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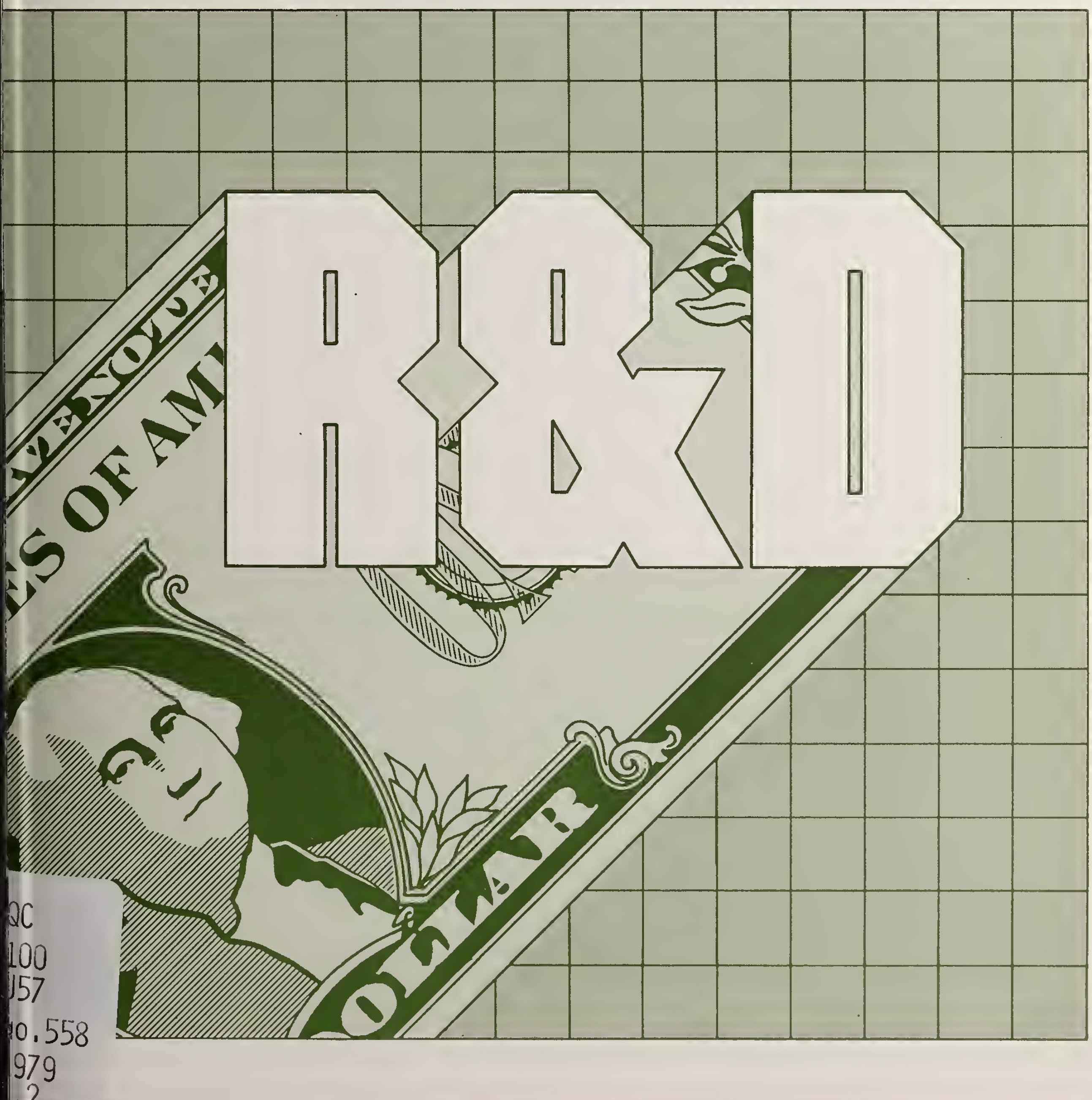
NBS Special Publication 558

Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology



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PREFACE

This study was conducted by the Applied Economics Group in the Center for Building Technology (CBT) at the National Bureau of Standards. The purpose was to demonstrate how economic evaluation techniques can be applied to the evaluation of benefits and costs of research leading immediately to new technologies. The intended audience for the resulting report is the National Bureau of Standards as well as other government and private applied research groups that are concerned with determining efficient allocations of their research budgets.

