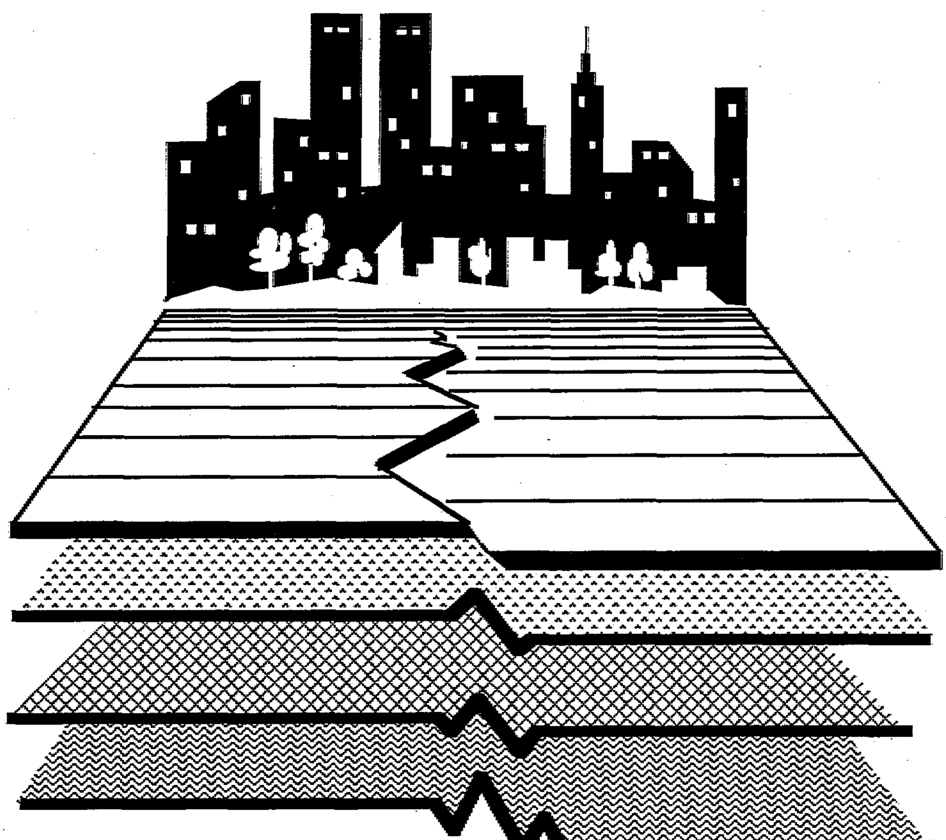
Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model

Volume 2 - Supporting Documentation



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NATIONAL EARTHQUAKE HAZARDS

REDUCTION PROGRAM

SEISMIC REHABILITATION

OF FEDERAL BUILDINGS:

A BENEFIT-COST MODEL

VOLUME 2
SUPPORTING DOCUMENTATION

Prepared for the Federal Emergency Management Agency
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by

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This report was prepared under Contract EMW-92-6-3976 between the Federal Emergency Management Agency and VSP Associates, Inc.

For further information regarding this document, additional copies, or the software to operate the model, contact the Federal Emergency Management Agency, Mitigation Directorate, Washington, DC 20472.

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FEMA FORWARD

FEMA is pleased to have sponsored the development of these two new publications *(A Benefit-Cost Model for the Seismic Rehabilitation of Federal Buildings. Volume 1: User's Guide* and *Volume 2: Supporting Documentation)*, and the associated software, for inclusion in the series of documents dealing with the seismic safety of existing buildings. In this endeavor, FEMA gratefully acknowledges the expertise and efforts of VSP Associates, Inc., its consultants, the Advisory Panel, and Ms. Diana Todd of the National Institute of Standards and Technology, Technical Advisor to FEMA.

The Federal Emergency Management Agency

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CHAPTER 1: INTRODUCTION

This is the second of two volumes in "A Benefit-Cost Model For The Seismic Rehabilitation of Federal Buildings." Volume 1 is the User's Guide and contains detailed information about the benefit-cost analysis which accompanies this report. This Volume is the Supporting Documentation and contains more detailed background or reference information.

Chapter 2: Valuing Government Services, Quasi-Willingness-to-Pay reviews the economic literature on valuing public sector services and provides background information on the Quasi-Willingness-to-Pay (QWTP) model used in the benefit-cost program to value government services lost to the community due to seismic damage.

Chapter 3: Discount Rates and Multipliers, OMB Circular A-94 reviews the economic literature and interprets OMB guidance on appropriate discount rates for Federally-funded projects.

Chapter 4: The Value of Life reviews the economic literature on the dollar value of human life. This chapter is reprinted from Appendix 1 of Volume 2 of A Benefit-Cost Model for the Seismic Rehabilitation of Buildings (FEMA 228, 1992).

Chapter 5: Technical Issues, reviews two major technical issues which affect benefit-cost analysis of seismic rehabilitation projects: a) Seismic Risk, and b) Sensitivity Analysis.

CHAPTER 2: VALUING GOVERNMENT SERVICES: QUASI-WILLINGNESS-TO-PAY

Executive Summary

The benefit-cost model (BCM) for seismic rehabilitation of federal buildings presents few conceptual difficulties from an economic point of view. All of the costs of earthquake mitigation measures correspond to specific expenditures of federal dollars that represent purchases made at market prices. Many of the benefits of earthquake mitigation take the same form: any mitigation in damage to buildings and contents will reduce federal expenditures if and when an earthquake occurs, and the magnitude of these avoided expenditures can be used as the measure of benefits.

Two categories of benefits do not fit this straightforward paradigm: the deaths and injuries that might be avoided by earthquake mitigation measures, and the value of government services that might otherwise be interrupted by earthquake damage. Procedures for assigning economic value to avoiding deaths and injuries have been addressed in developing the BCM for private sector buildings; no new issues are raised in the federal case. However, avoiding interruptions in the output of government services represents a benefit with no similar component in the private sector model.

To account for these losses of government output, we need a simple procedure for assigning economic value to government services. The problem is that government services, almost by definition (in the U.S.), are those to which markets do not assign a value. Therefore private methods of analysis (and similar methods related to privatization and user fees) are either unavailable or unsuitable. Moreover, traditional methods of benefit-cost analysis tend to be overwhelmed by the problem, since so many different types of services are involved. Hedonic pricing and travel-cost methods would capture only a fraction of the value, at best, of government services. Survey methods are unreliable and expensive, and not easily adapted to the range of services in question.

We conclude that a simple procedure is best: the default assumption in the model is that if the government is paying $5,000 a month to employ an individual in an office with a computer, then the loss of that individual's services—whatever they might be—for one month will cost the nation $5,000. Sometimes this is called collective or politically-determined willingness to pay; we will call it quasi-willingness to pay (QWTP). If one were doing a benefit-cost analysis of a federal program from scratch, this method would be of little use because it would be circular. But for seismic rehabilitation it is superior to alternative techniques. A decision to rehabilitate a federal office building is not the appropriate occasion for a *de novo* reexamination of the

rationales and values underlying the federal programs it houses. Rather, the rehabilitation analysis should accept as a given the decision to provide a certain variety and level of services, and proceed from there to the question of how best to protect those services. Users of the BCM can provide a "continuity premium" to indicate the extra importance that certain functions might have in the immediate wake of an earthquake.

I. Introduction

Assigning economic values to non-market goods and services is usually the most challenging part of a benefit-cost analysis, either because there is little data from which to estimate values, or because it raises deeper conceptual problems like the treatment of intergenerational transfers, the validity of "existence" values, and other areas of theoretical controversy.

For the most part, the Benefit-Cost Model (BCM) for seismic rehabilitation of Federal buildings presents few such difficulties. All of the costs of earthquake mitigation measures are "pecuniary" costs on the federal budget. That is, we can identify specific expenditures of federal dollars that correspond to all of the economic costs, and these dollar flows can be taken as a complete quantitative measure of the underlying economic costs because they represent purchases of goods and services at market prices. Many of the benefits of earthquake mitigation take the same form: any mitigation in damage to buildings and contents will reduce federal expenditures if and when an earthquake occurs, and the magnitude of these avoided expenditures can be used as the measure of benefits.[1]

If all of the benefits took this form, then earthquake mitigation decisions could be modeled as pure internal government investments. Under OMB guidelines,[2] all of these budget flows would be converted to expected values (using the estimated probabilities of various outcomes), then summed to a net present value using a real discount rate equal to the federal cost of borrowing (about 4 percent), without having to apply any special multipliers to account for economic stimulation, for the excess burden of taxation, or for the shadow price of capital. (See Chapter 3 on discount rates and multipliers.)

Two categories of benefits do not fit this straightforward paradigm: the deaths and injuries that might be avoided by earthquake mitigation measures, and the value of government services that might otherwise be interrupted by earthquake damage.

Assigning economic value to deaths and injuries raises conceptual (or at least rhetorical) difficulties as well as practical ones, but these have been fully explored elsewhere.[3] Standard estimates of the value of life are incorporated into the BCM, and life-saving benefits are discounted at the same rate as other benefits in the model (4 percent). Although technically the value of life is measured in dollars of private consumption that are not strictly comparable to federal budget dollars (because of the

[1] With a few possible exceptions (museum artifacts, for example), earthquake damage caused to buildings and their contents can be estimated by referring to market prices for repair or replacement.

[2] OMB, Circular A-94.

[3] See Chapter 4 of this volume for a review of the value-of-life literature.

excess burden of taxation), the BCM does not include an "excess-burden multiplier" to make them comparable. The standard BCM output includes a statement of net benefits both with and without the life-saving benefits,[4] so that the user may easily interpolate the influence of small changes in the value-of-life; additional sensitivity analyses can be run as needed. Using an excess burden multiplier in this context would only add confusion and would not improve the accuracy of the BCM.[5]

Interruptions and reductions in the output of government services also can produce real economic losses without any corresponding change in government outlays; and it is important to try to estimate these costs. In some cases it might be possible to observe indirect effects in the local economy, as businesses or individuals turn to substitutes for certain types of government services—Post Offices and Veterans' hospitals are federal facilities with obvious private substitutes. In many cases, however, the drop in government output will simply produce welfare losses among the public, with no easily observable economic manifestations. With broad public goods—such as federal research or national defense—the losses will not even be confined to the geographical area of the earthquake.

None of the benefit categories in the private-sector BCM is directly comparable to the reduced loss of government services. In modeling the decision process for private buildings, the primary point of view was that of the building owner/occupant. In the case of federal facilities, however, there is no useful distinction to make between private and social benefits. The federal government is a self-insuring entity owned by the public, so that the proper point of view for the benefit-cost analysis is that of the public as a whole. For example, while a commercial entity might care about profits but not consumer surplus, a public entity should try to take account of losses in consumer surplus.

Thus we need a manageable procedure for assigning an economic value to losses of output of government services from a building, which may house one federal agency—or a dozen. This is a simple question, yet any practicing economist will find it humbling. The problem is that government services, almost by definition, are those to which the market cannot assign a value, and the traditional methods of benefit-cost analysis for estimating values are overwhelmed by it. To explain why, this chapter reviews some of the standard methods available.

In the end, we conclude that a simple procedure is best: the default assumption in the BCM is that if the government is paying $5,000 a month to employ an individual in an office with a computer, then the loss of that individual's services—whatever they might be—for one month will cost the nation $5,000.

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[4] Note that the BCM includes a forecast of net benefits without the value of life *not* because there is any doubt about whether life-saving benefits should be counted, but to show the user what the source of benefits is and how they break down between on-budget and off-budget effects.

[5] See Chapter 3 of this volume.

This approach recognizes that the level of output of government programs is decided not by the market, but by legislative and executive decisions--ultimately political decisions--about program funding levels, tax burdens, and budget deficits. If this process achieved economically efficient outcomes, then the value of each government program at the margin would be equal to its marginal cost. Since accurate information about the cost of government programs is more easily obtained than accurate information about the benefits, we could use cost as a proxy for economic value.[6]

Using price-paid as an indicator of value is a standard procedure for assigning values to private goods and services, and is usually referred to as the "willingness-to-pay" measure of consumer preferences. When governments (as opposed to individuals) are paying the bill, however, this term cannot be rigorously applied.[7] Instead, this method has sometimes been called "collective" willingness to pay, or "politically determined" willingness to pay. We will use the term quasi-willingness to pay (QWTP) in order to stress that it is related to the standard willingness-to-pay measure of value, but with some important differences.

The most important difference is that QWTP implicitly relies on the assumption that various government services are provided at economically efficient levels. While this assumption might fairly be called "heroic," it also is one of the main advantages of QWTP in the context of the BCM. Any alternative method for estimating the value of government services--one that implicitly assumed that the economically efficient mix of government services differed substantially from the actual mix of services--would likely achieve neither political acceptability nor economic credibility.

II. Literature Review

A. Private Decisions, Privatization, and User Fees

In searching for a method to assign value to government services, the obvious place to look for inspiration is the array of techniques used by the private sector to make decisions. Households and firms have been weighing benefits and costs for a long time—long before there were economists—and the problem of rehabilitating a federally owned building closely resembles the problem of rehabilitating a privately owned building. There are critical differences, however. One is information: households are

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[6] "Marginal" here refers to relatively small changes in the level of services. For example, there is no inconsistency in believing that the value to the nation of having a military capability is many times greater than what we pay for it, and at the same time that the value of any single military installation is about equal to what we pay for it--as long as we do not lose them all at once!

