis calculates only the NPV.

[19] This specification of WTP benefits and their variance is much more detailed than it was in the original analysis that was done for the formal IDB loan approval process.

[20] Ardila (1993) and Hazilla (1999) explain how to compute the distribution of expected values using the delta method, bootstrapping or numerical approximation assuming asymptotic normality of the parameter estimates that appear in the "function of interest," the formula for WTP. Table 3 reports standard errors (SE) for the Tietê WTP means obtained via analytical formulas for the nonparametric means and via the delta method for most of the parametric means. Vaughan *et al. (*1999) review the plausibility and deficiencies of the alternative central tendency measures.

Table 3. Estimates of Mean Willingness to Pay and the Standard Error (SE) of the Mean

Central Tendency Measure	WTP per Household per Month (*1998 Reals)*			
	Contiguous Districts		Non-Contiguous Districts	
Parametric Measures	**Mean**	**SE**	**Mean**	**SE**
Bounded Probit Mean	140.10	*n.a.*	60.46	*n.a.*
Truncated Mean [C’]	9.73	*1.29*	6.16	*0.75*
Truncated Mean [$C^{\sim}$]	7.66	*0.71*	5.03	*0.44*
Untruncated Mean / Median [C+ / C*]	4.74	*1.66*	–1.27	*1.56*
Truncated Mean, Log Transform [$C^{+}_{\ln}$]	4.66	*n.a.*	1.46	*n.a.*
Truncated Mean, Log Transform [$C^{\sim}_{\ln}$]	3.49	*n.a.*	1.23	*n.a.*
Nonparametric Measures				
Boman et. al. (1999) Upper Bound (Paasche)	12.77	*1.61*	9.67	*0.87*
Kriström’s (1990) Intermediate	9.42	*1.19*	7.09	*0.66*
Haab and McConnell’s (1997) Lower Bound (Laspeyres)	6.07	*0.80*	4.51	*0.47*

The statistical margin of error can be summarized by a confidence interval around the estimates of, say, 99%, or roughly ±2.6 standard errors on either side of the mean. These confidence intervals show a percentage variation about the several means of roughly 75% for households contiguous to the river and 51% for more distant households. The second kind of uncertainty is about which of the several alternative means to use. The statistical margin of error is far less than the relative range between the low and high estimates of the mean using the different estimation methods. Leaving out the very high estimate obtained with the bounded probit model, the range of mean willingness to pay for those in districts contiguous to the river is R$3.49 to R$12.77; the means for those not contiguous to the river range from R$1.23 to R$9.67. For those contiguous to the river the percentage variation around the midpoint of the range (i.e. the ratio of the range to the mid-point) is 114% and ascends to 155% for those not contiguous to the river.

Characterizing Uncertainty About CV Benefits

There is no unambiguously correct way to summarize this range of estimates for the Monte Carlo risk analysis, but there are at least three plausible alternatives.[21] The first is to choose one measure, such as

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[21] The bounded probit means are outliers, being more than 10 times greater than the next highest estimate. It is highly unlikely that average willingness to pay is this high. This improbability should be reflected in the risk analysis. It is also worth noting that the untruncated linear model yields an average willingness to pay that is negative. This result is inconsistent with theory since it implies that the population would have to be paid in order to acquiesce to

the Turnbull lower bound mean, as preferred. The advantage is simplicity and the ability to incorporate statistical uncertainty, but the disadvantage is that any subjective uncertainty is assumed away. In contrast, a judgmental distribution for the mean could be formulated based on the gamut of possibilities in Table 3 to reflect subjective uncertainty about which is the "best" estimate. The disadvantages of this route are that all of the alternative measures have to be calculated in order to make probabilistic assignments, and that statistical uncertainty is difficult to incorporate. The work of Boman *et al.* (1999) promises the best of both worlds because the upper and lower bound nonparametric means offer a way to span a good part of the range and simultaneously incorporate statistical uncertainty.

The Subjective Approach

Since the uncertainty with respect to the appropriate central tendency measure is much greater than the statistical uncertainty, this version of the risk analysis uses a judgmental (subjective) distribution of the central tendency values shown in Table 3 plus an additional subjective adjustment to allow for error in questionnaire design and the timing of its application.

In addition to statistical error and possible error from choosing the wrong method to estimate central tendency, there is possible error associated with the questionnaire and its implementation. The Tietê questionnaire was not absolutely clear that the improved quality would still produce unpleasant odors from the river one month per year. If respondents had known this, their WTP to pay might have been less. Working in the opposite direction, the survey was conducted at a time when Brazil was in deep recession. People were worried about keeping their jobs. In more normal times, average WTP might have been higher than stated at this moment. To reflect these possibilities, it is prudent to keep the ranges wide.

The subjective analysis characterizes the uncertainty with a histogram. For districts contiguous to the river, it establishes a lower range between R$2.00 and R$4.00. The lower bound is less than the lowest mean (R$3.49) and incorporates the possibility that the respondents might have expressed a lower WTP if they had clearly understood that the project would deliver an odor free river only 11 months a year, or if they had more time to consider the implications of the income burden the elicited monthly payments would impose annually. The upper bound of the low range incorporates the lowest estimated mean (R$3.49). The analysis here assigns a subjective probability of 30% to this range of the histogram.

The second range in the histogram goes from R$4.00 to R$7.00. We assigned the second range a probability of 50%. This range includes three of the eight means estimated. The relatively high weight indicates our judgement that the true WTP is probably within this range. The third bar of the histogram is for the range R$7.00 to R$10.00 and has a probability of 15%. This range includes the three higher estimates of means that we considered possible but less likely. The fourth range runs from R$10.00 to R$50.00. The statistical analysis produced no estimates in this range, but we considered the range more probable than the alternative of leaving a gap and consigning the entire remainder of the distribution to the interval defined by the bounded probit mean, which appeared unreasonably high. We assigned a probability of 4% to this range. It allows for the fact that true WTP might be higher than estimated because of statistical error in the means that appear in the earlier range, or because the survey was carried out in recession. The final range is from R$50.00 to R$140.00. This includes the extreme measure of the mean from the bounded probit, which was assigned a probability of 1%, meaning it is highly unlikely but not impossible. A similar procedure was used to characterize the WTP of households in districts far from the river.

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cleaning up of the river. It is possible that some people might have to be paid to accept the project. Certain individuals may believe, for example, that they will be inconvenienced by more than they are benefitted by works of the project located in their vicinity. The average person, however, should be positively affected by the project and should have a non-negative willingness to pay.

The subjective probability distributions for average WTP are summarized in Table 7 and pictured below. The mean WTP for contiguous households implied by the distribution in Figure 1 is R$7.09 per month, which is R$1.02 higher than the corresponding Turnbull lower bound measure. The average is R$ 3.76 per household per month for the non-contiguous distribution in Figure 2, which is R$0.75 lower than the corresponding Turnbull mean.[22]

Figure 1. Subjective WTP Distribution

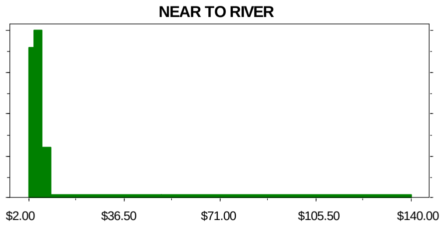
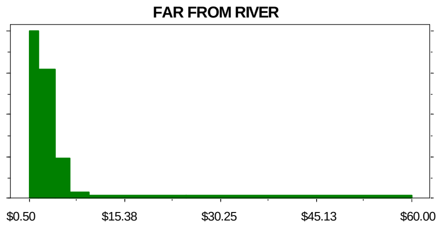


Figure 2.Subjective WTP Distribution



The subjective WTP distributions are positively skewed, and this assumption will be mirrored in the distribution of the outcome, NPV. In contrast, the alternative assumption of a lower bound Laspeyres (Turnbull) mean with all variation coming from normally distributed random (statistical) error would make the outcome distribution of NPV look more normal.