The case studies of this paper are adapted from an earlier, unpublished report entitled "Impact of CBT Activities on the Building Community," submitted on March 31, 1975, to Dr. Richard Roberts, Director, National Bureau of Standards, and prepared by the authors, et al.

This project was interdisciplinary in that research personnel from disciplines other than economics helped the authors in the formulation of the two case studies. Special thanks are due to Edwin Mansfield of the Department of Economics at the University of Pennsylvania, to Stephen Weber and Bob Chapman of the Applied Economics Group of CBT, and to Kenneth Gordon of the NBS Planning Office, who reviewed the economics aspects of the paper; to Carl Muehlhouse of the Center for Consumer Product Technology, who provided a policy review; to Robert Wyly, from the Service Systems Program of CBT, who provided data and information about reduced-size venting; and to Robert Mathey, from the Building Composites Program of CBT, who provided assistance and data on roofing shingles. Appreciation is also extended to the many persons within the National Bureau of Standards and persons outside in the plumbing and roofing industries who contributed data and reviewed the manuscript.

ABSTRACT

Public and private administrators of research programs are concerned with maximizing the payoffs from their research investments; that is, with allocating their limited budgets most efficiently. Benefit-cost, rate-of-return, payback, and other evaluation methodologies are examined for their usefulness in helping administrators to decide whether to accept or reject research projects leading directly to applications; to plan the scale of these research projects; and to identify priorities among alternative research investments, all of which may be profitable. Data needs for applying these evaluation methodologies are outlined. The net-benefits and rate-of-return methodologies are applied to two case studies involving research in the Center for Building Technology (CBT) of the National Bureau of Standards. The first deals with a heavier asphalt shingle for roofing, and the second deals with reduced-size venting in plumbing. The case studies show high payoffs in these two areas of research, both for society as a whole and for CBT's contribution in undertaking the research. Recommendations from the study are that research funds be allocated on the basis of anticipated payoffs determined through these evaluation techniques, and that benefit and cost data for evaluating new technologies be collected.

Key words: Benefit-cost analysis, building technology; economic impacts; economics; efficiency; payback; plumbing; roofing; shingles; venting.

CONTENTS

Figures

Tables

EXECUTIVE SUMMARY

The research and development (R&D) community is a major industry in terms of the resources that it controls. Research managers and planners, in both the public and private sectors, need guidelines for evaluating R&D alternatives so that they can maximize the payoffs from their R&D activities, given limited resources. A quantitative approach is particularly useful when R&D results directly in a marketable application.

The purposes of this report are (1) to provide research administrators with an examination of alternative methods for evaluating future, existing, and past research projects related to direct applications and (2) to provide a description of the data needs for evaluating the impacts of the ensuing technological change.

The National Bureau of Standards (NBS), a scientific research agency of the U.S. Department of Commerce, has attempted to improve its resource allocation process by requiring all major operating units to do a "microstudy" of their research impacts on society. This report is an outgrowth of the microstudy for the Center for Building Technology (CBT) of NBS. It is developed in a general framework, however, so that it can be used by any government agency allocating applied research funds, and in many cases, by universities and research firms as well.

Following the introduction, section 2 provides definitions of terms relating to the measurement of impacts from technological change. The different perspectives of research groups, as indicated by their different objective functions and different measures of program benefits and costs, are discussed. Three selected methods of project evaluation—benefit-cost analysis, the internal rate of return, and payback—are evaluated for their use in comparing alternative R&D investments.