[7] There are technical reasons for this. For example, transitivity of preferences is taken as axiomatic for individual consumers, but has been shown to be impossible in the context of collective choice. So "revealed preference," "compensating variation," and the other standard tools of consumer welfare analysis cannot be strictly applied to government actions. Nor, of course, can the theory of the profit-maximizing firm be applied.

presumed to know their own preferences, and firms are guided by market prices for both inputs and outputs. A government agency cannot be assumed to have any special insight into individual preferences, nor can it refer to market prices to determine the value of its output. Another major difference is that private decisionmakers face well-bounded problems; they need not worry about externalities, for example. A government agency must take a broader perspective and attempt to account for externalities and other messy complications.

In the past 15 years there has been a surge of interest in applying private management methods to the provision of government services, either through privatization of government-owned organizations, or through the use of user fees.[8] In the United States privatization and user fees were central features of President Reagan's domestic program, but far more research (and far more privatization) has been done in countries that initially had more socialized economies or more nationalized industries. Some early work was done in New Zealand and Great Britain; later several South American countries actively pursued privatization programs. With the rejection of communism in Eastern Europe,[9] the reunification of Germany, and the breakup of the Soviet Union, research on methods of privatization is stronger than ever.[10]

Unfortunately, the types of analysis used in privatization decisions are of little use in benefit-cost analysis. The government services that are most susceptible to privatization are those that supply essentially private goods. While a privatization analysis does assign a value to government services (and may estimate a demand curve), it is intended to find the conditions under which that service can be operated as a commercial enterprise. Such an analysis would not offer much insight into the value of most federal programs because it would tend to focus on private gains, rather than social benefits.

Even in the case of services for which a persuasive privatization analysis could be assembled, such as the Post Office or the Veterans' hospitals, the results would be controversial. The Postal Service is not subsidized, but it does enjoy a legal monopoly in first-class mail. One result is that there are more Post Offices than a fully private postal service would operate. Still, the Postal Service would be unlikely to concur in a conclusion that Post Offices should not be protected from earthquake damage because we have too many of them! Similarly, the Department of Veterans' Affairs could be expected to argue that the services it provides should not be evaluated from the perspective of potential profitability, because such an analysis would ignore larger social goals and commitments that justify the subsidies that its hospitals receive.

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[8] Hopkins, 1988.

[9] Note that the rise of communism and socialism in Europe was accompanied by the development of a large technical literature on methods of resource allocation in centrally planned economies. This literature is now almost unanimously regarded as worthless.

[10] The U.S. Agency for International Development is sponsoring a large program of technical assistance to the newly independent states, including teams of experts on privatization.

The same comments apply with even greater force to the analysis of user fees, which have been adopted for many (and proposed for many more) Federal services. While user fees can help ensure that such services are used more efficiently (say, in the case of boaters who request Coast Guard rescue), they will not usually tell us at what level the program should be funded or what its total social value is. Typically user fees are proposed for programs that provide a mix of private and public goods, and are intended to ration the private component. Thus they will only reflect a portion of the total value associated with the program, and will only cover a fraction of its costs.

B. Public Decisions and the Development of Benefit-Cost Analysis

The techniques of benefit-cost analysis focus largely on the problem of assigning value to public goods. Public goods are defined as those which are nonrivalrous (my consumption does not diminish what is available to you) and/or non-exclusive (if I buy some I cannot prevent you from enjoying it too). National defense is the classic example of a public good: however we decide to distribute the costs of defense, the benefits are inevitably shared. Markets cannot be relied on to elicit the right level of production of public goods, so governments (in theory) do. Not all public goods are provided by government: nature supplies clean air and scenic vistas; private charity supplies wilderness preserves and homeless shelters. Moreover, not everything that the government does can be easily explained as a public good. Nonetheless, the theory of public goods is the right place to look for guidance, because it deals with the general problem of how to assign economic value to goods and services that are not traded in a market.

Benefit-cost analysis is a twentieth-century development, and its origins are in the U.S. Department of Defense. Initially, it was applied to civil works of the Army Corps of Engineers. The River and Harbor Act of 1902 required the Corps to evaluate costs and benefits of water projects; the Flood Control Act of 1926 added the requirement that all projects proposed by the Corps must have positive net benefits. During World War II the United States and Great Britain developed a variety of mathematical methods for allocating scarce strategic materials and optimizing military operations. Program budgeting, linear programming, and other tools of "operations research" were developed and later incorporated into cost-effectiveness and benefit-cost analysis. The Defense Department continued to be a central focus for developing these methods, particularly in the Kennedy administration; President Johnson then initiated a campaign to export them to civilian agencies. In one guise or another benefit-cost analysis has been featured in proposed budget reforms ever since (although it still cannot be said that benefit-cost analysis is driving the Federal budget).

The growth of Federal regulatory agencies generated a whole new set of applications for benefit-cost analysis. President Nixon initiated a "Quality of Life Review" process that required an evaluation of regulatory costs and a review by the Executive Office of the President; every subsequent president has ordered some type of regulatory review and balancing between benefits and costs.[11] Many recent advances in benefit-cost methodology have focused on evaluating regulations. While benefit-cost analysis still finds only limited statutory support in either budget programs or regulatory programs, it is generally accepted as best means of assessing the efficiency of government programs.

The latest refinements in benefit-cost analysis have been associated with its use in litigation. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (a.k.a. Superfund) called for federal regulations outlining methods of assigning value to natural resources that have sustained damage from spills of oil or hazardous substances.[12] In later amendments to CERCLA and in the Oil Pollution Act of 1990[13] Federal and state governments were authorized to bring civil suit for damages to natural resources. The resulting litigation has made valuation of public goods one of the most active areas of economic research today.

While the literature on benefit-cost analysis explores a variety of methods for assigning value to public goods, all of them are aimed at estimating the sum of individual willingness to pay to obtain a desired outcome.[14] This measure of value is comparable to the market prices that we use to value private goods and services, and it is straightforward in theory. In practice, however, it can be next to impossible to measure. Two basic approaches are used: one relies on revealed preferences--i.e., behavioral data; the other relies on expressed preferences, or survey data.

C. Revealed Preference Methods

The theory of economic welfare builds on the preferences of individual consumers, as revealed by the decisions they make in the market place to buy—or not to buy—goods and services that are offered at various prices.[15] Since public goods are not traded in markets, no direct data on consumer preferences can be found there. The standard methods of benefit-cost analysis use indirect clues: by interpreting the behavior of consumers with respect to related private goods, it is possible to assign approximate values to public goods. Within this group, two well-developed quantitative techniques

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[11] President Clinton signed Executive Order No. 12866, *Regulatory Planning and Review,* on September 30, 1993. It maintains the requirement for benefit-cost analysis and affirms the principle that regulatory decisions should be guided by the results: "[A]gencies should select those approaches that maximize net benefits . . ., unless a statute requires another regulatory approach."

[12] Section 301(c). Responsibility for drafting regulations was delegated to the Department of the Interior by Executive Order.

[13] Prompted by the Exxon *Valdez* oil spill. The Oil Pollution Control Act is administered by the Department of Commerce, which is developing its own regulations governing the estimation of damages.

[14] Rarely, willingness to *accept* compensation to *forego* the desired outcome is used instead. The difference should usually be small.

[15] Samuelson, 1957, developed the revealed preference theory for market goods.

are available: hedonic methods and travel cost methods.

Hedonic methods attempt to find private goods whose market prices include a component attributable to the public good (or bad) being evaluated. Housing prices may tend to be depressed near the town dump, and may be elevated near a pristine lake. Econometric techniques can be used to sort out the many different factors that contribute to housing prices. Hedonic prices, for example, are used to estimate the market value of a closet in a new home--even though no separate market for closets can be observed. In exactly the same way, it is possible to extract from housing prices an estimate of the cost of the dump (in terms of its nuisance to near neighbors) or the value of the lakefront.

Standard estimates of the value of life are another example of hedonic methods. Econometric techniques were used to examine the determinants of wages in different jobs, with relative risk of accidental death as one of the independent variables. Since such studies consistently show that higher wages are associated with high-risk jobs, it is possible to extract the "price" that people place on their own safety.

Unfortunately, for the great majority of government services it would be impossible to find a suitable hedonic measure of value. While proximity to a National Park will certainly enhance nearby home values, it is unlikely that a typical federal office building would show much of an effect. If it did show an effect, the values extracted by this method could not account for more than a small fraction of the total value of the building's services, since access to these services is not strongly dependent on the location of the customer's residence.

The other well-developed revealed-preference technique is the travel-cost method. This is most often used to estimate the benefits of recreational opportunities, such as fishing or hiking; it resembles hedonic pricing in that it relies on spatial relationships. Instead of market prices, the travel cost method extracts willingness-to-pay estimates from the choices people make about how far to travel to enjoy a particular service. People will spend more time, as well as more money, to reach a more desirable fishing spot. By doing so, they reveal their preferences on a monetary scale--even though the fishing itself is free. As with hedonic pricing, this method would be applicable to only a small fraction of government services, and would likely measure only a fraction of the value of those.

D. Expressed Preference or Survey Methods

Dissatisfaction with the limitations of hedonic and travel-cost methods led the Environmental Protection Agency to sponsor a program of research in "contingent valuation" surveys. These resemble public opinion polls or market research surveys, but they are designed for the specific purpose of estimating individuals' willingness to pay for public goods. Respondents are confronted with a choice (one early study showed them photographs of the Grand Canyon with visibility impaired by varying levels of air pollution), and are asked how much they would be willing to pay for the outcome they prefer. Estimates of value are aggregated across the relevant population (often the entire nation) to get a total value.

Contingent valuation surveys are classified as an expressed-preference method, because values are calculated from what people say, rather than inferred from what their behavior reveals. Advocates of expressed preference methods sometimes call them "direct" methods, because they are indeed less roundabout than the revealed preference methods described above. They have serious drawbacks, however, and for a while it seemed likely that this line of research would be abandoned. Contingent valuation surveys have experienced a strong revival, however, in the litigation authorized by CERCLA and the Oil Pollution Act of 1990. Both the Department of the Interior and the National Oceanographic and Atmospheric Administration have undertaken rulemakings to standardize valuation procedures for natural resource damages, and survey methods will play a prominent role in both of them.

There are serious philosophical disputes about the validity of expressed preference methods on a number of grounds. People who never use a good or service in any observable way may still express a large (and unverifiable) willingness to pay simply for the existence of, say, a pristine shoreline in Alaska. Such "non-use" values can skew resource allocation decisions, because there are so many non-users and no limit on what values they might express. Moreover, expressed preference methods do not conform to the usual scientific standards of verifiability. Given the large divergence between what people say in contingent valuation surveys, and what they actually do, it is still unclear whether the economics profession ultimately will accept survey data as a reliable indicator of value.

In any event, contingent valuation surveys require very careful design and execution, and large sample sizes. They tend to be far too expensive for most analytical purposes, and are popular only in the context of large civil lawsuits.

III. Quasi-Willingness-To-Pay

A. Relationship to Willingness-To-Pay Methods

The overarching goal of a benefit-cost analysis is to estimate the changes in the well-being of individuals, where each person's welfare is measured according to his or her own preferences. Individual preferences are revealed by individual behavior—i.e., the decisions made in response to choices offered by the market. This is why market prices can be used as a gauge of individual values, and why individual willingness-to-pay is accepted as the conceptually correct measure of value in benefit-costs analysis, even when a real market is not present.

Firms do not have welfare, so no values can be ascribed directly to their behavior. But when markets are competitive, the economic theory of the firm provides a strong link between the choices a firm makes and the preferences of its customers, suppliers, employees, and stockholders. In a benefit-cost analysis firms are generally assumed to be using factors of production efficiently and prices and quantities are assumed to be set by supply and demand.

In effect, the "quasi-willingness-to-pay" (QWTP) method adds one more heroic assumption: that government agencies are also allocating resources efficiently, so that their expenditures accurately reflect the underlying preferences of voters. This approach recognizes that the level of output of government programs is decided not by market processes but by legislative and executive budget decisions, ultimately controlled by electoral politics. If this process achieves economically efficient outcomes, the value of each program at the margin will be equal to its marginal cost. Thus for marginal changes in output, we can use the level of funding for a particular government function as a proxy for value. In simple cases, QWTP works as follows. If a government office experiences a 10 percent decline in productivity for one month, but no change in outlays, the lost output would be valued at 10 percent of the funding budgeted for that function.

On the surface, QWTP closely resembles conventional willingness to pay. Instead of trying to glean the preferences of individuals; QWTP looks instead at the preferences of the public collectively, as expressed through the democratic and administrative processes of government. Thus it is sometimes referred to as "collective" willingness to pay, or "politically determined" willingness to pay.

QWTP is not a formally developed procedure, because its scope of application is limited. It is sometimes used to rebut unreasonable damage assessments in natural resource cases. For example, a corporation accused of damaging a wetland may point out that the government bringing the civil suit has itself decided to develop wetlands, or has foregone opportunities to protect wetlands, and that those decisions imply a much lower value for wetlands than the lawsuit implies.

Often QWTP arguments are used inappropriately, as when an agency claims that if Congress has set a certain statutory goal—say, "preserving our heritage"—then attaining it must be worth, *ipso facto*, whatever the cost turns out to be. Used in this way, it is a rejection of benefit-cost analysis rather than an application of it.

One fruitful way to apply QWTP is to look for inconsistency across a number of programs with similar objectives. For example, in assessing various measures that were intended to achieve "energy independence" the Energy Department and its predecessor agencies used implicit values for saving a barrel of oil. While the method did not supply any independent indicator of what a barrel of oil was really worth, it did enable the Department to recognize when one conservation measure was putting an unrealistically high value on a barrel, or was out of line with other programs in terms of its cost-effectiveness.