The Nonparametric Limits Approach

Were it not for the insights of Boman *et al.* (1999) our treatment of uncertainty on the side of public good benefits would have to stop here, with two sharply contrasting and ultimately unsatisfactory approaches that handle either statistical uncertainty or subjective uncertainty, but not both. Fortunately, Boman *et al.* have linked the choice among benefit measures to economic theory, which opens the door to an interpretation that narrows the extent of subjective uncertainty compared with the judgment-based method above, and simultaneously accounts for statistical variation around mean WTP.[23]

To make the link to welfare theory suppose the proportions of "Yes" responses to a referendum CV survey are plotted against the bids and the points connected by interpolation to produce a picture of the survival function.[24] The acceptance proportions should generally decrease as the bid level increases. Interpreting the proportions as the fraction of individuals who would be willing to buy a fixed amount of a public good (the quantity) if it were offered at a specific bid price, the survival function is analogous to a demand curve (Johansson 1995, pp. 84-85). The bid levels represent marginal willingness to pay and average willingness to pay is the integral under the survival function (see the derivation in Vaughan *et al.* 1999 and Vaughan and Rodriguez 2000).

Panel A of Figure 3, adapted from Boman *et al.*, shows the demand for a public good, *z*, as a function of its hypothetical price. The price is equal to the representative individual's marginal willingness to pay, MWTP. The change in the level of public good provision is $z_1 - z_0$.

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[22] The subjective distributions were not consciously designed to reproduce any of the other means. These numbers are only for purposes of comparison.

[23] In order to pursue the route based on our elaboration of Boman *et al.*'s arguments, the CV survey data must be reliable. If the analyst has doubts about the survey, the only recourse is to re-do the survey or adjust the mean WTP data ex-post based on subjective judgment.

[24] The analytical formulas for the nonparametric means in Vaughan and Rodriguez (2000) employ the distribution function, where the probability of rejection increases with the bid levels. The acceptance proportion at any bid level is just one minus the rejection proportion, yielding the survival function plotted in Vaughan *et al.* (1999), Figure 3.

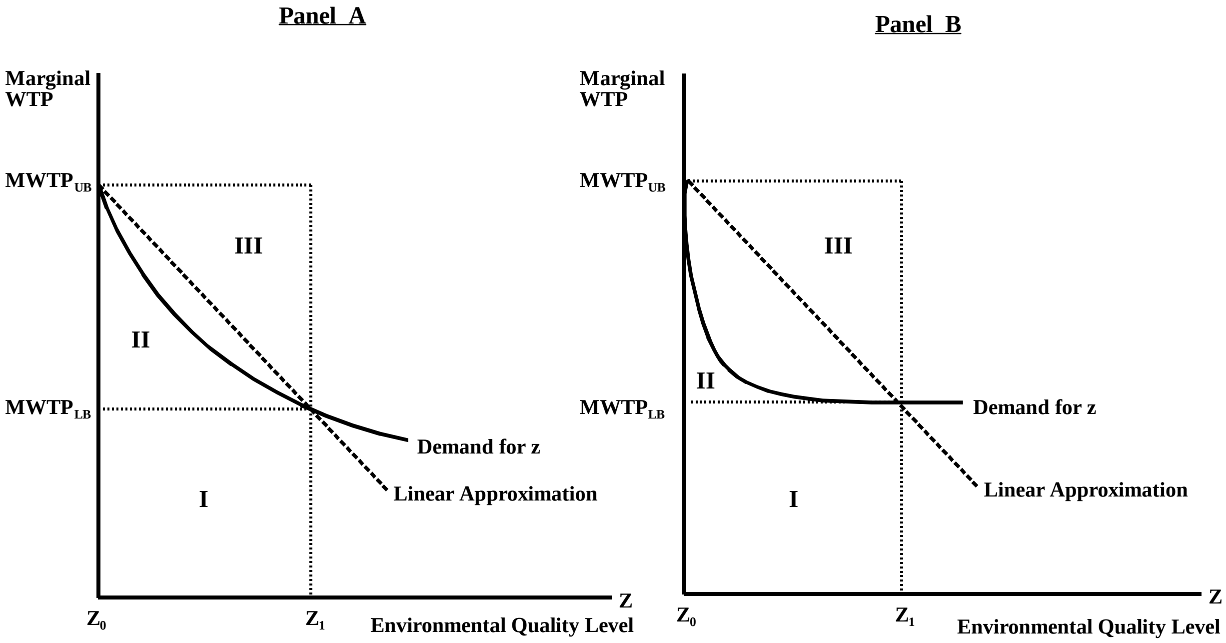

Figure 3. **Welfare Measures**

The Laspeyres lower bound monetary measure of welfare improvement, L, is represented by the area labeled as I, which is the product of the quantity change and the lower, post-change price, $MWTP_{LB}$. The Paasche upper bound measure, P, is the sum of areas I, II, and III, or the product of the quantity change and $MWTP_{UB}$. The true welfare change is the integral under the demand curve between z_1 and z_0, or area I plus area II.

Adding a linear approximation to the non-linear demand curve shown in Boman *et al.*'s original graph provides a rationale for Kriström's non-parametric mean, which falls between the Paasche and Laspeyres means. That is, the true welfare measure, T, is approximately equal to L + ½ (P ! L) or ½ (L + P) = Area I + ½ (Area II + Area III). Panel B of Figure 3 shows that the Kriström approximation to the true mean gets worse as the true demand curve becomes more convex. At some point the approximation error in Kriström's mean will exceed the approximation error of the lower bound Laspeyres (Turnbull) mean, as it does in Panel B. From this analogy it is clear that the upper bound mean should never be used by itself as a welfare measure in CBA because it always overstates benefits by more than Kriström's intermediate mean, which will also overstate E(WTP) if the demand curve is convex to the origin. It also tells us that the true mean lies somewhere between the Kriström intermediate mean and the Laspeyres (i.e. Turnbull) lower bound. In this sense (unless the demand curve is concave to the origin) the Kriström intermediate mean, not the Paasche mean, is the operative upper bound.

Kriström's intermediate mean is probably a reasonable comprise, if a single measure is desired, but so is the Turnbull lower bound for analysts who prefer a more conservative, less forgiving measure. We fall somewhere in between, and prefer to approximate the true mean with a weighted average of the Paasche and Laspeyres means. To do this in the Monte Carlo analysis, a weighting factor, ?, is drawn from a uniform distribution over the interval of 0.50 to 1.0. The factor is multiplied by the

Turnbull mean and added to the product of one minus the factor times the Paasche mean, where both means are randomly drawn from normal distributions with the standard errors specified in Vaughan and Rodriguez (2000). So T ≈ 6 $ L + (1S6) $ P, where the weighting factor, 6, is $ 0.5.

Our approximation always gives the Paasche mean equal or lesser weight than the Laspeyres mean in computing a linear approximation to the true mean, rather than the equal weights of 0.5 used by Kriström. In fact, since the mean of the uniform distribution between 0.5 and 1.0 is 0.75, on average our calculation produces a WTP that assigns 75% of the weight to the lower bound Laspeyres (Turnbull) mean WTP and 25% to the upper bound Paasche mean.[25] The mean WTP for contiguous households implied by our unequally weighted procedure is R$7.75 per month, which is R$0.66 higher than the corresponding subjective measure, but R$1.67 lower than Kriström's intermediate mean. The unequally weighted average is R$5.80 per household per month for the non-contiguous distribution, which is R$2.04 higher than the corresponding subjective mean, but R$1.29 lower than Kriström's mean.[26]

Benefits From Additional Hydroelectric Generation

Until 1992, half of the flow of the Tietê was pumped to Billings reservoir to generate electricity at the Henry Borden power plant. "Transitory Provisions" in the state's 1989 Constitution now prevent pumping wastewater from the Tietê to Billings Reservoir. With the treatment plants of Stages II and III, the water to be pumped would no longer be waste water and the environmental authorities might consider the water good enough to pump. Thus the Tietê project may have benefits by permitting additional hydroelectric generation.