Research projects in building technology are examined as case studies in sections 3 and 4 from the standpoint of their payoffs to society and NBS. A case study of a heavier asphalt shingle for roofing (235 shingles) shows that the net benefits to society of the new shingle totaled approximately $4.0 billion during the period 1962 through 1974, in terms of present value savings from increased shingle life. A substantial part of these net benefits, $1.7 billion, are estimated to be attributable to CBT's efforts in helping to develop the shingle. The internal rate of return to society from its total investment in the new shingle is estimated to be 33%; the internal rate of return on CBT's investment is estimated to be 70%.

Sensitivity analysis shows the net benefits of research in 235 shingles to be high over a broad range of values for the variables that most influence the level of impact; namely, the time lag between initial research and introduction of the new technology, rates of diffusion, and the interest rate used to convert past and future values to a common time basis.

The second case study measures economic impacts of research investments in reduced-size venting (RSV), a type of sanitary drainage vent system that utilizes smaller vent pipes than those currently permitted by plumbing codes. Over the period from 1975 through 1985, the net benefits (i.e., net dollar savings in venting costs) to society from introducing RSV are estimated to be about $106 million.

Suggestions for further research are made in section 5. Analysis of past and ongoing innovations is needed to help predict rates of diffusion of new technologies. Without reliable predictions of diffusion rates, benefits accruing in the future cannot be estimated. A second area of research need is the development of a system of recordkeeping on past and current projects so that benefits and costs of R&D can be identified, quantified, and related to specific activities. A third area of research need is the computation and comparison of private and social payoffs on specific projects to see where government support of R&D is warranted. A fourth need is the determination of government cost-sharing (i.e., grant) formulas for supporting R&D in those private sector projects where payoffs to society at large far exceed payoffs to private firms making the research investment. A final research need, and one that would be particularly useful to a large research concern that funds many low-budget projects, is the development, review, and assessment of simplified approaches for use in determining the relative economic efficiency of alternative research projects, and the extension of these to fit specific kinds of projects. An approach that is simpler, cheaper, and more quickly applied than the benefit-cost and internal-rate-of-return approaches described here, but generally reliable, would be helpful as an initial screening device for selecting among alternative research projects.