QWTP has sometimes been used to estimate the implicit value of life in various government safety programs. In this context, one author concludes:

> If it could be assumed that governments act purposefully, rationally, and consistently, then the observed willingness to pay for increased longevity could be interpreted as a politically determined value of statistical life. The main problems with using data derived from the political process as the basis for assigning values are the strong assumption concerning the rationality and consistency of the political process, and the difficulty that even rational decisionmakers would have making consistent decisions in the face of substantial information gaps concerning the effects of various public policies on mortality.[16]

Even this may be an optimistic assessment, because "the strong assumption about rationality and consistency" may still not be enough to ensure a correspondence between government decisions and the values of individuals. It has to be acknowledged that there is no economic theory to demonstrate that governmental decision processes produce an efficient level of services.

Musgrave and Musgrave, after reviewing a variety of models of voting behavior, conclude that none is completely persuasive. While they recognize that the connection between individual preferences and fiscal decisionmaking is indirect, they do not dismiss it:

> More likely than not, the public receives about the level of public services which it desires, and those who find this level deficient or excessive reflect departures from majority preferences rather than proof that the political process is itself grossly inadequate in giving expression to these preferences.[17]

In the context of the BCM, there are good reasons to use the level of funding as an indicator of the marginal value of Federal programs. It allows the user to take politically determined outcomes as a given. It does not require the modeler to develop an estimate of the value of Star Wars research, for example, independent of the decisions that the political process has arrived at. In this way, QWTP avoids fundamental inconsistencies between earthquake planning and the routine operations of the agency, and automatically keeps damage mitigation measures in proper proportion to all of the other competing priorities and resource constraints that each agency faces.

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[16] Freeman, 1979, pp. 172-3.

[17] Musgrave and Musgrave, 1976, pp. 118-119.

The Department of Transportation Analysis

The Department of Transportation has used QWTP to estimate the value of transportation facilities that might be damaged by an earthquake.[18] In support of seismic safety standards for new buildings, DOT used illustrative values for an average "generic" building in a benefit-cost analysis. Three types of benefits were estimated: the "Benefit from saving the building," the "Benefit from persons and property saved," and the "Benefit from function preserved."

To assign a value to the building's function, "We start by assuming that the building is economically justified by the transportation function it facilitates."[19] DOT then uses the cost of the building as a lower bound on the economic value of the services that flow from it.[20]

Although the DOT analysis is only roughly sketched and does not evaluate any actual building, it is interesting to note the scale of the results that they get. The largest component of benefits from seismic protection is the benefit from persons and property saved, accounting for roughly 90 percent of total benefit. In contrast, the "benefit from function preserved" is less than 1 percent of the total benefit of seismic protection. This suggests that QWTP values need only be approximately correct. It is highly unlikely that they will be a major source of error in the overall benefit-cost analysis, given the large uncertainties that are unavoidably embedded in other components of the model.

Advantages of Quasi-Willingness-to-Pay

There are two main advantages of the QWTP method. One is the relative ease of data collection. Revealed preference methods would require huge amounts of market research, and heroic manipulation of the resulting data, to produce estimates of estimating willingness to pay for even a few Federal services. Expressed preference methods would require the design and execution of complex consumer surveys, and the results would be of questionable reliability. In contrast, the data required by QWTP is already available. It is far easier to find out what we are paying to deliver a service than to find out what it is worth to those who receive it.

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[18] Nutter, Robert D. *Final Regulatory Evaluation for the Earthquake Rule Implementing E.O. 12699: Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction.* Office of Regulatory Affairs, U.S. Department of Transportation: March 25, 1993.

[19] ibid., p. 11.

[20] In the BCM, the value of one day's worth of services from a building is taken as the cost of operating it for one day, including the salaries of the people inside. That is, for the duration of the disruption, we assume that the services of the employees will be lost along with the services of the building. In the DOT analysis, only the cost of the building itself is used, perhaps because they assume that employees who are not killed in an earthquake will find something useful to do.

The second advantage of QWTP is consistency with the existing allocation of resources within the Federal budget. If another method were to impute values to federal programs using an independent measure of value, some Federal facilities might be found to have zero or negative value. While such results might well be credible, the BCM is not the right place for them to be applied. Seismic rehabilitation decisions should accept as given the values implicit in politically determined resource allocations.

IV. Considerations in Applying a "Continuity Premium"

The BCM allows the user to add a continuity premium to the QWTP estimate of the value of government services. This is an extra amount (per day-of-interrupted-services avoided) that the user feels would be reasonable to pay to maintain the flow of services from a particular site. The magnitude of this adjustment is left up to the user, but several things should be kept in mind when estimating a continuity premium.

Identify the Size of the Disruption

In some cases the damage to an individual building will cause a loss of services from multiple sites. This may be true when a facility is a node in a network: a transportation or communication hub, a mail-sorting center, or a command and control center. The question to ask in these cases is: In the event of quake damage, will the reduction in output from this facility effectively idle other, non-damaged facilities? While it might be possible to account for this effect by assigning a continuity premium to the critical facility, a better method is available. In estimating the value of lost services, the user should input cost figures that represent all of the capacity that is effectively disabled, rather than just the cost of the damaged node. (Of course, sites that do not experience direct earthquake damage should *not* be included when estimating benefits from structural, property, and life-safety protection.) This should capture all of the value of lost services.

Post-Earthquake Demand Shifts

An important assumption underlying the QWTP method is that the demand for any particular service is largely unaffected by an earthquake event. Obviously, there are many types of service for which that is untrue.[21] There will be a large increase in the demand for hospital services, communications services, police services, and possibly military services. In some cases—a tourist bureau, for example—demand may shrink after an earthquake, so that a negative value could be assigned to maintaining continuity of service. It may be difficult to assign a precise monetary value to services that will experience a large increase in demand. On the other hand, it is likely to be unnecessary, since the need to protect emergency facilities will generally be self-evident without the BCM.

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[21] Hurricane Andrew reminded us that anemometers tend to blow away just when everyone wants to know what they say.

Avoiding Double-Counting

One hazard of QWTP (and of any method of valuing government services) is that some benefits might be inadvertently double counted. The BCM will be estimating the additional costs that will be incurred to maintain services after an earthquake, as well as the value of the services that will be lost. It will be important to keep a clear distinction between these two, particularly when workload is shifted from one facility to another or from one time-frame to another. For example, few Social Security checks will be permanently lost, although many may be delayed. Processing those checks will shift either to other centers or to the future. In analyzing any particular facility the user will need to be aware of whether the workload is shifting, or disappearing altogether.

There is a range of methods available for maintaining continuity of service: protecting the building, maintaining redundant facilities and off-site capacity, and using an aggressive response plan after an earthquake occurs to restore lost capacity. One of the functions of the BCM is to weigh the cost of structural rehabilitation against the benefit of avoiding post-earthquake relocation and other expenses. Adding a continuity premium puts a thumb on the scale in favor of prior structural rehabilitation. To be fair, a user who is adding a continuity premium to the QWTP value of a particular site should also be sure that the estimate of the duration of disruption is realistic. In general, government programs (such as emergency services) that one would expect to display a large continuity premium would in any event experience only very brief interruptions of service.

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CHAPTER 3: DISCOUNT RATES AND MULTIPLIERS OMB CIRCULAR A-94

Executive Summary

The benefit-cost model (BCM) for seismic rehabilitation of Federal buildings is designed to conform to the provisions of OMB Circular A-94, Revised: *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* (October 29, 1992). While the previous version of Circular A-94 (dated March 27, 1972) mandated a 10 percent real discount rate for all benefit-cost analyses, the new version offers more complex guidance, both on discount rates and on the use of multipliers for benefits and costs.

OMB recommends evaluating most government projects from a risk-neutral perspective, using unbiased estimates of risk. It also recommends using real (rather than nominal) cost estimates and discount rates, to avoid having to forecast inflation. As recommended, the BCM uses real, risk-free, discount rates and monetary values throughout.

Based on the assumption that markets are in full-employment equilibrium, Circular A-94 prohibits the use of economic output multipliers, which are intended to account for the stimulating effect that Federal expenditures can have on a regional economy. While this assumption could be questioned (earthquakes can knock a regional economy out of equilibrium for some time), the use of output multipliers in the BCM would be very complicated and would most likely make seismic rehabilitation look less desirable. In any event, it is unwise to try to incorporate macroeconomic effects into a model that is intended to apply to single buildings. Thus the BCM does not use economic output multipliers.

In projects that produce costs and benefits both on- and off-budget, Circular A-94 requires that the on-budget costs and benefits be inflated by a factor of 1.25 to account for the "excess burden" associated with federal taxation. In the BCM, all costs and most benefits are on-budget. The two major exceptions are the value of government services and the value of life, both of which represent private consumption. However, the "quasi-willingness-to-pay" (QWTP) methodology used to estimate the value of government services yields an answer that is expressed in terms of on-budget dollars. Moreover, sensitivity analyses explore the full range of reasonable values for life-saving benefits. The BCM treats all dollars as equal, and does not use an excess-burden multiplier.

A third type of multiplier, the "shadow price of capital," is sometimes used in benefit-cost analyses to account for the productivity of capital in the private sector. Instead of this technique, Circular A-94 offers a choice of two discount rates: either the prevailing rate of return on Treasury notes (approximately 4 percent) for "internal government investments," or a much higher rate (7 percent) for more general "public investments" that may displace private capital. Using the higher rate would reduce the benefits of seismic rehabilitation by about one-third. Seismic rehabilitation of a federal building comes close to meeting the definition of a pure internal government investment and, since no private capital will be displaced, there is no reason to use the higher rate. Accordingly, the BCM uses a "risk-free" real default discount rate of 4 percent for all costs and benefits.

I. Introduction

The Office of Management and Budget (OMB) generally requires that Federal spending programs and regulations be evaluated using benefit-cost analysis, incorporating certain standard methods and assumptions. President Clinton has recently reaffirmed this principle,[1] and OMB continues to update and enforce is guidance on benefit-cost analyses.

On October 29, 1992, OMB issued Circular A-94, Revised, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.*[2] On February 25, 1993, OMB issued an updated Appendix C of this Circular, *Discount Rates for Cost-Effectiveness, Lease-Purchase, and Related Analyses,*[3] in order to bring discount rates in line with the most recent economic data and with the economic assumptions underlying the President's budget submission to Congress. The discount rates and related guidance contained in Circular A-94 "must be followed in all analyses submitted to OMB in support of legislative and budget programs," as well as in all regulatory analyses. In particular, "the guidelines in this Circular apply to any analysis used to support Government decisions to initiate, renew, or expand programs or projects which would result in a series of measurable benefits or costs extending for three or more years into the future."[4]

Since virtually all applications of the federal benefit-cost model (BCM) will be subject to Circular A-94, the model is designed to conform to its provisions. Most of these are straightforward statements of standard practice in benefit-cost analysis, and do not require any special modification of the model. An appendix to this chapter, organized according to the Sections of Circular A-94, summarizes the applicable provisions and how the BCM complies with them. In addition, Appendix A of the Circular, *Definition of Terms,* and the updated Appendix C are reprinted in full as attachments to this chapter.

For the purpose of developing the BCM, Circular A-94 raises two key methodological considerations: the procedures for assigning values to non-market goods and services, discussed in the previous chapter, and the choice of a discount rate, discussed in this chapter. Closely related to the choice of a discount rate is the decision whether to use a multiplier to account for the excess burden of taxation and another to account for the shadow price of capital.

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[1] "[A]gencies should select those approaches that maximize net benefits . . ., unless a statute requires another regulatory approach." Executive Order No. 12866, *Regulatory Planning and Review,* September 30, 1993.

[2] OMB Transmittal Memo No. 64, October 29, 1992.

[3] "1993 Discount Rates for OMB Circular A-94," Memorandum for the Heads of Departments and Agencies from Leon E. Panetta, Director. February 25, 1993.

[4] OMB, Circular A-94 Section 4.

While a previous version of Circular A-94 (dated March 27, 1972) mandated a 10 percent real discount rate for all federal benefit-cost analyses, the current version offers more complex guidance. In particular, it recommends a relatively low real discount rate (approximately 4 percent) for "internal government investments," and a much higher real rate (7 percent) for more general "public investments" and for federal regulations. The BCM represents an intermediate case: seismic rehabilitation of a federal building comes close to meeting the definition of a pure internal government investment, but does not quite do so because some of its benefits take the form of reduced loss of life and reduced loss of government services—both external (i.e., off-budget) benefits.

At the same time, the choice of a discount rate makes a large difference in the quantification of benefits. Given a thirty to forty year expected lifetime for rehabilitated buildings, switching from a 7 percent to a 4 percent discount rate will raise estimated benefits by almost half, while leaving costs virtually unchanged. This is clearly a major decision, and in order to help make an informed choice this chapter explores the rationale contained in A-94 and in the underlying literature for selecting a discount rate.

II. Inflation and Uncertainty

A. Real vs. Nominal Rates

The first order of business is to decide whether the analysis is to be performed in real or in nominal terms. Actual market prices and market rates of interest are "nominal" in that their reported value is the same as their face value at the time that a transaction takes place: that is, they include the effect of inflation.[5] "Real" prices and rates are more difficult to observe, but are often much easier to use for decision analysis, for two reasons: inflation is both very difficult to forecast, and is irrelevant to most resource allocation decisions.