It is not certain, however, that pumping will be allowed. While it is true that the water of the Tietê will no longer be wastewater, it will not be good water. Billings reservoir is classified as a Class II water body. By regulation, water pumped to a Class II body can not degrade the quality to less than 5 mg/l of dissolved oxygen, more than 5mg/l of biochemical oxygen demand, or more than 4,000 fecal coliforms per 100 ml. Billings reservoir is already out of compliance with Class II standards at the point where the Tietê/Pinheiros water would be injected. Thus, in principle, the only water that could be pumped there would be distilled water.

The water to be pumped from the Pinheiros pumping station will not attain Class II quality in either Stage II or III (see Table 1). Billings, however, is a very large reservoir. Its present quality ranges from Class IV (where Pinheiros/Tietê water would be injected) to Class I in the area where water is released for potable uses in the Santos region. The environmental authorities could reclassify sections of Billings to reflect present reality and the fact that the reservoir functions as a natural treatment plant. If the part of Billings where the Tietê water would be pumped were reclassified as Class IV, Tietê water could be pumped. It is highly uncertain, however, whether Billings will be reclassified, if such pumping will be allowed, when it will be allowed, and how much will be allowed.

The Monte Carlo risk analysis simulates a number of scenarios that reflect the political pressures that might be exerted by various institutions and stakeholders. The analysis assigns a subjective probability distribution to various scenarios. It assigns a 50% probability to the most adverse case: diversion of Tietê water is never permitted. The analysis assumes

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[25] Rather than drawing from the upper and lower bound means inside the Monte Carlo simulation, an alternative way of accomplishing a similar result would be to calculate the 75/25 weighted mean and variance directly by adapting the calculation of Kriström's mean and variance set out in Vaughan and Rodriguez (2000). The standard errors differ between the two approaches.

[26] No attempt was made to calibrate the subjective mean to match the mean based on weighted bound values. On the contrary, the two exercises are totally independent because the subjective distribution was designed several months prior to the publication of Boman *et al.* (1999), which inspired our weighted mean. The Monte Carlo results under these two competing approaches can be viewed as if they were undertaken by different analysts.

that there is a 5% probability that pumping will be possible a year after the second stage is completed, a 10% probability in the fourth year after Stage II is completed, a 17.5% probability a year after the third stage is completed and a 17.5% chance four years after the third stage is completed.

Note that in a risk analysis the time lag (pause) between Stages I and II and the length of the Stage II execution period are not fixed, but instead are drawn from probability distributions. The probability that energy benefits will come on line in a certain number of years after completion of either Stage II or Stage III is also drawn from a distribution, as noted in the computational steps below under base case execution timing:

Scenario	Draw a Uniform Random Number and Choose Scenario if Range Is:	Year Energy Benefit Flows Initiated: Base Case Execution
1	0.00 to 0.05	12
2	0.05 to 0.15	15
3	0.150 to 0.325	19
4	0.325 to 0.500	22
5	0.50 to 1.00	Never

If there are execution delays, in our spreadsheet analysis setup the energy benefits are moved into their correct starting year position using time indices and Excel's VLOOKUP function.

The acceptance of pumping is not the only uncertainty. If pumping is allowed, the benefits from using Tietê/Pinheiros water will depend on the amount of energy to be generated and the time of day when it will be generated. To estimate the amount of additional energy that might be generated, historical data were obtained on the amount of water processed by the Henry Borden Power Station before and after the restriction was imposed on pumping from the Pinheiros/Tietê (Table 4).

The average difference is equivalent to a continuous flow of 67.0 m^3/s. This flow resulted from a 50-50 division of the Tietê's flows. A master plan for the water resources of the State of São Paulo suggests that a 60-40 division might be possible. If so, it might be possible to pump the equivalent of a continuous 80 m^3/s to Billings. The amount that can be pumped will be determined after a political negotiation of stakeholders with divergent interests. It is not known with certainty. The Monte Carlo risk analysis uses the range (67.0 to 80 m^3/s) in the calculations.

Table 4. Henry Borden Power Plant Energy Production and Water Use Before and After Restriction on Pumping from the Tietê to Billings

Year	**Energy Produced** (MWh)	**Water Used** (M^3/S)
Before Restriction		
1985	3702424.5	75.4
1986	4244978.9	86.4
1987	5056923.8	104.5
1988	4816698.2	99.1
1989	5230506.9	108.1
1990	3603258.4	74.2
1991	4798196.6	98.1
Average 1985-1991	**4493283.9**	**92.3**
After Restriction		
1992 a/	2811472.1	57.2
1993	1579454.0	32.1
1994	694913.7	14.1
1995	1255767.6	26.2
1996	1535861.1	31.0
1997	1131306.8	23.3
Average 1993-1997	**1239460.6**	**25.3**
Difference of Period Averages	**3253823.3**	**67.0**

a/ In 1992, the restrictions on pumping were imposed.

The incremental energy generated is the difference between the energy that can be generated at Henry Borden with the pumped water less (1) the energy that could be generated with the water on the ten downstream plants on the Tietê, and (2) the energy used in pumping. Henry Borden has a production capacity of 5.654 MW/m3/s. To pump a cubic meter from the Pinheiros/Tietê to Billings reduces the net production by 0.314 MW/m3/sec. Thus, Henry Borden's net gain from receiving a cubic meter per second is 5.34 MW/m3/s. This net gain is also reduced by the losses of the hydroelectric plants on the lower Tietê.

Table 5 shows that the production generated by a cubic meter passing through all the plants is 2.1336 MW/m^3/s. Thus, the net national gain from transferring a cubic meter of water from the Tietê to Billings is 3.206 MW/m3/s (i.e. 5.3400 minus 2.1336). This converts to 27,084.56 MWh of additional energy per cubic meter per year. If the incremental water pumped to Billings is between 67 and 80 cubic meters, the incremental energy is in the range of 1,881,665 MWh to 2,246,763, MWh per year.

Table 5. Power Stations on the Tietê Downstream from Edgard Souza

Power Plant	Production (MW/m^3/s)
Rasgão	0.1754
Porto Góes	0.1887
Barra Bonita	0.1727
A. Souza Lima	0.1881
Ibitinga	0.1872
Promissão	0.2057
Nova Avanhandava	0.2605
Ilha Solteira	0.3902
Jupiá	0.1982
Porto Primavera	0.1669
Total	2.1336

Because Billings is an enormous reservoir with interannual storage, it is possible to produce most of the incremental energy at peak. The plants on the lower Tietê have enough storage capacity to guarantee peak operation with or without the diversion to Billings. The decrease in power on the Tietê will be power off-peak. It is not certain, however, that Borden will be allowed to use all the Tietê water during peak hours, because the power company may be ordered to increase the amount of water that is released at a constant rate to prevent saline intrusion in another river basin (the Cubatão). If such releases are required, they will be off-peak. The value of high voltage energy during peak demand is between R$37.33 and R$42.69 per MWh, depending on whether it is wet or dry season, and the value off peak is between R$25.67 and US$30.20 per MWh, again depending on the season. The economic analysis uses a range of R$30.20 to R$42.69 in its calculations. These values are based on the long run average incremental cost of supply at high voltage.

The risk analysis presented later in this paper combined the information about uncertainty with respect to amount of energy that would be generated each year and its value by multiplying the low extreme of one by the low extreme of the other (1,881,665 Mwh x R$ 30.20) and the high extreme by the high extreme (2,246,763, Mwh x R$42.69). It used a symmetric triangular distribution to describe the probability.[27] The probability distribution is summarized in Table 7.