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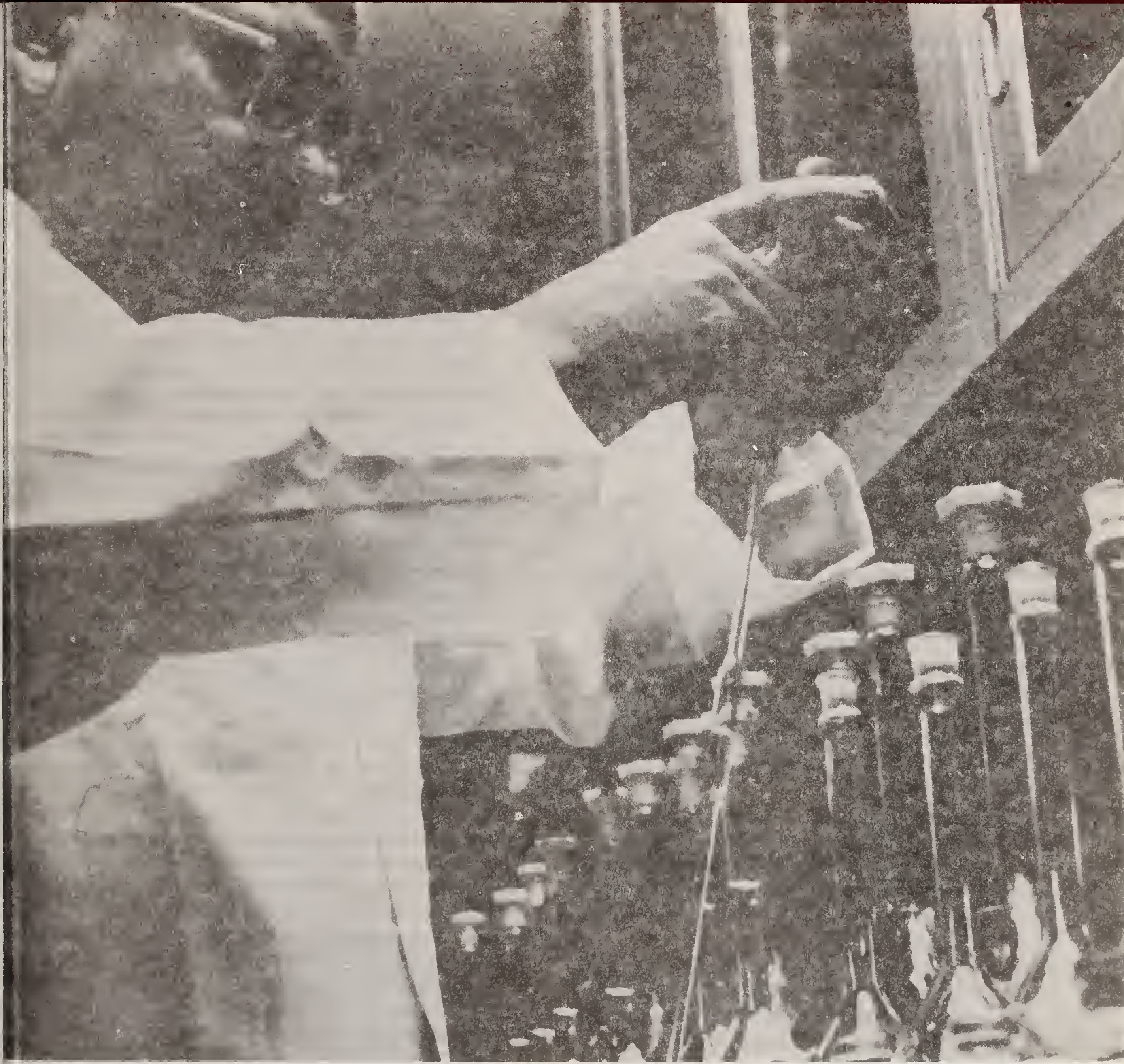
This scientist is working on analytical techniques for determining various constituents in blood sera.



1. INTRODUCTION

1.1 BACKGROUND

The research and development (R&D) industry is a major industry in terms of the total resources that it controls. Expenditures in the United States for R&D, based on National Science Foundation statistics, have risen in current dollars from $23.8 billion in 1967 to $40.8 billion in 1977. Applied research accounted for $9.0 billion and basic research for $5.2 billion out of the 1977 total of $40.8 billion. Figure 1.1, based on those same statistics, shows that total R&D spending increased over twice as fast in the most recent 5-year period (1972-1977) as in the previous 5 years (1967-1972). Federal R&D spending, comprising more than half of the total, rose 56% over the 10-year period whereas nonfederal spending rose 110%. Expenditures for R&D are estimated to have represented 2.2% of the Gross National Product for 1977. In the United States, an estimated 542,000 R&D scientists and engineers were employed in 1976. Approximately one-third of all scientists and engineers historically have been employed in R&D work.[1]

[1] National Science Foundation, *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1977,* NSF 77-310 (Washington, D.C.: U.S. Government Printing Office), pp. 1-2.

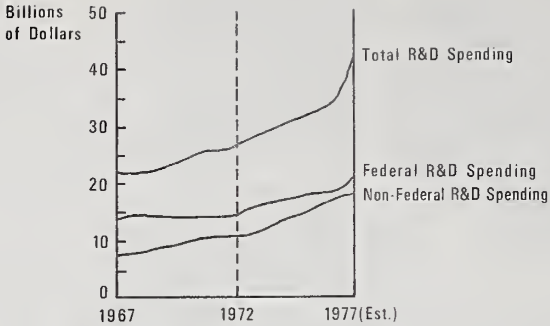


FIGURE 1.1 *R&D funding trends, 1967-1977 (Expenditures are in current dollars).*

Government and private organizations that fund and conduct research have a responsibility to taxpayers and stockholders respectively to allocate their limited resources efficiently. The National Bureau of Standards (NBS), a scientific research agency of the U.S. Department of Commerce, has attempted to improve its resource allocation process by requiring all major operating units to do a "microstudy" of their research impacts on society. The microstudy report prepared for the Center for Building Technology (CBT) was the starting point for this study. The impact evaluation methodologies developed and applied in this paper to case examples from CBT are provided as models that government agencies, universities, and research firms might follow in allocating research funds where impacts of applied research are expected in the near future.