For these reasons, benefit-cost analysis is usually done in real terms. Note that this is not the same thing as assuming there will be no inflation. Rather, by working with real values the analyst can be agnostic about inflation, and can avoid making any particular assumptions about it. If someone needs the results of the analysis in nominal dollars (in order to plan budget allocations, for example), then the conversion can be done after the benefit-cost analysis is complete. In this way, the benefit-cost analysis and the inflation forecast can be kept separate.

Circular A-94 recognizes that for some types of analysis, nominal values are preferred. For example, when performing a lease/purchase analysis, one side of the ledger is typically a long-term lease contract that is denominated in nominal dollars—the actual payments that the government will be obligated to make under the lease contract. In this case, the most straightforward comparison is with the cost of purchasing the same asset, financed at nominal interest rates that reflect the government's cost of borrowing. When necessary, OMB recommends that the Gross Domestic Product deflator be used as the index of inflation.

In general, however, OMB recommends using real values: "Analysts should avoid having to make an assumption about the general rate of inflation whenever possible."[6] The BCM is designed to use real discount rates and monetary values throughout, and does not contain any assumptions about inflation.

B. Treatment of Uncertainty

A variety of methods are available for dealing with uncertainty in benefit-cost analyses. One method that is commonly used in financial analysis is *not* appropriate for benefit-cost analysis, however: the use of higher discount rates on uncertain streams of benefits in order to compensate for risk. In both Circular A-94 and in its guidelines for Regulatory Impact Analyses (RIAs), OMB emphasizes this point:

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[5] In this context, *nominal* dollars and *current* dollars are synonymous; *real* dollars and *constant* dollars are also synonymous. Note that "1988 dollars" are an example of real dollars.

[6] OMB, Circular A-94 Section 7.

> In general, variations in the discount rate are not the appropriate method of adjusting net present value for the special risks of particular projects.[7]

> It is conceptually incorrect to adjust the discount rate as a device to account for the uncertainty of expected future benefits and costs. This procedure will virtually never lead to a correct adjustment of benefits and costs.[8]

As recommended by OMB, the BCM uses risk-free discount rates.

Because it is driven by the risk of earthquakes, uncertainty is a central feature of the BCM. OMB recommends evaluating most government projects from a risk-neutral perspective, using statistically unbiased estimates of risk. The BCM is a linear model,[9] so that the various uncertainties that affect it can be adequately characterized by using expected value estimates in the base case, and by using sensitivity analysis to see how they affect the results of the model. Users of the model should generally use best estimates of all model inputs, and should vary these as appropriate to explore the behavior of the outputs. Note, however, that model runs combining multiple "worst-case scenarios" will not give meaningful benefit-cost ratios.

The recommendation that the government (or the nation) should be treated as risk-neutral is based on the assumption that the risks in any particular project are relatively small when viewed in the context of the entire national budget (or the national economy), and that they do not correlate systematically with other risks that are large in the broader context.[10] This assumption appears valid in the case of the BCM, since the effect of earthquakes is generally regional, but not national, in scope.

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[7] OMB, Circular A-94 Section 9.d.

[8] OMB, RIA Guidance, p.728.

[9] The BCM is linear because the various components of benefits and costs, and their associated probabilities, are assembled with linear equations. Doubling the frequency of earthquakes, for example, will double the benefits of avoiding the damage they do. This means that the properties of the model can be adequately characterized without having to use Monte Carlo simulations and other stochastic techniques.

[10] "The absolute variability of a risky outcome can be much less significant than its correlation with other significant determinants of social welfare, such as real national income." Circular A-94 Section 9.d.

III. The Use of Multipliers

In addition to discount rates, Circular A-94 discusses three types of "multipliers": one type it prohibits, another type it requires, and a third it urges to be used only with extreme caution. Multipliers are adjustment factors applied to estimates of benefits and costs but, unlike discount factors, multipliers are not time-dependent.

A. Economic Output Multipliers

The type of multiplier that Circular A-94 prohibits is the traditional economic output multiplier, which is used to account for the demand-stimulating effect that a dollar of expenditure can bring to an economy. This is really a tool of macroeconomic analysis, which measures economic activity, whereas benefit-cost analysis is a microeconomic method intended to measure economic welfare. Although they are related, economic activity and economic welfare are very different concepts, and are often confused. It is commonplace, particularly in the media, to characterize economic benefits as job creation and economic development. In contrast, economists tend to think of economic benefits as "consumer welfare"—the happiness that people derive from being well fed, well housed, and well clothed, from having leisure time, a healthy family, a clean environment, and whatever else they desire. Jobs and investments are neither goods nor bads, but intermediate means to an end—or to many ends. Were it not for the income and satisfaction they bring, most of us would just as soon forego jobs.

Circular A-94's recommendation against multipliers is based on the assumption that markets usually are close to equilibrium. When markets, including labor markets, are in equilibrium (so that resources are fully employed), prices and wages will accurately reflect the relative scarcity and abundance of resources. Thus prices can be used in a benefit-cost analysis to represent the opportunity cost of any particular resource—without using any multipliers. If markets are *not* in equilibrium (for example, if a region is experiencing involuntary unemployment), then a case can be made for using multipliers in a benefit-cost analysis because the additional economic activity generated by an expenditure makes an extra contribution to consumer welfare by employing resources that otherwise would be idle.

OMB's equilibrium assumption is worth questioning because in the aftermath of a large earthquake or other natural disaster, there is a good chance that the regional economy will not be in equilibrium for some time. For example, in the wake of Hurricane Andrew South Florida grappled with the need to rebuild infrastructure, replace lost capital (including homes), and get the local economy back to full employment. Under these conditions, it is certainly correct for some federal decisions, such as the level of disaster assistance or the future of Homestead Air Force base, to take account of the stimulative benefits of extra spending.

Other analyses of the benefits of earthquake mitigation have attempted to grapple with multiplier effects. One concluded that there will be indirect multiplier effects (though it does not attempt to include them in estimated benefits) and points out that such effects can be complex:

> The multiplier effects arise when output losses in one sector trigger losses in purchasing power which cause reduced demand and output in other sectors. Assuming no other offsetting factors are relevant, it is reasonable to assume a multiplier of at least 2, . . . This estimate is too simplistic, however, because there will be ***positive*** indirect output effects associated with any earthquake: namely, the ***increase*** in construction and related activity from rebuilding the affected area. It is conceivable, if not likely, that within the first six months following the quake—and certainly within the first 12-18 months—the total of these positive effects would outweigh any induced multiplier losses from the initial drop in output. Indeed, it is even conceivable that when measured over a sufficiently long horizon, the additional output due to reconstruction will outweigh ***both*** the initial direct losses and any related multiplier effects.[11]

Note the difficulty this can cause: an earthquake appears beneficial to the local economy because it stimulates economic activity. Of course, stimulating activity is not the same thing as conferring benefits, and economic welfare will still suffer a net decline. This illustrates one of the hazards of using output multipliers in a benefit-cost analysis.

In the case of the BCM, incorporating output multipliers into the model would most likely reduce the apparent desirability of earthquake mitigation measures. Seismic rehabilitation of federal buildings increases federal expenditures today, in exchange for a decrease in federal expenditures that would be required in the aftermath of an earthquake. Thus, using output multipliers to account for the stimulative effect of federal spending on the local economy would tend to attribute more benefits to spending in the disequilibrium that prevails after an earthquake than it would attribute to spending beforehand, when markets are in relative equilibrium.

In any event, it appears unwise to attempt to incorporate macroeconomic effects into a model that is intended to be used to evaluate single buildings. Thus, the BCM adopts OMB's assumption that markets are generally in equilibrium and should not apply output multipliers to the cost and benefit streams.

B. The Excess Burden of Taxation

The type of multiplier that Circular A-94 requires is an "excess burden" multiplier, intended to account for the net costs that federal taxation imposes on the economy. Despite the renowned efficiency of the IRS, it is estimated that every dollar of revenue that it raises imposes a cost on the private economy of $1.25. In part this reflects the administrative costs of the IRS and the compliance costs of taxpaying businesses and

[11] Earthquake Project, 1992, p. 52. This source cites Hal Cochrane (1990) for a similar assessment.

individuals; in part it reflects the economic costs of various strategies (both legal and illegal) that businesses and individuals use to minimize their tax burden.

In an analysis that deals only in private costs and benefits (such as a regulatory program), no excess-burden multiplier is needed, since no taxes are raised to pay for such a program. Similarly, in a pure public investment, where all costs and benefits are on-budget, no multiplier is needed because applying the same multiplier to all of the costs and benefits would not change the conclusion of the analysis. An excess-burden multiplier is only required in analyses that mix on-budget benefits and costs with private benefits and costs:

> The presentation of results for public investments that are not justified on cost-saving grounds should include a supplementary analysis with a 25 percent excess burden. Thus, in such analyses, costs in the form of public expenditures should be multiplied by a factor of 1.25 and net present value recomputed.[12]

In the BCM, all costs are federal costs,[13] and many of the benefits are federal cost savings. The two major exceptions are the value of government services, and value of life. In principle, the value of government services represents a private consumption stream not subject to the excess-burden multiplier. However, the "quasi-willingness-to-pay" (QWTP) methodology that is used to estimate the value of services yields an answer that is expressed in terms of on-budget dollars. That is, the excess-burden multiplier is already implicitly accounted for in the QWTP calculation, and should not be applied again.

That leaves the value of life as the only component of benefits that is not subject to the excess-burden multiplier. The most reliable estimates of the value of life in the literature[14] are typically based on wage studies, which implies that they are denominated in terms of private consumption. These estimates are often used in regulatory analyses where they are balanced against the private costs of regulatory compliance. In the BCM, life saving benefits are combined with a variety of on-budget costs and benefits. Thus, literal compliance with Circular A-94 would require multiplying all dollar estimates by 1.25, *except* for estimates of the value of life.

Unfortunately, this could lead to a lot of confusion. The BCM will be used by a wide variety of people: agency officials, planners, budget analysts, architects, engineers,

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[12] OMB, Circular A-94 Section 11.a.

[13] The assumption here is that rehabilitation of federal facilities will be paid for with federal money, and this should be valid for both owned and leased facilities. If the BCM were used to justify a regulation that imposed some costs on the private sector (for example, a rehabilitation requirement that applied to buildings only partly leased to federal tenants, or to buildings with federally guaranteed financing), then this assumption would need to be revisited.

[14] See FEMA 228, 1992, p. A13-A19, for a review of the value-of-life literature.

and others. It would be difficult to convey to all of these users the rationale for inflating virtually all inputs by 1.25. It is likely that on many occasions, a user would look at a particular number—a cost of material, value of inventory, etc.—and regard it as unrealistic based on his or her own expertise and information. Ironically, the one monetary value in the model that would not be inflated—the value of life—is perhaps the "fuzziest" estimate in the model, in that it does not correspond to any market price or budget number that users will be familiar with.

A mathematically equivalent procedure could avoid this confusion: instead of inflating all other monetary values by a factor of 1.25, the BCM could *deflate* the value of life by a factor of 0.8 (1/1.25) in order to express it in terms that are equivalent to federal-budget dollars. While this approach is less likely to lead to errors, it could be difficult to explain to a hostile audience why the government proposes to value life less than the public does. Perhaps the best solution is to use no explicit multiplier for excess burdens. The BCM is designed to allow sensitivity analyses with a range of values for life, and one of the standard outputs is a measure of the net benefits of mitigation that excludes the value of life altogether. Thus the range of sensitivity analyses already effectively encompasses a case that is equivalent to the analysis OMB requires to account for excess burdens. Incorporating an excess-burden multiplier would make the model more confusing, without making it any more comprehensive or more accurate.

C. Shadow Price of Capital

A third type of multiplier is sometimes used in benefit-cost analyses to account for the productivity of capital in the private sector; it is usually referred to as the shadow price of capital. Circular A-94 is ambivalent about its use:

> Using the shadow price of capital to value benefits and costs is the analytically preferred means of capturing the effects of Government projects on resource allocation in the private sector. To use this method the analyst must be able to compute how the benefits and costs of a program or project affect the allocation of private consumption and investment. OMB concurrence is required if this method is used in place of the base case discount rate.[15]

Because the costs of earthquake mitigation projects in federal buildings are on budget, there should be no effects on private investment that would require the use of the shadow price of capital. Nonetheless, it is important to understand the nature of this adjustment in order to characterize the relationship between the two different types of discount rate that Circular A-94 offers, which will be discussed in the next section.

Two Traditional Schools

The earlier literature on discount rates contains two schools of thought that continue to

[15] OMB, Circular A-94 Section 8.b.(3).

influence OMB policy in Circular A-94. One argued that government projects should be evaluated using a relatively low discount rate: the consumer's (or consumption) rate of time preference (CRTP). The other argued that government projects should be evaluated using the higher rate of return that is earned by private capital investments.

Consumption Rate of Time Preference

Pro: Consumers generally are willing to trade consumption today for a slightly larger amount of consumption in the future. In the early part of this century, authors would often write about consumers' discount rates as a type of "myopia" or a "defective telescopic faculty." More recently, economists recognized that consumers' time preferences were neither irrational nor immutable, but were simply a type of price, determined through the interaction of supply and demand.[16] Thus the CRTP is determined in an equilibrium balancing consumers' preferences with the opportunities available for productive investment. After removing the effects of risk, taxes, and inflation, the CRTP in the United States appears to be in the range of 2 to 4 percent per year. Many economists have argued that governments should evaluate projects using a discount rate equal to the CRTP in order to maximize consumers' welfare.