Project Timing: Delays in Stage II Execution and Phasing

The economic analysis performed by the IDB usually assumes that the length of time between the beginning of construction and the beginning of operation and initiation of benefit flows (the execution period) is the 4 (or more recently 5) year period stipulated in the loan contract. Most analyses do not estimate the impact of slow execution on NPV. Analyses for a multi-stage projects assume no phasing delays between the end of one stage and the beginning of another. Omission of the risk of delays or pauses gives an overly optimistic view of NPV when net benefits are growing a rate lower than the discount rate (the usual case).

To examine the realism of the 4-year execution period, we reviewed IDB data on 17 sanitation projects undertaken between 1980 to 1992 in Argentina, Brazil, Chile, Mexico, and Uruguay. The frequency distribution displays positive skewness, with an average execution period of 5.75 years, a

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[27] This simplified treatment was adopted in order to accommodate the complexities of execution timing more easily in the spreadsheet design. It implies that the value of energy and the amount produced are perfectly correlated, which may overestimate the probability of very high or very low energy benefits. Had the energy price and quantity risks been specified independently, the distribution of the estimate of energy benefits would have been more compact, as high draws from one distribution would have frequently been offset by low draws from the other.

median of 5.5 years, and a mode of 4.75 years. All exceed the 4-year execution period usually assumed. (Equivalent data on phasing of multi-stage projects are not available.)

The execution period for the first stage of the Tietê was 6 years (known with certainty). To reflect the uncertainty about the execution period for the second stage, the analysis assumed that it will be similar to that experience cited above. The risk analysis draws from the empirical frequency distribution for the execution period for Stage II, while holding Stages I and III fixed at the 6 years actually experienced in Stage I and the 7 years planned for Stage III. The probability of delay is characterized by the empirical histogram with a 61.5% probability of an execution period of between 5 and 6 years, a 23.1% probability of an execution period between 6 and 6.5 years, and a 15.4% chance of delays between 6.5 and 10 years (see Table 7).

Phasing delays between the end of Stage I construction and the start of Stage II are only relevant for the economic analysis of the entire multi-stage program. In the absence of any hard historical data on phasing delays, the analysis assumes that a hiatus of between 0 to 4 years could occur with equal probability (uniform probability distribution) between Stages I and II, while allowing Stage III to follow without delay (see Table 7).

STANDARD RESULTS AND SENSITIVITY ANALYSIS

Most project analyses report only a single payoff (NPV or internal rate of return, IRR) as if it were the only result possible, and analysts almost always choose one point estimate of per-unit benefits without exploring or necessarily being aware of other possibilities. In the past the unbounded parametric mean has been the measure commonly extracted from referendum CV surveys, but in this case it breaks down because of a negative willingness to pay estimate (see Table 3). For illustrative purposes, the Turnbull lower bound mean is a close substitute. If an analysis had been conducted for Stages II and III using only the most likely or mid-point estimates about the factors that determine project payoff, basing benefits on the Turnbull mean, it would have shown that the NPV of continuing the project is negative. The incremental investment loses R$44 million,[28] so the project does not appear to be economically feasible.

Sensitivity analysis is the method most multilateral financial institutions use to address the uncertainty in the projects they appraise, if they address it at all.[29] In this case, the negative NPV result would halt project approval. If strong pressure for approval were to be exercised by influential stakeholders, it would probably send the analyst searching for factors that, with "small" adjustments, might make the investment appear to be profitable and hence bankable.

A standard sensitivity analysis reflects the uncertainties about project outcome by looking at the impact on NPV (or IRR) of standard, but arbitrary, percentage increases and decreases of the factors that determine a project's outcome. Occasionally, it presents calculations of the "critical value" of each influence that will drive NPV above zero if the NPV is negative or below zero if it is positive, called *switching values*. The crudest approach is to increase or decrease gross benefits and costs, while a more refined approach explores the effects of varying the factors driving these aggregates.

Table 6 presents the best estimate for NPV of Stages II and III and a sensitivity analysis that is more detailed than those generally presented. It shows the NPV that would result if benefits, construction period, energy benefits, timing, costs and shadow price factors were 10% or 25% higher or lower than their "base estimate" values.[30] It uses the mean of the Turnbull distribution of WTP as the best estimate, and instead of using the available statistical information about the uncertainty of benefits (the confidence interval), it arbitrarily applies the same percentage change factors to everything. This type of presentation is more detailed than the typical presentation, but shares the feature that both statistical uncertainty (that is, in fact, quantifiable), and methodological uncertainty are totally ignored.

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[28] This calculation treats the capital costs in Stage I as "sunk" so they are not relevant in calculating the incremental net returns from Stages II and III.

[29] Ardila *et al.* (1998) found that, of the 18 water-quality investment projects approved by the IDB over a ten year period, seven reported no sensitivity analysis at all, eight used standard up/down sensitivity, three of statistical uncertainty in benefits, and one performed a Monte-Carlo risk analysis that incorporated statistical and subjective judgements about the uncertainty of the factors that determine outcome.

[30] In this example, the base estimate of each of the factors that influence the NPV outcome is generally a mean value (see Table 6, Note e and Table 7 below), so NPV is an expected value. Often, however, project analyses do not clearly distinguish between mean and modal values so their base estimate of NPV may have no clear statistical meaning.

On the basis of Table 6 most analysts would probably conclude: "The project is not economically feasible because it has an NPV below zero; the project entails a net loss of 44.2 million reals. With the exception of a shorter execution period, small favorable changes on the order of 10% in the most important factors that determine the outcome would not make it feasible." If the sensitivity analysis used only aggregated benefit and cost flows (see Part II of Table 6), the interpretation would simply be that "An increase of 10% in all benefits or a 10% decrease in all costs would raise the NPV to about R$14 million." If the sensitivity provided additional detail (Part I of Table 6), the analyst might go further and report, "The sensitivity analysis explored the impact of changes of all the factors important to project success. It found that the project is most sensitive to the WTP of families in districts contiguous to and not contiguous to the river, followed by the shadow price of non-tradables, the execution period, and the timing of energy benefits. Public good benefits are a given from the contingent valuation survey, and the non-tradeables shadow price has been firmly established by a study. The execution period and the timing of energy benefits depend critically on institutional and legal issues in the host country and are hard to predict. But, it would appear that unless the project yields hydroelectric benefits very early-on or can be built more quickly, it is not economically feasible. The population growth rate and shadow prices for labor have a marginal effect on NPV and are inconsequential factors."

Of course, one could never find an explanation like this in the official record, because the IDB only finances economically feasible projects. In this case, the execution period assumption is the most obvious and easiest one to fix. If the analyst managed to shorten the execution period by one year, say through negotiating an accelerated construction schedule with the project's borrower and executor, the project could be nudged into the feasible region and its financing could be approved. Then, similar official conclusions about sensitivity would emerge in mirror image, substituting "shorter" for "longer execution period," "decrease" for "increase of 10% in benefits," and so on. And, the analyst would probably be right, but perhaps for the wrong reason, unless the revised execution period could truly be said to be consistent with reasonable expectations. The right reasons emerge from a more profound treatment of perceived uncertainty.

What has been overlooked here? Uncertainty about benefits, as it often is. Using the mean WTPs from the subjective distribution and the baseline assumptions for all other variables would have produced a less negative NPV of !R$12.11 million, which grows to a positive R$109.85 million with our unequally weighted average of high and low non-parametric WTPs and swells to R$263.27 using Kriström's intermediate means. The project's economic feasibility is so firmly established using the latter WTPs that it becomes impervious to the magnitudes of the changes customarily invoked in the up and down elevator economics of standard sensitivity analysis. The trouble with sensitivity analysis is that the real distance the elevator has to travel between the basement and the penthouse and how many stops it makes along the way are unknown.

Sensitivity analysis is better than no analysis, but it has flaws. First, it provides the decision maker no context to evaluate the likelihood of a 25% or a 10% adverse change. For example, the decision maker has absolutely no idea of the likelihood of a 25% adverse change in the willingness to pay benefits. Had the analyst used only one estimate of WTP, the Turnbull, s/he would have found that the 99.5% confidence interval has a range of more than ± 50%, much greater than the arbitrarily chosen ±25%. The range, considering alternative central tendency estimates, is greater yet. A sensitivity analysis that calculates "switching values" (the last column of Table 6) provides more information. It indicates the magnitude of the favorable change necessary to bring

Table 6. Sensitivity Analysis, Incremental Project (Stages II & III)

(Base Case NPV in 000 R$ is !44,176)

			NPV with Percent Changes in Variables from their Base Case Means[e] *(000 R$)*					
Degree of Detail and Variable	**Units**	**Base Case Mean**	**-25%**	**-10%**	**+10%**	**+25%**	**NPV Range**	**Switching Value**
I. Detailed								
Water Quality Benefits, Near River[a]	R$ WTP/Household	$6.07/Month	(136,760)	(81,322)	(7,022)	48,406	185,166	$6.80/Month; 12% Increase
Water Quality Benefits, Far From River[a]	R$WTP/Household	$4.51/Month	(89,466)	(62,212)	(26,141)	1,112	90,578	$5.61/Month; 24% Increase
Project Execution Period[b]	Years	6	n.a.	20,551	(27,846)	(63,782)	84,334	5 Years; 17% Decrease
Energy Benefit Initiation[c]	Project Year	19	21,908	(12,871)	(59,909)	(83,070)	70,198	Year 12; 37% Decrease
Value of Energy Benefit	R$/MWH	$36.44	(53,900)	(48,066)	(40,287)	(34,453)	13,613	$77.98/MWH; 114 % Increase
Shadow Price, Non-Tradeables[d]	Factor	0.78	(114,569)	(73,616)	(14,538)	29,920	103,236	0.90; 15% Increase
Population Growth Rate Near River	%/Year	0.75	(47,398)	(45,367)	(42,811)	(40,923)	4,444	3.1%/Year; 313% Increase
Population Growth Rate Far From River	%/Year	1	(46,249)	(45,009)	(43,340)	(42,077)	2,932	5.7%/Year; 470% Increase
Shadow Price, Unskilled Labor	Factor	0.49	(40,003)	(42,438)	(45,916)	(48,350)	5,913	None. NPV Negative at 0
Shadow Price, Skilled Labor	Factor	0.79	(37,598)	(41,545)	(46,808)	(50,755)	9,210	None. NPV Negative at 0
II. Crude								
All Costs (Investment plus O&M)	000 R$ NPV	$313,171	101,388	14,109	(102,403)	(189,741)	203,790	$589,370; 7% Decrease
All Benefits (Water Quality plus Energy)	000 R$ NPV	$589,370	(191,519)	(103,114)	14,760	103,166	206,280	$633,573; 7.5% Increase

NOTES:

a. Turnbull lower bound mean.

b. The lower limit on the execution period is 5 years in the spreadsheet model, so NPV cannot be calculated below that.

c. Conditional mean assuming energy benefits materialize computed as the normalized probabilities in each year times the alternative initiation years. That is, 0.05/0.5* 12+0.1/0.5*15+0.175/0.5*19+0.175/0.5*22 .

d. This factor is applied to all benefits and non-tradeable costs, so NPV increases as the shadow price factor increases because shadow priced benefits increase more than costs.

e. Sensitivity Settings:

Variable	Base Case Mean	-25%	-10%	+10%	+25%
Base Case NPV	($44,177)				
CV Water Quality Benefits, Near the River/month	$6.07	$4.55	$5.46	$6.68	$7.59
CV Water Quality Benefits, Far From the River/month	$4.51	$3.38	$4.06	$4.96	$5.64
Project Execution Period	6	4.50	5.40	6.60	7.50
Energy Benefit Initiation	19	12.00	15.00	22.00	Never
Value of Energy Benefit	$36.44	$27.33	$32.80	$40.08	$45.55
Shadow Price, Non-Tradeables	0.78	0.59	0.70	0.86	0.98
Costs (Investment plus O&M)	$633,547	$475,160	$570,192	$696,901	$791,934
Population Growth Rate Near the River	0.75%	0.56%	0.68%	0.83%	0.94%
Population Growth Rate Far From the River	1.00%	0.75%	0.90%	1.10%	1.25%
Shadow Price, Unskilled Labor	0.49	0.37	0.44	0.54	0.61
Shadow Price, Skilled Labor	0.79	0.59	0.71	0.87	0.99

the NPV to zero, one factor at a time. This is better than arbitrarily limiting the sensitivity analysis to standard, pre-specified percentage changes from the initial conditions, but it provides the decision maker with no information on the probability that the factor could reach the switching value.

A second flaw of sensitivity analysis is that it usually does not look at combinations of adverse assumptions. Combinations can be important. Two of the three most important benefits of the Tietê project are the WTP benefits for groups in districts contiguous and not contiguous to the river. These benefits depend on the same thing, improvement of water quality to a certain minimum standard. They are highly (or perfectly) correlated. If WTP of those contiguous to the river are lower than expected, so will be the benefits of those who are not contiguous. The calculation of the impact on NPV of an adverse or favorable change in one while holding the other constant is misleading. It will underestimate the adverse impact on NPV. In general sensitivity analysis provides no indication of the probability or impact on NPV of several adverse or favorable changes occurring simultaneously rather than singly (ex cost overruns, low WTP benefits, and execution delays). Thus it is a poor representation of real world uncertainty.

As emphasized throughout the text, all estimates that go into CBA have a margin error. If the probability that all the “best estimates” are simultaneously correct is unknown, the probability that the deterministic outcome predicted with these estimates will occur is also unknown. To accurately reflect what we think we know about the potential return of a project, it is necessary to use all the information that we have about the estimates and their margins of error. The obvious technique for doing this is Monte Carlo simulation.

MONTE CARLO RISK ANALYSIS

Monte Carlo simulation overcomes the limitations of sensitivity analysis. It produces a probability distribution of a project's net return based on either empirical or judgmental probability distributions for the factors that determine the outcome. It does this by repeatedly computing the economic return, each time picking input values from their respective probability distributions, to obtain a frequency distribution of economic returns which is a good approximation of the probability distribution of the outcome (see Vose 1996, Morgan and Henrion 1990).[31]

Table 7 summarizes the variables simulated, the range of values assumed and the shape of the probability distribution used for our risk analysis. Many of the probability distributions are subjective rather than empirical. They reflect a judgement as to whether any number within a range is equally likely (a uniform distribution) or whether some values are more likely than others (a normal, triangular, or custom histogram distribution). The most important judgmental distributions involve the timing of energy generation benefits and the range of WTP.

Monte Carlo Simulation Results: Incremental Project (Stages II and III)

Two Monte Carlo analyses were made. One considers the project as a whole (Stages I, II, and III); the second considers only the second and third stages. The second analysis is relevant for the decision to continue the program, since the first stage has already been carried out and its capital costs cannot be recovered. For now the analysis concentrates on the results for the analysis of Stages II and III under the alternative assumptions that WTP is distributed following either the subjective or weighted bounds models.

NPV Under the Subjective WTP Distribution

Figure 4 presents the probability distribution of the NPV calculated for Stages II and III based on the subjective distribution of WTP. The distribution of the NPV outcomes provides the decision maker with a rather different picture from that provided by the deterministic calculation with sensitivity analysis. It shows an average (expected) NPV of R$4.6 million, which changes the investment decision from "no-go" to "go" because it is positive and higher than the deterministic loss of R$!12.1 million mentioned earlier.

The expected NPV is higher because the subjective probability distribution for WTP allows for the possibility that average willingness to pay is very high (its probability distribution is skewed to the right). A few draws of high WTP values pulls up the simulated average NPV.

Figure 4 indicates that there is more risk than the decision maker would have known about had s/he been given a standard sensitivity analysis. All the sensitivity analysis said was that if the project were undertaken it would incur a loss unless the execution period could be shortened by 17% or unless energy benefits could come on line in two-thirds the time originally expected. It consequently advised that project approval should be delayed until a new execution timeline could be worked out with the borrower.