Con: On the other hand, private capital investments are evaluated with an effective discount rate that is higher than the CRTP. The tax structure in many countries, and especially the United States, penalizes investment by taxing returns to capital more heavily. Thus private investments must earn a higher before-tax rate of return in order to appear attractive. OMB estimates that risk-free private investments (a somewhat artificial construct) must earn a real rate of return of about 7 percent per year. This presents a paradox for benefit-cost analysts.

For example, if the government uses the CRTP to evaluate projects while the private sector is using the higher discount rate, then the government will undertake projects that would be rejected by private investors, and that have no rationale for government involvement other than that the government is using a lower rate. Thus the government sector will grow at the expense of the private sector—a particular irony since it is the effect of government taxation that caused the private sector to reject those projects in the first place.[17]

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[16] The modern theory of interest begins with Fisher (1930), although he still has a disturbing tendency to talk about the "frailties of human nature" as the underlying explanation for time preferences.

[17] Or consider the case of similar office buildings, both public and private, in an earthquake-prone area. If public decisionmakers use a 4 percent discount rate to evaluate prospective mitigation measures, and private decisionmakers use a 7 percent rate, then after a long time, and many earthquakes, only government buildings will be left standing. This is clearly not the desired outcome.

Private Return to Capital

Pro: For this reason, many economists argued that government investments should be required to earn a rate of return at least as great as private investments. One author summarized this point of view:

> It is my view that efficient allocation of the nation's resources for maximum social welfare requires private and public projects to be evaluated by the same standards, and that these standards are best revealed in private sector competitive markets. The same rate of discount would serve as a common denominator for the evaluation of projects in both the private and public sectors, assuming comparable determination of the cost and benefit streams. Proper project evaluation—not ideology—should determine the relative rates of growth in the two sectors.[18]

The assumption underlying this position is that government spending displaces private investment, and therefore should not be permitted to earn inferior returns. This is the rationale behind the 10 percent discount rate that OMB required in its earlier version of Circular A-94, and it continues to be the rationale behind the 7 percent discount rate required for most analyses under the new version.

Con: But the use of this type of discount rate also leads to paradoxical results. If the government uses a higher rate of return, it is forgoing projects that are demonstrably beneficial. An example (but not the only example) is an internal government investment that raises costs this year but lowers them next year, financed through Treasury notes sold to individual purchasers who buy them voluntarily. Such a project is a pure "Pareto improvement"—a transaction that makes some individuals better off and none worse off. Any method of benefit-cost analysis that rejects pure Pareto improvements is highly suspect.

The Lind Resolution

The work of a number of economists[19] in the 1970s led to a resolution of these two paradoxes and to a new mainstream view, articulated most fully in a book published in 1982.[20] The prevailing view since then has been that the CRTP is the right discount rate to use, but that first the stream of costs and benefits must be adjusted to account for the higher opportunity cost of private capital. This is done by multiplying any project costs that displace private investment by the "shadow price of capital" (difficult to estimate, but roughly a factor of two to four). This converts capital costs into their equivalent value in terms of pure consumption. Similarly, any project benefits that can

[18] Mikesell, 1974, p. 1.

[19] Especially Bradford (1975).

[20] Lind, 1982.

be shown to represent increased capital investment should be multiplied by the shadow price to convert them to a consumption equivalent.

An alternative two-step technique has been developed by the Environmental Protection Agency: it involves amortizing any capital costs at the rate of return to private capital, then using the lower CRTP to discount the amortized payments. Mathematically this is equivalent to the shadow price method, but EPA finds its own method a bit more intuitive when applied to regulatory costs.[21]

It is not mathematically possible to choose a single discount rate that takes into account both the consumption rate of time preference and the opportunity cost of capital: if a project's costs and benefits have non-uniform effects on private capital and consumption, then either the shadow price of capital or EPA's dual rate method must be used to get an accurate result.[22]

IV. The A-94 Choice: The Treasury Rate vs. 7 Percent

OMB has not explicitly adopted the shadow price of capital approach. OMB claims not to be trying to discourage the use of the shadow price of capital, but believes it is difficult to apply and wants to exercise quality control through prior consultations with agencies that use this method.[23] Instead, Circular A-94 offers a choice of two discount rates: either the prevailing rate of return on Treasury notes (now roughly 4 percent—see Circular A-94 Appendix C and the discussion below), or 7 percent, depending on the type of project. This choice is reminiscent of the two schools of thought on discounting that are described in Section III. C:

> ***Internal Government Investments*** — Some Federal investments provide "internal" benefits which take the form of increased Federal revenues or decreased Federal costs. An example would be an investment in an energy-efficient building system that reduces federal operating costs. Unlike the case of a Federally funded highway (which provides "external" benefits to society as a whole), it is appropriate to calculate such a project's net present value using a comparable-maturity Treasury rate as a discount rate. [Circular A-94, Section 8.c.(3)]

At first glance, the use of the Treasury borrowing rate for internal investments appears to be a case of OMB ignoring its own advice and doing the analysis from the point of view of the Government's narrow advantage, rather than from the point of view of society as a whole. This is not the case, however, because the Treasury borrowing

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[21] Kolb, 1986.

[22] Mazur, 1985.

[23] Arthur Fraas, OMB, private communication, 1993.

rate is not only a measure of the government's cost of financing, it also happens to be one of the best measures available for estimating the CRTP. Treasury notes are the nearest thing we have to a riskless investment, and they are sold in competition with the full range of private investment vehicles. Thus the real Treasury rates indicate individual investors' willingness to trade present consumption for future consumption:

> *Public Investments* — [P]ublic investments . . . provide benefits and costs to the general public. . . In general, public investments . . . displace both private investment and consumption. . . Constant dollar benefit-cost analyses of proposed investments . . . should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years. [Circular A-94, Sections 8.b. and 8.b.(1)]

Circular A-94's 7 percent discount rate for general public investments is clearly meant to account for the displacement of private capital, as was its 10 percent predecessor. Unfortunately, as discussed above, no single discount rate (used without a shadow price of capital) can perform this task accurately. Because seismic rehabilitation of federal buildings has some external benefits, it qualifies as a public investment, and thus for the 7 percent rate. There is some additional guidance for hybrid projects, however:

> *[Mixed cases]* — Some Federal activities provide a mix of both Federal cost savings and external social benefits. For example, Federal investments in information technology can produce Federal savings in the form of lower administrative costs and external social benefits in the form of faster claims processing. The net present value of such investments should be evaluated with the 7 percent real discount rate discussed in Section 8.b. unless the analysis is able to allocate the investment's cost between provision of Federal cost savings and external social benefits. Where such an allocation is possible, Federal cost savings and their associated investment costs may be discounted at the Treasury rate, while the external social benefits and their associated investment costs should be discounted at the 7 percent real rate. [Circular A-94, Section 8.c.(3)]

It is not clear how the costs of seismic rehabilitation could be allocated between cost-saving and life-saving benefits, nor is it clear how the value of government services should be classified under this scheme. No guidance can be found in the underlying literature, because this hybrid procedure finds no support there. A-94 might be read as requiring a 7 percent rate to be applied to life-saving benefits, but not to other costs and benefits in the model. This does not make much sense, however, because the rationale for the higher discount rate is based on a presumed displacement of some private investment by the project being evaluated. Lives saved by seismic rehabilitation are benefits, not costs, and they are pure consumption streams. There is no reason to think that any displacement of investment is occurring, and thus no reason to use the higher discount rate. If the BCM were using the shadow price of capital approach, the discount rate would be the CRTP (the Treasury rate of 4 percent), and none of the costs or benefits would be multiplied by the shadow price of capital because none displaces private investment. By the same logic, none of the costs and benefits should logically be subject to the 7 percent rate that represents the return on private capital.

Deriving the Treasury Rate

The preceding discussion uses 4 percent as the Treasury cost of borrowing, but that is a simplification. Instead of a single Treasury borrowing rate, Circular A-94 includes two tables, giving nominal and real interest rates for Treasury debt of various maturities. (See Appendix C, reprinted below.)

In theory, nominal long-term rates should reflect more uncertainty about future inflation, whereas real rates should be relatively stable over different terms. In fact, however, OMB's real rates show a slightly more exaggerated term structure (from 3.1 percent at 3 years to 4.5 percent at 30 years) than do the nominal rates (5.6 percent at 3 years to 6.8 percent at 30 years). The most likely reason for the apparent increase in real rates in the out years is that the public is using different assumptions about future inflation than the official assumption that OMB used to derive these rates. For this reason, the short-term real rates may be a better indicator of the rate of time preference (and actual Treasury borrowing costs) than are the longer term rates.

The BCM is designed to use a single real discount rate. At first glance it might seem that the 30-year rate is most appropriate, since a rehabilitated building should generally have an expected lifetime of 30 years or more. However, that conclusion is not correct since much of the value of a Treasury bond represents the face value at maturity, while a rehabilitation project produces returns beginning in the first year, with very little residual value at "maturity." Circular A-94 requires that the selected discount rate correspond to the cost of debt of "comparable maturity to the period of analysis."[24] Elsewhere it suggests a comparable "duration."[25] In the context of bonds and discount rates, duration is a term of art and is *not* synonymous with maturity—generally the duration of a note or bond will be slightly shorter than its maturity, because duration assigns a weight to all of the interim coupon payments the bondholder receives, as well as to the face value at maturity.

The difference between maturity and duration is even greater when dealing with building projects. A seismic rehabilitation project with a 30-year lifetime ("maturity") and little salvage value will have an effective "duration" of about 15 years. Thus, choosing

[24] Circular A-94 Section 8.C.(1).

[25] Circular A-94 Appendix C.

a borrowing rate by matching durations will give about 4.3 percent.

The most accurate method of choosing a discount rate is a variation of the comparable duration method. The proper comparison is between the project in question and a *portfolio* of bonds of varying maturity, selected so that the cash flow of the portfolio matches that of the project.[26] Since the BCM uses level year-to-year estimates of earthquake risk and damage functions, the stream of expected benefits also is level.[27] To simulate this level cash-flow one would need a portfolio of both short and long-term Treasury securities. In choosing a single discount rate to approximate the rate of return of this portfolio, the short-term rates will count more heavily. This, together with the earlier observation about the effect of inflation on long-term rates, suggests tilting a bit more toward the shorter-term (i.e., lower) rates. The default discount rate in the BCM is 4 percent (corresponding to 7-year Treasury bonds) for the base case. Reasonable sensitivity analyses could use real discount rates as low as 2 percent and as high as 7 percent.

V. Summary of the Recommended Approach

Seismic rehabilitation of federal buildings is best evaluated as an internal government investment. Accordingly, the BCM uses a real risk-free discount rate of 4 percent for all costs and benefits, with no economic output multipliers, no excess-burden multiplier, and no multiplier for the shadow price of capital. The rationale for this approach is that almost all costs and benefits either represent federal expenditures, or are denominated in federal expenditure-equivalent dollars.

The only significant exception to this generalization is the value of life, which represents an external benefit denominated in private consumption-equivalent dollars. A literal interpretation of Circular A-94 would require that the value of life be deflated by a factor of 0.8, to account for the excess burden of taxes, and discounted at the higher 7 percent rate of return to private capital. However, the higher discount rate in this context is not supported by the literature on which Circular A-94 is based. Moreover, since the BCM is designed to produce sensitivity analyses that display the effect of a variety of assumptions about the value of life, *ad hoc* adjustments such as the excess burden multiplier would not add anything (except perhaps controversy) to the model.

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[26] Geoffrey White, Treasury Department, private communication, 1993. (Mr. White did much of the research for revising Circular A-94 while at the Defense Department.)

[27] One component of the benefit stream, salvage value, can be anticipated to change from year-to-year, but this will not have a large enough effect to skew the choice of discount rate.

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Appendix: Compliance Outline for Circular A-94

This section reprints language from Circular A-94. Commentary on the relevance of Circular A-94 language to the BCM is shown in bold italics.

Sections 1 - 4: Purpose, Rescission, Authority, and Scope

The goal of this Circular is to promote efficient resource allocation. It provides general guidance on benefit-cost analyses and specific guidance on discount rates. This guidance will serve as a "checklist" of whether an agency has considered and properly dealt with all of the elements for sound analyses.

It replaces OMB Circular A-94, Revised (dated March 27, 1972) and Circular A-104 (dated June 1, 1986). It is issued under the authority of 31 U.S.C. Section 1111 and the Budget and Accounting Act of 1921, as amended. It does not supersede agency practices which are prescribed by law, Executive Order, or other Circulars.

These guidelines must be followed in all analyses submitted to OMB, and are suggested for internal planning by agencies. Specifically exempted are water resource projects, acquisition of services under Circular A-76, and Federal energy management programs. This Circular applies to all agencies of the Executive Branch of the Federal Government.

Clearly most applications of the BCM will be subject to Circular A-94.

Section 5: General Principles

Benefit-cost analysis is recommended as the technique to use in formal economic analysis of Government programs or projects. The standard decision criterion is the net present value of benefits minus costs. Benefits and costs should always be enumerated, quantified where possible, and monetized where feasible. Cost-effectiveness analyses can be used where alternatives under consideration have the same stream of benefits.

The analysis should always include a statement of the policy rationale for Government action. Assumptions should be explicit; alternatives should be evaluated; results should be verified.

The BCM complies with these principles. The policy rationale is simply that the Government owns or operates many facilities and is the only entity that can make the necessary decisions about earthquake mitigation measures.