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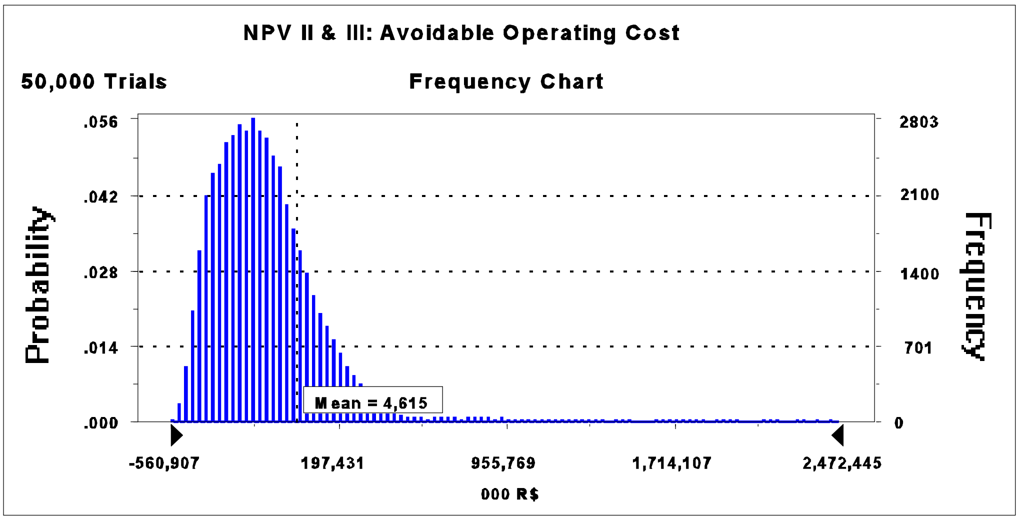
[31] For this exercise, a combination of Microsoft Excel and Crystal Ball from Decisioneering Inc. in Denver, Colorado, was used. Crystal Ball can exploit a spreadsheet's ability to slide blocks of benefit and cost flows up and down across analysis periods in repeated draws.

Table 7. Assumptions About Input Variables in the Monte Carlo Simulations

Variable	Distribution	Measures of Central Tendency and Spread	Remarks	
Operating and Investment Cost Variation Factor	Subjective, Triangular	Most Likely = Mean=1.0 Range = 0.85 to 1.15	Symmetric. Total Costs are Multiplied by Factor	
Skilled Labor Shadow Price Factor	Subjective, Triangular	Most Likely=Mean= 0.79 Range = 0.75 to 0.84	Asymmetric. Costs are Multiplied by Factor	
Unskilled Labor Shadow Price Factor	Subjective, Triangular	Most Likely = 0.48 Mean = 0.49 Range = 0.45 to 0.55	Asymmetric. Costs are Multiplied by Factor	
Non-Tradeables Shadow Price Factor	Subjective, Triangular	Most Likely = 0.75 Mean = 0.78 Range= 0.67 to 0.91	Asymmetric. Costs are Multiplied by Factor	
Execution Period, Stage II	Empirical, Custom Histogram	Mean = 6.0 Years Range = 5 to 10 Years	Range, Yrs 5.0-6.0 6.0-6.5 6.5-7.0 7.0-10.0	Rel. Prob. 0.615 0.231 0.077 0.077
CV Benefit (WTP/Household) Contiguous, **Wtd. Ave. of Turnbull and Paasche Means**	Empirical, Each Normal	Mean = R$7.75/month Std. Error = R$1.23	Reflects Methodological and Statistical Uncertainty	
CV Benefit (WTP/Household) Non-Contiguous, **Wtd. Ave. of Turnbull and Paasche Means**	Empirical, Each Normal	Mean = R$5.80/month Std. Error = R$0.86 Correlated with Contiguous (r=0.80)	Reflects Methodological and Statistical Uncertainty	
CV Benefit (WTP/Household) Contiguous, **Expert Judgement Estimate**	Subjective, Custom Histogram	Mean = R$7.09/month Std. Error = R$10.74	Range, R$ 2.00-4.00 4.00-7.00 7.00-10.00 10.00-50.00 50.00-140.00[a]	Rel. Prob 0.30 0.50 0.15 0.04 0.01
CV Benefit (WTP/Household) Non-Contiguous, **Expert Judgement Estimate**	Subjective, Custom Histogram	Mean = R$3.76/month Std. Error = R$4.95 Correlated with Contiguous (r=0.80)	Range, R$ 0.50-2.00 2.00-4.50 4.50-7.00 7.00-10.00 10.00-25.00 25.00-60.00[a]	Rel. Prob 0.35 0.45 0.14 0.03 0.02 0.01
Energy Benefit Factor	Subjective, Triangular	Mean = 1.0 Range = 0.7 to 1.30	Symmetric. Total value in R$ multiplied by factor.	
Energy Scenario	Subjective, Custom	NA-Categorical. 50% chance of no benefits	Asymmetric. Discrete. See text for probabilities and timing of the 5 Scenarios	
Population Growth Rate, Contiguous	Subjective, Triangular	Mean = 0.75% per yr. Range = 0.5% to1.0%	Symmetric. Small range due to urban space constraints.	
Population Growth Rate, Non-Contiguous	Subjective, Triangular	Mean =1.0% per yr. Range = 0.75% to1.25%	Symmetric. Small range due to urban space constraints.	

Figure 4. **Incremental Project NPV Under Subjective WTP Distribution**



Most decision makers would find it useful to know the amount of the average loss they face if, in fact, there is a loss. This loss can be estimated as the probability of each loss times its size (the mathematical expectation of losses). The decision maker can look at the size of this loss to see if s/he can afford to take the risk.

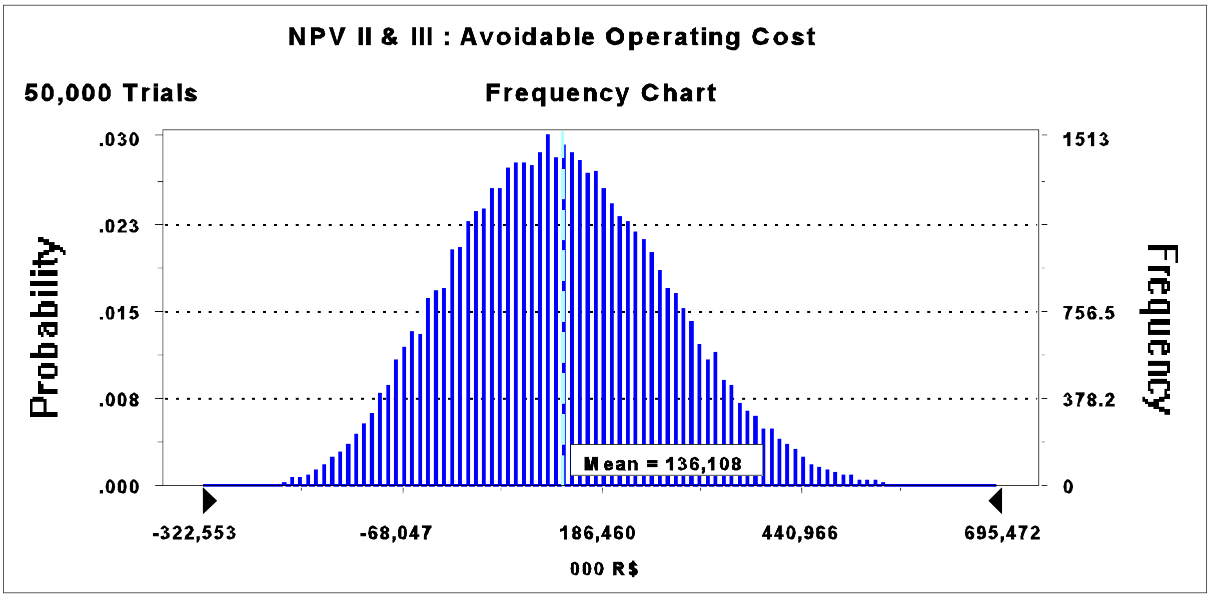
The expected loss, however, has a more sophisticated interpretation and use. The expected loss is also the *cost of uncertainty*. It reflects the maximum amount of money a risk neutral decision maker should be willing to pay to eliminate all uncertainty about the factors that determine the outcome. It is the maximum amount because it would be better to face the expected loss than pay more than that to obtain additional information to eliminate uncertainty. With information about the expected loss in hand the decision maker can choose to (1) undertake the feasible project but risk an expected loss; (2) reject the feasible project, avoid the *cost of uncertainty*, but face an expected loss arising from the potential gains foregone (called the *cost of irrationality*); or (3) collect more information to reduce the cost of uncertainty.

Figure 4 and Table 8 show that although approval need not be delayed, since the investment passes the positive NPV test, there is a 73% chance that the project will register a negative NPV (is not economically feasible) and only a 27% chance it may register a gain. The expected loss that would be incurred by making the investment is the average of the negative NPVs, R$!228.1 million, multiplied by the probability of a loss, yielding R$!167.2 million. The average potential gain from the project is huge, R$643.3 million, and, when multiplied by the probability of a gain (27%), the expected gain of R$171.8 slightly exceeds the expected loss. The difference between average gains and losses, both weighted by their

Table 8. Monte Carlo NPV Distribution for the Subjective WTP Assumption

Percentile	Million 1998 R$
0%	-560.9
10%	-384.6
20%	-319.5
30%	-261.8
40%	-206.3
50% (Median)	-150.1
60%	-93.2
70%	-26.0
80%	64.7
90%	228.0
100%	13135.4

Figure 5. **Incremental Project NPV Under Weighted Nonparametric WTP Bounds Distribution**



respective probabilities of occurrence, is the overall expected NPV of R$4.6 million. The subjective distribution of WTPs tells decision makers that a loss is three times more likely than a gain, but the average payoff is also about three times higher. However, the median payoff that can be expected with 50% probability is negative (R$! 150.1 million) and far below the mean because the NPV distribution is skewed to the right. Risk averse investors might be wary of this bargain, even though it has a small positive expected overall payoff.

Distribution of NPV for the Weighted Average of the Upper and Lower Bound WTP Distributions

The degree of apparent risk associated with the incremental investment is reduced appreciably when the subjective WTP distribution is replaced by a 75-25 weighted average of the Turnbull lower bound and Paasche upper bound distributions of WTP. In contrast with Figure 4 and Table 8, the distribution of NPV in Figure 5 and Table 9 is more symmetric, which reflects the strong influence that the underlying normal distributions of the expected value of WTP have on the outcome.

Table 9. Monte Carlo NPV Distribution for the Weighted Average WTP Assumption

Percentile	Million 1998 R$
0%	-322.6
10%	-36.5
20%	17.9
30%	59.7
40%	96.6
50% (Median)	131.7
60%	167.2
70%	205.9
80%	251.8
90%	314.2
100%	695.5

The global expected value of NPV is more sanguine yet at R$136.1 million, which is almost one standard error away from the critical value of zero. The investment no longer looks so borderline because the probability of a loss is just 16%, which is almost exactly what would be expected for a normally distributed random variable (from the cumulative unit normal distribution, the probability of a value more than one standard error above zero is 15.87%). The average loss falls to R$! 60.8 million, or only one-fourth of what was predicted under the subjective WTP distribution, so the expected loss that might be suffered by making the investment becomes R$! 9.9 million rather than R$! 167.2 million. The average of the positive NPVs, R$174.3 million, produces an expected gain of R$146.0 million after multiplying by the probability of a gain of 84%. Again, the difference between the expected gains and losses (R$146.0 ! R$9.9) equals the global mean NPV. Even a risk averse investor would probably like these odds.

Summing Up: From Frog to Prince

The standard decision rule for CB analysis is that the government should undertake all projects with a non-negative expected NPV. This rule is based on the assumption that a government undertakes many projects and can afford to look at the average (mean result) knowing that some projects will come out better than average and some worse.[32] But when a single project absorbs a large percentage of the investment budget, a large adverse result may prevent undertaking other projects. There may be no chance to let project returns average out. The stages of the Tietê constitute a large project both for SABESP and for the city of São Paulo, so it is certainly worth looking at information other than the expected (mean) NPV. We have told just two alternative stories about the worth of the investment based on risk analysis. Potentially there are several other interpretations, which are summarized in Table 10.

If one were to argue that operating costs from Stage I should be ignored (are sunk), the economic justification for the incremental project is extremely strong.[33] The mean NPV is over three standard deviations above zero for all benefit assumptions except the subjective distribution, which places the mean 0.4 standard deviations away from the breakpoint. Even if Stage I's operating costs are included in the cost stream (are "avoidable"), the incremental investment looks extremely promising if it is evaluated using the intermediate nonparametric distribution of WTP. It still remains fairly promising when a weighted average of the lower and upper bound distributions of the expected value of WTP are used instead.[34] A recommendation against going forward with the project can only be made if the best representation of public good benefits is taken to be the conservative Turnbull lower bound WTP distribution.

What initially looked like an unattractive investment under a deterministic analysis that used conservative (low) estimates of average benefits was transformed into an attractive but risky or moderately risky investment when the nuances of benefits uncertainty and random variations in costs and timing were incorporated via Monte Carlo risk analysis. This transformation is not trickery, but a reflection of how much (or how little) the analyst knows. There is no unique bottom line in this case; it only proves that rigid adherence to a deterministic non-negative NPV investment criterion can be simplistic, dogmatic and oftentimes misleading. While no actual CB analysis would ever report this broad spectrum of alternatives, for fear of needlessly confusing decision makers, Table 10 makes it clear that conclusions about the economic viability of an investment are rarely free of subjective judgment or completely unambiguous. Risk analysis forces the full disclosure of those assumptions and reveals the extent of the ambiguity.

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[32] This can imply carrying out a project with a non-negative expected NPV even though the probability of non-negative returns is less than 50-50 because the probability distribution of NPVs is highly skewed to the right.

[33] This was the preferred assumption in the official CB analysis done by the authors for IDB loan approval.

[34] To drive the overall expectation for NPV below zero, on average the weight attached to the lower bound mean WTP would have to be 0.93 rather than 0.75.

Table 10. Effect of Benefit Assumptions on Risk Analyses Results for the Incremental Project						
	Central Tendency			**Downside Risk**		
WTP Distributional Assumption	**Mean NPV**	**Standard Deviation**	**Median NPV**	**Probability of Losses**	**Average of Losses**	**Expected Loss**
	(10^6 R$)	*(10^6 R$)*	*(10^6 R$)*	*%*	*(10^6 R$)*	*(10^6 R$)*
Operating Costs of Stage I Are Avoidable (Are Charged to Stages II&III)						
Turnbull Lower Bound	($24.4)	$91.0	($26.9)	61.6%	($81.3)	($50.1)
Subjective	$4.6	$822.6	($150.1)	73.3%	($228.1)	($167.2)
Weighted Average	$136.1	$134.9	$131.7	16.2%	($60.8)	($9.9)
Kriström Intermediate	$298.5	$131.6	$296.0	0.8%	($37.9)	($0.3)
Operating Costs of Stage I Are Sunk (Are Not Charged to Stages II&III)						
Turnbull Lower Bound	$295.5	$87.8	$292.9	nil	($9.9)	.0
Subjective	$324.6	$822.3	$169.2	19.9%	($68.1)	($13.6)
Weighted Average	$456.0	$133.3	$451.7	0.0%	$0.0	$0.0
Kriström Intermediate	$618.4	$130.4	$615.5	0.0%	$0.0	$0.0