Section 6: Identifying and Measuring Benefits and Costs

Benefits and costs should be evaluated from the point of view of the United States as a whole (rather than of the Government narrowly). Only incremental benefits and costs (those affected by the decision) should be counted; sunk benefits and costs should be ignored, and pure transfers should be ignored.

Willingness-to-pay is the preferred measure of benefits and costs, and should be determined from market prices (corrected for any distortions), from hedonic prices, or from other market behavior. Inframarginal valuations (i.e., consumer surplus) should be estimated, since benefits will often take this form. Economic output multipliers should be avoided.

> ***The BCM for federal buildings is broader than the version of the model for private buildings (FEMA 227, 228), in that it estimates benefits and costs from the point of view of society as a whole. Most estimates of benefits and costs are inferred from market prices; the value of life is derived from hedonic wage studies. The value of government services cannot be determined from market data; instead, the BCM uses quasi-willingness-to-pay estimates of value (see Chapter 2 of this voume). No output multipliers are used.***

Section 7: Treatment of Inflation

OMB recommends the use of real monetary values and real discount rates in most analyses and recommends the GDP deflator to adjust for inflation when necessary.

> ***The BCM uses real values and rates. See Section II. A. above.***

Section 8: Discount Rate Policy

For public investments and for regulations, use a 7 percent real discount rate, with sensitivity analyses in both directions. Use a shadow price of capital only with prior OMB approval.

For lease-purchase analyses, use nominal Treasury borrowing rates found in Appendix C (reprinted on page 3-27).

For cost-effectiveness analyses, including internal government investments and government asset sales, use real Treasury borrowing rates, found in Appendix C.

> ***The BCM most closely resembles an internal government investment, and uses a real Treasury borrowing rate as the discount rate. See Sections III. C. and IV. in the main body of this chapter. Also see Chapter 2 of this volume on valuing Government services.***

Section 9: Treatment of Uncertainty

The sources and nature of uncertainty should be characterized (with probability distributions where possible), and the limitations it imposes on the analysis should be discussed. Net present values should use unbiased expected values for benefit and costs streams. Sensitivity analyses should be used to explore the properties of the analyses. Discount rates should not be adjusted to account for risky projects; rather, certainty-equivalent values should be used where necessary to adjust for risk-aversion or for risk correlation.

> ***The BCM uses risk-free discount rates and best estimates of expected values for all variables that enter into the model; sensitivity analyses are used to reveal the effect of assumptions on the model's output. See Section II. B. in the main body of this chapter.***

Section 10: Incidence and Distribution Effects

> ***Since both benefits and costs are largely on the federal budget, incidence and distribution effects are not expected to be important for the BCM model.***

Section 11: Special Guidance for Public Investment Analysis

Analyses of public investments should include a supplementary analysis using an excess burden of 25 cents per dollar of revenue, applied to all public expenditures.

> ***This Section has limited applicability because earthquake mitigation measures are best treated as internal government investments, with few external benefits. Estimates of the value of lost services already reflect the excess burden of taxation, because of the nature of the quasi-willingness-to-pay methodology. (See Chapter 2 of this volume.) Estimates of the value of life do not reflect the excess burden of taxation, but sensitivity analyses will encompass any effect this adjustment could have on the BCM's output. (See Section III. B. in the main body of this chapter.)***

Section 12: Special Guidance for Regulatory Impact Analysis

Additional guidance for analysis of regulatory policies is provided in the *Regulatory Program of the United States Government*, which is published annually by OMB. (See "Regulatory Impact Analysis Guidance," Appendix V of *Regulatory Program of the United States Government* for April 1, 1991, to March 31, 1992.)

> ***This section will not apply to the BCM unless it is used to develop***

regulations that prescribe seismic rehabilitation of federal buildings. In any event, the BCM is expected generally to be in compliance with the OMB's guidance for RIAs.

Section 13: Special Guidance for Lease-Purchase Analysis

Not applicable to the BCM.

Sections 14-15: Related Guidance, and Implementation

Contains a list of related OMB Circulars and other guidelines; and specifies that implementation of Circular A-94 will be enforced through the procedures outlined in Circular A-11, *Preparation and Submission of Annual Budget Estimates*, and Circular A-19, *Legislative Coordination and Clearance*.

Section 16: Effective Date

This Circular is effective immediately.

Section 17: Interpretation

Questions concerning interpretation of this Circular should be addressed to the Office of Economic Policy, Office of Management and Budget (202-395-5873) or, in the case of regulatory issues and analysis, to the Office of Information and Regulatory Affairs (202-395-4852).

Circular A-94 Appendices

Appendix A.: Definition of Terms

Reprinted in its entirety below.

Appendix B: Additional Guidance for Discounting

Contains a sample format for discounting analyses; a conversion ratio between end-of-year and mid-year discount factors; and a table of illustrative discount factors.

Appendix C: Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses.

Reprinted in its entirety below.

Definition of Terms
Circular A-94, Appendix A

Benefit-Cost Analysis — A systematic quantitative method of assessing the desirability of Government projects of policies when it is important to take a long view of future effects and a broad view of possible side-effects.

Capital Asset — Tangible Property, including durable goods, equipment, buildings, installations, and land.

Certainty-equivalent — A certain (i.e., nonrandom) outcome that an individual values equally to an uncertain outcome. For a risk-averse individual, the certainty-equivalent for an uncertain set of benefits may be less than the mathematical expectation of the outcome; for example, an individual may value a 50-50 chance of winning $100 or $0 as only $45. Analogously, a risk-averse individual may have a certainty equivalent for an uncertain set of costs that is larger in magnitude than the mathematical expectation of costs.

Cost-Effectiveness Analysis — A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.

Consumer Surplus — The maximum sum of money a consumer would be willing to pay to consume a given amount of a good, less the amount actually paid. It is represented graphically by the area between the demand curve and the price line in a diagram representing the consumer's demand for the good as a function of its price.

Discount Rate — The interest rate used in calculating the present value of expected yearly benefits and costs.

Discount Factor — The factor that translates expected benefits or costs in any given future year into present value terms. The discount factor is equal to $1/(1 + i)^t$ where i is the interest rate and t is the number of years from the date of initiation for the program or policy until the given future year.

Excess Burden — Unless a tax is imposed in the form of a lump-sum unrelated to economic activity, such as a head tax, it will affect economic decisions on the margin. Departures from economic efficiency resulting from the distorting effect of taxes are called excess burdens, because they disadvantage society without adding to Treasury receipts. This concept is also sometimes referred to as deadweight loss.

External Economy or Diseconomy — A direct effect, either positive or negative, on someone's profit or welfare arising as a byproduct of some other person's or firm's activity. Also referred to as neighborhood or spillover effects, or externalities for short.

Incidence — The ultimate distributional effect of a tax, expenditure, or regulatory program.

Inflation — The proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price. Inflation is usually measured by a broad-based price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

Internal Rate of Return — The discount rate that sets the net present value of the stream of net benefits equal to zero. The internal rate of return may have multiple values when the stream of net benefits alternates from negative to positive more than once.

Life Cycle Cost — The overall estimated cost for a particular program alternative over the time period corresponding to the life of the program including direct and indirect initial costs plus any periodic or continuing costs of operation and maintenance.

Multiplier — The ratio between the direct effect on output or employment and the full effect, including the effects of second order rounds of spending. Multiplier effects greater than 1.0 require the existence of involuntary unemployment.

Net Present Value — The difference between the discounted present value of benefits and the discounted present value of costs.

Nominal Values — Economic units measured in terms of purchasing power of the date in question. A nominal value reflects the effects of general price inflation.

Nominal Interest Rate — An interest rate that is not adjusted to remove the effects of actual or expected inflation. Market interest rates are generally nominal interest rates.

Opportunity Cost — The maximum worth of a good or input among possible alternative uses.

Real or Constant Dollar Values — Economic units measured in terms of constant purchasing power. A real value is not affected by general price inflation. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

Real Interest Rate — An interest rate that has been adjusted to remove the effect of expected or actual inflation. Real interest rates can be approximated by subtracting the expected or actual inflation rate from a nominal interest rate. (A precise estimate can be obtained by dividing one plus the nominal interest rate by one plus the expected or actual inflation rate, and subtracting one from the resulting quotient.)

Relative Price — A price ratio between two goods as, for example, the ratio of the price of energy to the price of equipment.

Shadow Price — An estimate of what the price of a good or input would be in the absence of market distortions, such as externalities or taxes. For example, the shadow price of capital is the present value of the social returns to capital (before corporate income taxes) measured in units of consumption.

Sunk Cost — A cost incurred in the past that will not be affected by any present or future decision. Sunk costs should be ignored in determining whether a new investment is worthwhile.

Transfer Payment — A payment of money or goods. A pure transfer is unrelated to the provision of any goods or services in exchange. Such payments alter the distribution of income, but do not directly affect the allocation of resources on the margin.

Treasury Rates — Rates of interest on marketable Treasury debt. Such debt is issued in maturities ranging from 91 days to 30 years.

Willingness to Pay — The maximum amount an individual would be willing to give up in order to secure a change in the provision of a good or service.

Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses
Circular A-94 (rev. 10/29/92), Appendix C (rev. 2/25/93)

Effective Dates. This appendix is updated annually around the time of the President's budget submission to Congress. This version of the appendix is valid only through February, 1994. Updates of this appendix will be available upon request from the Office of Economic Policy in OMB (202-395-3381). Copies of the appendix and the Circular may also be obtained from the OMB Publications Office (202-395-7332).

Nominal Discount Rates. Nominal interest rates based on the economic assumptions from the budget are presented in the table below. These nominal rates are to be used for discounting nominal flows, as in lease-purchase analysis.

Nominal Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-year	5-year	7-year	10-year	30-year
5.6	6.0	6.3	6.7	6.8

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

Real Discount Rates. Real interest rates based on the economic assumptions from the budget are presented below. These real rates are to be used for discounting real (constant-dollar) flows, as in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-year	5-year	7-year	10-year	30-year
3.1	3.6	4.0	4.3	4.5

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

CHAPTER 4: THE VALUE OF LIFE

Value of Life

Benefit-cost analysis (BCA) can be used to assess public-sector resource allocation decisions. However, to identify and objectively measure all benefits of public projects can be very difficult if not impossible (Bentkover, 1986). One of the principal benefits of seismic rehabilitation of hazardous buildings is reducing the expected number of fatalities resulting from an earthquake. Methods of measuring the value of reducing the risks to life and health in BCA are diverse and until recently, controversial (Broome, 1985, and Cochrane, et al. 1987).

Four principal methods have been used to derive the value of life in BCA. They are the human capital approach, the court awards approach, the risk-cost method, and the willingness-to-pay approach. These approaches will be briefly described and evaluated. Finally, a suggested procedure to measure the value of a statistical life for the Benefit-Cost Model (BCM) will be outlined.

Human Capital Approach

Initially the value of health was estimated by measuring the lost wages, medical expenses and indirect costs resulting from the loss of life or injuries (Rice and Cooper, 1967, and Buehler, 1975). This approach is easy to conduct since only the deaths that can be prevented and the expected lifetime earnings need to be estimated. But Viscusi (1986a) concludes that this is a poor proxy for the value of reducing health risks. The benefit of a government program is the reduction of the probability of death or some other health aspect for a large number of individuals rather than the prevention of a certain number of deaths that might be identified after the fact.

This approach suffers from other deficiencies. Persons with low expected future income are under-represented (valued) under this approach. A very old person has a small amount of future earnings and a very young person's earnings are sufficiently distant that current discount rates reduce them to almost nothing in a BCA (Keech et al. 1989). This approach assumes that income determines individual utility and the value of life, and as a result, ignores all non-market goods consumed by individuals.

Court Awards Approach

Courts awarded damages for wrongful deaths are usually based on potential future earnings, which could serve as a proxy for the human capital approach, but they may include punitive damages and bereavement of the family or related consequences (Keech et al. 1989). Since it would be difficult to separate all of the influences that were included in the amount of the judgment, it probably cannot be used to evaluate the reduction.

Court awards are also based on specific historical cases but reducing earthquake hazards saves future lives which are statistical in nature and not individual-specific. Therefore, the use of court awards to evaluate risk reduction in public projects would not be a valid measure of the value of life.

Risk-Cost Approach

Another method used to value life is simply dividing the amount of project expenditures by the number of deaths that will be reduced by the project (Baecher et al. 1980). This approach transfers the responsibility of placing an explicit value on life from the analyst to the political level.

This approach does not value human life but provides decision makers with criteria for comparing programs dealing with safety and health related issues. The variation in the cost of lives saved for various public programs was found to be high which indicates that the procedure does not estimate the correct value of reducing risks to human safety (Broder and Morral, 1983).

Willingness-To-Pay Approach

Willingness-to-pay is a valid methodology for determining the value of risk reduction in BCA (Cochrane et al. 1987, Viscusi, 1986a, and Keech et al. 1989). The theoretical foundation for this method is that individuals will maximize their own utility by trading-off wealth or income for reducing the probability of death (Linnerooth, 1979). Cochrane et al. (1987) summarized why willingness-to-pay is the most correct method available of estimating the value of human life (page 21):

1. The value of life is embedded in the concept of willingness-to-pay for improved safety.

2. The concept provides a framework of establishing tradeoffs between wealth and greater safety.

3. The tradeoffs can be measured.

4. The concept is consistent with benefit-cost analysis because it poses the choice process that would enhance welfare.

5. The concept provides a pecuniary index of safety which is additive to other damages.

6. The willingness-to-pay for safety is a function of age, income and the perception of risk.

Willingness-to-pay assumes that individuals are rational (maximize utility), and correctly perceive the wealth-risk trade-off. These assumption may not be entirely met in all of the different empirical applications of the willingness-to-pay approach. Three basic procedures to measure willingness-to-pay have been developed and accepted as valid methods for valuing reductions in risk (Zeckhauser, 1975). These are: the survey approach; the labor market approach; and the consumer expenditure approach.

The Survey Approach -- for deriving willingness-to-pay is also called the contingent valuation method (CVM). The survey simulates a "market" of the public or nonmarket goods. This analogy, or continent market, is presented to the subject as providing public goods in return for one's payment. Summing across all individuals provides an estimate of value of the public good. In initial CVM studies, individuals were simply asked to value the reduction of the risk in question (Acton, 1973, and Jones-Lee, 1976). Those studies were criticized because of flaws in the design procedure. First, the free rider issue was ignored, and second, the individual's inability to perceive small differences in risk was not recognized (Cochrane, 1987). In addition, the individual subject to a CVM survey may perceive the environmental or social value rather than the individual's intended behavior (Bishop and Heberlein, 1979). Randall et al. (1983) have since offered a number of requirements to properly frame the situation to the subject to avoid these biases. This approach has also produced a wide variance of estimates (Blomquist, 1982).

The Labor Market Approach -- is the willingness of workers to accept additional wages for riskier jobs. This approach has been offered as an indirect indication of the value of life (Keech et al. 1989). Econometric models are used to estimate the wage differential earned by workers in risky jobs. This approach assumes that labor is mobile and that labor markets are competitive. These conditions are rarely achieved, which results in an underestimation of the risk differential in wages. In addition, most models use gross wages rather than after tax income which also produces biased results.

Labor market studies also produce high variations in estimates if voluntary versus involuntary risks are not specified. High risk jobs are voluntary and attract risk adverse labor that require small risk premiums. However, very small involuntary risks may produce high value estimates (Viscusi, 1986b). This method has the advantage of re-estimating existing econometric equations using different assumptions or new data to produce new estimates (Miller, 1986). The use of union or non-union workers (Gegax et al. 1985, Dillingham and Smith, 1985, Olson, 1981, and Viscusi, 1980), before versus after tax wages, and fatal versus non-fatal risks have been tested by changing and re-estimating existing models (Keech et al. 1989). Variations in these assumptions are responsible for the high variations in labor market study estimates (Blomquist, 1982).

The Consumer Analysis Approach -- is observing the way consumers feel about risk. It is proposed that the value of relative risks of certain products can be measured by the willingness-to-pay for safer products. Econometric models are used to estimate the willingness-to-pay for products with better safety records. This approach assumes that consumers have perfect information on the relative safety of each product, and that estimates represent equilibrium demand-supply conditions that are seldom met (Keech et al. 1989). Using past societal decisions that imply health or life values also assumes that those decisions were optimal, which may not be true. As with previous approaches, most studies used very different assumptions and discount rates, and the results are quite variable and incompatible without modification (Viscusi, 1986a).

Attempts have been made to combine the human capital approach and the consumer expenditure approach. Landefeld and Seskin (1982) studied the willingness-to-pay for life insurance and estimated the value of life at $873,000 in 1985 dollars. The authors claim this was the first empirical estimate of human capital values, reformulated using a willingness-to-pay criterion, to produce the only clear, consistent, and objective value for use in BCA of policies affecting risks to life.

The use of safety items such as seat belts are also considered as indications of the value of life (Blomquist, 1979). The value of life has also been derived from automobile speeds (Ghosh et al. 1975, and Jondrow et al. 1983) and cigarette smoking (Ippolito and Ippolito, 1984).

Keech et al. (1989) derived the value of life for the Federal Aviation Administration using willingness-to-pay studies that had been done during the 1970's and 1980's. Miller (1986) had reviewed recently published willingness-to-pay studies and critically evaluated the analytical procedures used, risk variables, model specifications, and results. He found several studies that were judged appropriate and adopted those studies as a basis for determining the value of life.

Thirteen labor market studies were modified to assume after-tax wages, or to separate fatal from nonfatal risks. Nine consumer behavior studies were changed to reflect similar discount rates and other assumptions relating to value of time and family size. Three survey studies done on cancer risks, highway safety, and labor markets were also declared valid. Values from all 25 studies were adjusted to reflect 1985 dollars.

Updated estimates from these 25 studies were summed and an average value calculated. The estimate was then adjusted to 1987 dollars which yielded a "consensus" value of life of $1,577,129. This estimate was defined as the "private value of a statistical life" which is just part of the "social value of a statistical life". Keech et al. (1989) defines the social value of early death as also including foregone taxes, and medical, emergency, legal, court, and public assistance administration costs. The total of these costs, which is the social value of a statistical life, was estimated at $1,740,000 in 1987 dollars.

A "consensus" procedure was also used by Schulze et al. (1987) to derive a value of life of $1 million. The studies used in this procedure were reported by Violette and Chestnut (1983).

The use of willingness-to-pay to estimate the value of life has been accepted by many Federal agencies. Viscusi (1986a) concludes:

> Indeed as of 1984, the valuation of life has become a generally accepted component of the debate over risk regulation. The recent debate over an OSHA construction industry standard epitomizes this change. Rather than claiming that the value-of-life issue was too sensitive to be discussed, there was an open policy debate over the appropriate value of life. OSHA used a value of life of $3.5 million in its regulatory analysis based on results for the average blue-collar worker. OMB took a different approach, citing evidence regarding the heterogeneity in the value of life. After noting the high and well-known risks associated with construction jobs, OMB urged that OSHA use a lower value of life of $1 million. One Congressman viewed both of these estimates as too low, advocating a $7 million figure in line with results for the Panel Study of Income Dynamics. In each case, the willingness-to-pay approach was accepted, as was the importance of using labor market studies as a reference point. (page 207)

Cochrane et al. (1987), however, offer a more guarded endorsement:

> Despite the significant gains that have occurred over the past decade in refining survey instruments and honing theoretical constructs, the essential ingredients for incorporating risk into BCA are still clearly lacking. It appears that although market data provide a useful glimpse of what society at large is willing to tolerate in terms of risks, it is still no more than a glimpse. The use of expected values in these analyses tends to obscure the losses that result when the less probable events materialize. Perhaps the primary criticism that has been leveled at risk-cost methods is the lack of appreciation for the process of valuation. It is clear from the work of Starr (1985) and others that risk wealth tradeoffs may be nonlinear. Hence, the social losses may not be a simple additive adjustment to project net benefits as Baecher et al. suggests. These concerns have led to the development of alternative technical means (multiobjective and partitioned risk) of deriving an optimum strategy for those situations involving more than economic efficiency. (page 27)

Value of a Statistical Life

The "consensus" estimate of the private value of a statistical life derived by Keech et al. (1989) draws on the work of many scientists specializing in the value of life. The studies were reviewed by Miller (1986), adjusted or revised when possible, and judged to be adequate as value of life estimates. It seems reasonable to use the estimates as derived and reported by Keech et al. (1989) in this study . As stated before, Keech et al, (1989) has derived a "social" value of life based on the sum of the "private" value of life, foregone taxes and other direct costs of early death. This also seems appropriate for this study.

Foregone taxes are discounted present value of expected future earnings multiplied by the applicable state, local and federal tax rates. This value represents the lost tax revenues that the government will not collect as a result of early death. To estimate foregone taxes for this study, an age, sex, occupation, and income profile of potential death victims will need to be derived for the earthquake site.

A study by the National Highway Traffic Safety Administration (1986) included medical and emergency costs, legal and court costs (the cost of carrying out court proceedings, not the cost of settlements), and costs associated with the administration of public assistance insurance. The total direct costs using just these parameters was estimated to be $33,093 in 1987 dollars. Taxes foregone and other direct costs can be estimated for each individual test site.

Updating the Value of a Statistical Life

Keech et al. (1989) suggested that the value of a statistical life be updated using the GNP Implicit Price Deflator for Total Personal Consumption Expenditures for the following reasons:

1. The private willingness-to-pay estimates are based upon individual assessments which in turn are based upon income, consumption of a wide variety of goods and services in the economy, and the consumption of other non-pecuniary activities. The resulting monetary values probably closely correspond with the typical mix of goods and services available in the economy.

2. The other elements of the valuation of a statistical life are expenses or income measures which should increase in approximate proportion to economy-wide inflation.

These procedures to estimate the value of life for the BCM used in this study represent the least cost alternative which is defensible to the economics profession. The procedure is simple, the data needed for calculations are readily available, and the results are reasonable.

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CHAPTER 5: TECHNICAL ISSUES

Seismic Risk Assessment

Introduction

Seismic risk assessment is one of the most critical steps in benefit-cost analysis of seismic rehabilitation projects because seismic risk varies markedly with location, and seismic risk has a major impact on benefit-cost results. The type of seismic risk information required for benefit-cost analysis differs significantly from that required for engineering design purposes.

For design purposes, seismic risk is usually expressed in terms of a design earthquake (or earthquakes) with the design earthquake defined in terms of an exceedance probability for some stated time period. For example, a 10% exceedance probability in 50 years is used in the Uniform Building Code (UBC). This type of seismic risk is usually expressed as a single value of effective peak ground acceleration, PGA, such as 30% of g (the acceleration of gravity). When a detailed, site-specific geotechnical analysis is conducted, the result is also a single value. For example, for a given site the level of effective peak acceleration with a 10% chance of exceedance in 50 years might be calculated as 17% g. At such a site, 20% g might be used as the design earthquake.

For benefit-cost analysis, however, an explicit statement of the annual probabilities of the full range of damaging earthquakes must be made. Seismic risk assessment for benefit-cost analysis must be expressed in probabilistic terms because the timing and severity of future earthquakes is unknown. The benefit-cost program uses the expected annual probability of earthquakes in each "bin" or level of seismic ground motions (expressed as Modified Mercalli Intensity, MMI, and effective peak ground acceleration, PGA) to perform an expected value calculation. For example, if at a site under consideration, the annual probability of earthquakes of MMI VIII is 1%, then there is a one percent chance per year of such an earthquake. If each such earthquake causes $1,000,000 in damages, then on average (over a long time period) there will be $10,000 per year in damages. The $10,000 per year in average damages is the "expected" or statistical average damages per year. If these damages are avoided by a rehabilitation project, then the expected or statistical average damages avoided (i.e., the benefits) are $10,000 per year. To count fully the benefits of a seismic rehabilitation, the expected benefits of avoiding damages from the full range of damaging earthquakes must be counted, rather than simply considering one scenario or design earthquake.

Modeling Seismic Risk: Principles

Quantitative seismic risk assessment requires four steps:

a) identification of all active faults or fault zones,

b) estimation of the recurrence interval and magnitude of earthquakes expected on each fault,

c) determination of an appropriate attenuation relationship for the local geologic conditions, and

d) modeling site effects (amplification or attenuation) at the site under consideration.

Identification of the active faults affecting a given area and estimation of the recurrence intervals and magnitudes of earthquakes on each of the faults is ordinarily done through assessment of historical seismicity in the area. Inferences from historical seismicity are supplemented by knowledge of the tectonic setting of the faults and by analogies to other similar fault systems. The extent of current knowledge about regional seismicity varies substantially depending on the level of seismic activity. For example, highly active areas, such as portions of California near the San Andreas fault system, are much better understood than are seismically active regions in the Midwest or East, where the record of historical seismicity is much thinner because the recurrence intervals for earthquakes are much longer. For completeness, estimates of regional seismicity usually include "background seismicity" or "area sources" to account for earthquakes on faults not currently mapped or faults without surface expressions.

Determination of an attenuation relationship for the local geologic conditions is necessary to account for the diminution of ground motion with increasing distance from the causative fault. Finally, the intensity or level of ground shaking experienced in a given earthquake at a specific site depends on the site conditions. For example, soft soils may amplify ground motions so that soft soil sites experience higher levels of ground shaking than do nearby firm soil or rock sites. In some cases, especially at high levels of ground motion, site effects can also attenuate ground motions.

The principles of modeling seismic risk, as briefly summarized above, are well understood and have been applied to estimate seismic risk in numerous areas for planning purposes or for the design of individual structures. However, it is important to recognize that limitations of data, especially in low or moderate seismicity areas, may impart significant uncertainty to seismic risk estimates.

Modeling Seismic Risk: The Benefit-Cost Model

There are two methods for estimating seismic risk in the benefit-cost model. First, the default method, which is built into the model, uses the spectral acceleration contour maps prepared by the United States Geological Survey for the 1991 Edition of the NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings (Appendix). Second, if they are available, the user may enter site-specific geotechnical seismic risk assessments into the model.

Default Method

The default method uses the 0.3 second period spectral acceleration contours from the 1991 NEHRP Appendix maps or ground motions with 10% chance of exceedance in 50 years and 250 years. The 0.3 second data is used as being applicable to low and midrise buildings which constitute the vast majority of the building stock in the United States. Effective peak ground accelerations are obtained from the spectral acceleration values by dividing by a factor of 2.5, as per the NEHRP Appendix. Exceedance probabilities for other levels of ground motion are obtained by a log-log[1] fit of the 10% in 50 year and 10% in 250 year data points available from the NEHRP maps. Interval probabilities for the MMI/PGA bins are obtained by difference from the exceedance probabilities. For example, the annual probability for events between 8 and 16% of g is the annual exceedance probability for 8% g minus the annual exceedance probability for 16% g.