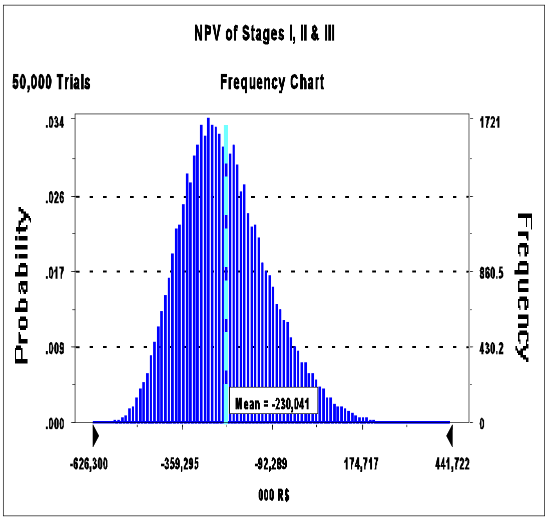
Risk Analysis of the Entire Project (Stages I, II, and III)

The IDB's loan for Stage I of the project was approved around the time of the heavily publicized United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992. The event raised expectations and encouraged countries to pursue sustainable development following the principles of *Agenda 21*. Cost-effectiveness analysis was used to justify going ahead with the first stage of investment, on the unproven assumption that the entire project was economically viable. This decision locked the borrower into contractual obligations for operation of the first stage facilities, repayment of the first stage loan, and continuance of the pollution control program. Now, having made that initial commitment, the best choice is to go ahead and complete the program.

Figure 6 shows that even under the highest of the plausible benefit estimates, Kriström's intermediate mean WTP, the entire project is not economically feasible. At best, the expected NPV is R$!230 million, and would be even lower under more conservative assumptions about benefits. This is an example of the rare extreme case mentioned in the introduction: the project fails the deterministic cost-benefit test even under the most favorable set of assumptions. So in hindsight, sophisticated analysis approaches would not have been needed to reach the conclusion that the investment should not be made. However, at the time the first stage was approved, benefit estimates were not available, so the expected payoff was unknown.

The probability distribution in Table 11 shows that the chance of losing more than R$!230 million is about 56%. At best, the probability that the entire project might have a non-negative NPV is only 5%, so the probability of incurring a net discounted loss is greater than 95%. The cost of uncertainty (the expected positive NPVs forgone by not making the

Figure 6. Entire Project NPV Under Kriström's Nonparametric WTP Distribution



correct decision to reject the project) is onlyR$3.5 million and the cost of irrationality (the expected value of losses from undertaking a project that is predicted to be infeasible) is R$!233.6 million.

It is worth asking why there is such a difference between the incremental project (Stages II and III) and the project as a whole. First, the cost of the project as a whole includes the investment costs of Stage I, which (although necessary for subsequent stages) had no measurable benefits. These costs weigh heavily against the NPV of the project as a whole, particularly since they occur years before any benefits begin to accrue. Second, the risk of delays between the first and second stages affects the net present value of the project as a whole, but not that of Stages II and III (both costs and benefits of the incremental project are delayed). These two factors have a very significant impact on the NPV of the three stages taken together.

Table 11. Monte Carlo NPV Distribution for Entire Project Under Kriström's Intermediate WTP Assumption

Percentile	000 R$
0%	-626,300
10%	-388,368
20%	-342,288
30%	-306,060
40%	-274,227
50% (Median)	-242,367
60%	-207,978
70%	-170,313
80%	-123,140
90%	-53,198
100%	441,722

Benefits Uncertainty and the Value of Information

The *value of information* is defined as the decrease in expected loss that results from greater precision in estimates about the variables that contribute to expected loss. To determine whether it is worthwhile to collect additional information, it is necessary first to determine which estimates most affect the spread in NPV. Table 12 shows that uncertainty about WTP benefits ranks highest among the possible

Table 12. Contribution of Uncertainty about WTP Benefits to Total NPV Uncertainty

WTP Distributional Assumption	Standard Deviation of NPV for Variation In: WTP Benefits Only *(Million R$)*	Standard Deviation of NPV for Variation In: All Variables *(Million R$)*	Amount of Total Variation Due to Uncertainty About WTP Benefits [a]
Incremental Project: Operating Costs of Stage I Are Avoidable (Charged to Stages II&III)			
Turnbull Lower Bound	$64.6	$91.0	71%
Subjective	$803.5	$822.6	98%
Weighted Average	$108.2	$134.9	80%
Kriström Intermediate	$94.7	$131.6	72%
Incremental Project: Operating Costs of Stage I Are Sunk (Not Charged to Stages II&III)			
Turnbull Lower Bound	$64.6	$87.8	74%
Subjective	$803.5	$822.3	98%
Weighted Average	$108.2	$133.3	81%
Kriström Intermediate	$94.7	$130.4	73%

Notes:
a. Calculated as the ratio of the standard deviations. When only variation in WTP is allowed, the default settings for the frozen variables are at the means (see Tables 6 and 7 above).

candidates, explaining more than two-thirds of the overall variation in NPV across a variety of circum stances. Having identified the main sources of uncertainty, it is then necessary to estimate the reduction in uncertainty that would result from further study or additional sampling (e.g. what the new probability distribution about the WTP estimate would look like if more data were collected). The value of more precise WTP information is determined by the difference between the expected losses of two simulations: the original risk analysis and the modified analysis that substitutes the probability distribution that would result from further study. To decide which information to collect and how far to go in collecting it, it is necessary to compare the value of information computed in the manner above with the cost of achieving the reduction in uncertainty. This kind of analysis is not as simple as it sounds; for details see Vaughan and Darling (2000).[35]

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[35] It is not necessarily true that the factor that has the highest value of information is the one that should receive the most attention. It may be that other important factors can be made more precise at lower cost. Our emphasis has primarily been on issues involving nonmarket valuation. Vaughan and Darling (2000) elaborate along this line by looking at the effect that larger CV surveys can have on reducing the uncertainty about WTP and NPV. Strategies for reducing the variance of cost estimates or other variables are not covered.

CONCLUDING OBSERVATIONS

This study demonstrates that any single point estimate of the net economic returns of a project does not provide a decision maker with much information and is likely to be wrong a majority of the time. Accompanied by the standard sensitivity analysis that assumes variations that may have nothing to do with the true margin of error, it may mislead the decision maker into being confident about a decision that, in fact, is risky, or being skeptical about a promising investment opportunity.

While it is true that many of the probability distributions in the analysis are subjective, they at least reflect a focused and explicit judgement by the analyst. They may not all be based on empirical facts, but they reflect the information at hand. The distribution of the economic results that come from these probability distributions are also not empirical facts, but they are consistent with best judgements of the analyst and open for all to review and question.

This case study also demonstrates that it is important to carry out CB analysis of projects, particularly multi-stage projects, before the first stage is initiated. Least-cost analysis alone is not sufficient. It is true that the requisite CB information about inputs, values and timing for projects with long maturation periods is necessarily imprecise at early stages. But, the CB risk analysis technique presented in this paper provides a method to meaningfully summarize what analysts know about a project and help design a cost-effective strategy to reduce this uncertainty, using the concept of the value information.

In the case of the Tietê, it is possible that decision makers, had they known that the expected NPV of the overall project was negative, would have started the project anyway. Economic reasons are not the only reasons for doing things. It is, however, possible that having seen the expected results, the decision makers might have changed the sequence of investments with better results. It is clear that it would have been better economically to invest first in connections and collection systems which had high economic returns. Having done that they could have concentrated the investment in clean-up in a shorter period and increased the NPV of the clean-up project (it probably still would not have had a positive NPV).

When millions of dollars are at stake in water pollution control program investments, cost-benefit analysis is worth the effort, even though the benefits of water quality improvement are hard to specify precisely (Wattage *et al.* 2000). However, that very uncertainty means that an honest economic appraisal should probably include a good risk analysis. We economists sometimes know less than we pretend, and others expect. These conclusions are hardly new (see Jenkins 1997) but, unfortunately, they seem to be too easily forgotten precisely at the times when their message means the most.

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