For the convenience of users, tabulated values of the NEHRP spectral acceleration contour values are compiled in Volume 1 of the User's Manual (Table 5.1 on page 5-24) for most of the major cities in the United States. Alternatively, for smaller cities or rural areas, users may read values directly from the contour maps, which may be obtained from the Building Seismic Safety Council, 1201 L Street, N.W., Washington, D.C. 20005.

The default method seismic risk assessment estimates depend directly on the NEHRP maps. These maps were developed using the general principles of seismic risk assessment outlined above. However, because these maps were intended to represent broad regional variations in seismic risk, only major faults were included. Therefore, for specific local sites, these maps may not include faults which may produce strong local ground motions. Therefore, while these maps do approximately represent regional seismic risk and thus clearly demarcate high seismicity areas from moderate or low seismicity areas, they may not accurately reflect the full seismic risk at all specific localities. For this reason, use of site-specific geotechnical seismic risk assessments is strongly recommended whenever such assessments are available.

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[1] A log-log fit is used because plots of earthquake probabilities versus magnitude typically fall on a straight line when log scales are used, in accordance with the well-known Gutenberg-Richter relationship between the size and number of earthquakes.

Uncertainty in the NEHRP spectral acceleration contours is greater for the 250-year maps than for the 50-year maps and greater for lower seismic areas than for higher seismic areas. Values from these maps should be used with caution. As noted on the 250-year maps:

> *The estimation of low values of probability of ground motion (250-year exposure time) may give unrealistic values of spectral acceleration because of uncertainty in attenuation of spectral values in fault rupture length. The uncertainty is increased in the central and eastern United States because of the difficulty of defining earthquake source zones and the infrequency of earthquake occurrence. Thus, any values on this map should be considered advisory and treated with caution.* (NEHRP 250-year map)

The probabilities of given levels of ground motion at a specific site depend not only on location relative to active faults, but also on site conditions. The default seismic risk assessment in the benefit-cost model includes a methodology for including site effects, using the 5-level NEHRP soil classification scheme:

SITE EFFECTS

	MULTIPLIER FACTORS AS A FUNCTION OF GROUND SHAKING[2]			
SOIL TYPE	25% g	50% g	75% g	100% g
SO Hard Rock	0.6	0.6	0.7	0.8
S1 Rock	0.7	0.8	0.9	1.0
S2 Very Dense Soil	1.0	1.0	1.0	1.0
S3 Stiff Soil	1.2	1.1	1.0	1.0
S4 Soft Soil	1.5	1.3	1.1	0.9

The default method of seismic risk assessment, discussed above, is based on an S2 soil type. For sites with soils other than S2, site effects are incorporated into the seismic risk assessment by using the multiplier factors shown in the above table.

[2] Multiplier factors are from preliminary unpublished data (April 1993) from the Design Values Panel which is preparing updates of the NEHRP seismic provisions.

Site-Specific Geotechnical Method

The best method for obtaining the seismic risk estimates required for benefit-cost analysis is through a detailed, site-specific, geotechnical risk assessment. The site specific analysis can include all of the local faults and thus most accurately model the site-specific seismic risk. Moreover, by including as much detail as available about site conditions, a site-specific analysis can more accurately model site amplification as well. A site-specific analysis can also quantify the probabilities of liquefaction and/or lateral spreading which may significantly impact engineering judgement about a building's seismic performance.

A building's seismic performance depends, in detail, on the frequency content (i.e., period of motion) of ground motions and on duration, as well as on the level of ground shaking. For example, a short building may be more vulnerable to high frequency motions (e.g., 0.3 sec period), while tall buildings may be more vulnerable to lower frequency motions (e.g., 1.0 sec period). A full geotechnical analysis would include frequency and duration information as well as ground shaking information. Ideally, this full information should be incorporated into the engineering evaluation of the building's seismic performance and then incorporated into the mean damage functions used as input into the benefit-cost analysis.

MMI/PGA Relationship

The Modified Mercalli Intensity (MMI) scale is qualitative, antiquated and may not adequately reflect the seismic performance of many modern building types. Nevertheless, the MMI scale has been used for many decades and a great deal of the historical seismic damage information is formulated in MMI. In particular, the two major sources of damage data for US buildings (ATC-13 and ATC-36), which are used in the benefit-cost model, both formulate building damage data in MMI.

Effective peak ground acceleration (PGA) is a quantitative, modern measure of the level of ground motion. However, PGA does not fully capture the seismic parameters which relate ground motion to building damages. In detail, building damages depend not only on the level of ground shaking but also on the duration and frequency content of the ground motions.

In the benefit-cost model, both MMI and PGA are used. The earthquake "bins" in which intensity-dependent information such as building damage function are entered are labeled in both MMI and PGA. MMI is used because of the wealth of historical damage data formulated in MMI. PGA is used as a good single quantitative measure of ground motion which is obtainable from site-specific geotechnical seismic risk assessment studies. More complex, multi-dimensional measures of ground motion (e.g., including duration and frequency content) were not used because of the paucity of damage data expressed in this form and the heavy burden of data collection which such analysis would place on the users of the benefit-cost program.

The relationship between MMI and PGA assumed in the model is shown below.

MMI/PGA Relationship

MMI	VI	VII	VIII	IX	X	XI	XII
PGA (% g)	4-8	8-16	16-32	32-55	55-80	80-100	>100

There have been many attempts, only partially successful, over the years to determine quantitative relationships between MMI and other more quantitative measures of ground motions such as PGA. None of these efforts have been compellingly successful, because of the multidimensional measures necessary to describe ground motions quantitatively and the qualitative, subjective nature of the MMI scale. Nevertheless, a broad correspondence between MMI and PGA is well established in the literature. A brief review of the MMI/PGA relationship is given in ATC-13 and is not repeated here.

Sensitivity Analysis

The benefit-cost analysis model has been extensively reviewed and is believed to be conceptually correct. However, results calculated by the model are, of course, subject to uncertainty and inaccuracies in the input data. The purpose of this section is to review the sensitivity of calculated results to uncertainties in the input data.

The equations which govern the benefit-cost model are all linear (i.e., calculated results depend on the sum or linear product of inputs). There are no higher order terms (exponentials or power functions) in any of the equations. Because the model is linear, it is very stable: small changes in inputs result in small changes in output (calculated results). There is no place in the model where a small change in any input drastically changes the output.

There are many input parameters in the benefit-cost calculations. However, many of these are known almost exactly (e.g., size of buildings), while others are usually well-determined (replacement value of building, value of contents, occupancy, agency budgets, etc.). Furthermore, many of the inputs have only minor impacts on the final results and thus uncertainties in these inputs do not substantially affect results. For example, the total benefits for a particular rehabilitation project are generally dominated by the building damages avoided and the value of avoided casualties. Other factors such as value of contents damages avoided, avoided relocation costs, avoided rental income losses, and avoided loss of government services, are generally quite small. While these other factors are included for completeness and for the few cases in which they may be unusually important, they are not of major importance for most analyses and, therefore, uncertainties in the input parameters which determine these benefits are usually not of major significance.

There are, however, several input parameters which do generally have major impacts on calculated benefit-cost results. The typical uncertainties in these parameters and the sensitivity of calculated benefit-cost results to such uncertainties are discussed below for each of these important input parameters. These important input parameters include: seismic risk, building mean damage function, effectiveness of the retrofit, occupancy and casualty rates, death rates, and the economic assumptions (discount rate and project lifetime or planning horizon). The other input data parameters (see Chapter 5 in Volume 1) generally are of lesser importance. These parameters, however, are necessary to include for completeness and because they may be important in some circumstances.

Seismic Risk

Seismic risk, expressed as the annual probability of a given level of ground shaking, varies enormously from location to location within the United States. Benefit-cost results are directly proportional to seismic risk: doubling the annual probabilities of each level of ground shaking doubles the expected (average) damages and other losses and thus doubles the benefits of avoiding these damages. Correspondingly, a given level of uncertainty in seismic risk corresponds exactly to the same level of uncertainty about benefit-cost results. Uncertainty in seismic risk estimates is probably the largest uncertainty in the benefit-cost calculations. There are, however, two mitigating aspects of uncertainty in seismic risk estimates:

1) the annual probabilities for low to moderate levels (MMI VI to IX), which are generally better determined, have much greater impact on benefit-cost results, than do the annual probabilities for extreme levels of ground shaking (MMI X to XII).

2) the relative ranking of prospective seismic rehabilitation projects within a given geographic area is unaffected by uncertainty in the absolute level of seismic risk.

Because of the first factor above, large uncertainties in the probabilities of extreme earthquakes have limited impact on benefit-cost analysis. Because of the second factor above, comparing benefit-cost ratios among a group of buildings in the same location has much less uncertainty than does comparing ratios for buildings in different locations.

Building Mean Damage Function and Rehabilitation Effectiveness

The seismic vulnerability of a given building is expressed in the model as a mean damage function (MDF) which indicates the average amount of damage (as a percentage of replacement value) expected for each bin of ground motion (MMI and PGA). Similarly, the seismic vulnerability of the rehabilitated building may be expressed as a MDF or, equivalently, as the effectiveness of the rehabilitation (i.e., the percentage reduction in MDF after rehabilitation).

There may be substantial uncertainty about the seismic vulnerability of an individual building. The uncertainty will be largest if default MDFs are used, which depend only on the building type. Uncertainty will be progressively less as more engineering information is available, ranging from a quick walk-through to detailed calculations and testing of materials. All other factors being equal, benefit-cost results are directly proportional to building MDF, because other damages to contents, loss of functionality and casualties are all closely related to building MDF. Therefore, a given level of uncertainty in building MDF corresponds to a closely similar level of uncertainty in benefit-cost results.

However, as with uncertainty in seismic risk, uncertainty in buildings' seismic vulnerability has less impact on relative benefit-cost results than on absolute results. Some classes of buildings (e.g., unreinforced masonry or non-ductile concrete moment frame buildings) typically have much higher seismic vulnerability than other classes of buildings (wood frame or steel frame buildings with shear walls). Reasonable engineering judgement about whether a given building is better (e.g., good detailing) or worse (e.g., major irregularities) than typical buildings is relatively robust. Therefore, benefit-cost analyses in which a modicum of good engineering judgement is applied are likely to identify correctly the most seismically vulnerable buildings. Because avoided damages (benefits) may be larger in more vulnerable buildings, benefit-cost analyses are likely to correctly identify the most vulnerable buildings as the best candidates for seismic rehabilitation.

Occupancy and Casualty Rates

All other factors being equal, the expected number of casualties in a given building for a given earthquake is directly proportional to occupancy. Therefore, the portion of the benefits of a rehabilitation project corresponding to the dollar values placed on deaths and injuries is directly proportional to occupancy. Average occupancy for buildings is generally very well determined. Therefore, uncertainties in occupancy contributes very little uncertainty to the average or expected value of benefits, even though occupancy may vary markedly depending on day of the week or time of day. Because benefit-cost analysis considers, quite properly, the average occupancy, uncertainties in occupancy contribute very little uncertainty to calculated benefit-cost results.

The expected number of casualties depends not only on occupancy but also on casualty rates per earthquake event. Casualty rates depend primarily on building MDFs - greater building damage will result in greater casualties. Therefore, uncertainties about the number of casualties avoided are subject to similar uncertainties to those discussed above under Building Mean Damage Function and Rehabilitation Effectiveness.

The economic value of casualties avoided is dominated by deaths avoided. Deaths in buildings during earthquakes occur primarily due to partial or full collapse. Therefore, an important aspect of casualty estimation is to determine the level of ground shaking likely to initiate collapse. Thus, as with building MDFs, good engineering judgement about a building's seismic performance is essential to obtaining useful benefit-cost results.

Economic Assumptions (Discount Rate and Project Lifetime)

Benefit-cost calculations require assumptions about discount rates and project lifetimes (or planning periods). Unlike the other input parameters discussed in this section, these economic inputs are policy decisions. Changes in the discount rate or project lifetimes assumed directly affect the benefit cost results. Such changes directly affect the absolute value of benefits (and benefit-cost ratios), but have no impact on relative benefit-cost results because they affect all prospective projects equally. The impact of discount rate and project lifetime combine to yield a "present value coefficient," which is the present value of $1.00 per year in future benefits. The impact of changes in these factors is shown below:

Present Value Coefficients

PROJECT LIFETIME	DISCOUNT RATE					
	3%	4%	5%	6%	7%	8%
20 years	14.88	13.59	12.46	11.47	10.59	9.82
30 years	19.60	17.29	15.37	13.76	12.41	11.26
50 years	25.73	21.48	18.26	15.76	13.80	12.23
100 years	31.60	24.50	19.85	16.62	14.27	12.49

Benefits and benefit-cost ratios are directly proportional to the present value coefficient shown in the table above. The impact of changing economic assumptions is shown by the changes in present value coefficient. For example changing from assumptions of 7% and 50 years to 4% and 100 years, changes benefit-cost ratios by 24.50/13.80 or a factor of 1.78.

Interpretation of Benefit-Cost Results

Because of the inherent uncertainties, benefit-cost results, like any other calculation, should not be interpreted blindly or in disregard of the uncertainties. Three prospective seismic rehabilitation projects with benefit cost ratios of 0.2, 1.2, and 2.2 are unambiguously distinguishable. Three prospective projects with benefit-cost ratios of 0.95, 1.00, and 1.05 are probably not significantly different. Three projects with ratios of 0.8, 1.0 and 1.2 may or may not be significantly different, depending on the validity of the input data.

References

Applied Technology Council (1985). Earthquake Damages Evaluation Data for California (ATC-13), Redwood City, CA.

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