Since decisions regarding the allocation of funds to R&D have traditionally been made with little or no formal analysis, one might ask why there is a need for evaluating impacts of applied research. The following description of R&D management problems answers this question at least in part.

> The R&D professional has essentially been interested in only technical performance. Cost and time have been considered as unnatural constraints in the scientific environment. But they cannot be ignored because they are scarce and vital resources. Skillful management of these and all other productive resources in research and development is necessary in order to maximize accomplishment and meet the challenge of a changing technology. As R&D projects have become larger and more complex, scientific activities have come to transcend the responsibility or interest of a single individual or even organization. Information and communication are tremendously important because duplication of effort is wasteful and omission can be disastrous.
>
> Research and development do not easily lend themselves to evaluation. . . . Projects are generally authorized on the basis of time, cost, and performance estimates of the scientists involved. There are frequent miscalculations, which make it difficult for management to draw sound technical evaluations of the problems involved. When program objectives are not achieved, this can cause strained feelings and disillusionment. Management must often base decisions on subjective factors rather than on accurate quantitative information.
>
> How can the creative accomplishment be evaluated and measured? What meaningful criteria can be established in the commercially directed R&D organization? How can R&D effectiveness be determined in organizations such as the government and military and universities, where there is no material incentive system?
>
> R&D can be a tremendous intangible benefit or a staggering liability, but present tools are inadequate to weigh either conclusively. Applying reliable criteria for measuring and evaluating R&D effectiveness would be an important step in managing the R&D process.[2]

The need for quantitative descriptions of research impacts also becomes apparent in budget requests. When contractions in government spending and shrinking profit margins in business result in budget squeezing, research is often the activity to be dropped. A formal and objective approach to ascertaining research impacts is needed to assure the efficient allocation of limited resources among competing research demands.

1.2 PURPOSE

This report has two major purposes. First, it provides research administrators (e.g., in CBT and NBS) with an examination of several quantitative methods for evaluating existing and past research projects both from the standpoint of widespread social impacts and from the standpoint of the impacts on their particular institution. This review of methods, with case applications, demonstrates one approach to analyzing research projects in an effort to promote more efficient allocations of limited research funds. The implementation of impact evaluation techniques described in this paper, where applicable, will enable CBT and NBS to give better service to the building community and to the nation's economy in general.

The second purpose of this report is to provide a description of the data needs for evaluating the impacts of new technologies that result from an agency's or firm's applied research programs. Data requirements must be defined for predicting *ex ante* the impacts of emergent technologies, as well as for measuring *ex post* the results of past research.

[2] Daniel D. Roman, *Research and Development Management: The Economics and Administration of Technology* (New York: Appleton-Century Crofts, 1968), p. 26.

1.3 SCOPE AND APPROACH

This report takes a long-run view of research planning and evaluation to encompass the entire period of time over which research leads to a new technology which diffuses through society. The focus is on specific benefits and costs of developing new technologies, with little attention being given to institutional considerations and other constraining factors. This does not imply that these are unimportant, but simply that they are assumed to be considered in the initial screening of research alternatives. Examples of such constraining factors which research managers are likely to find important are the compatibility of research projects with the organization's charter or mission statement, the ability to meet funding requirements within budget constraints, and the ability to gather the required staff and equipment to perform specific research tasks.

No attention is given in this paper to the step-by-step process by which research in the CBT (or other) laboratory makes its way (i.e., diffuses) as a new technology through codes, standards, or other processes to the ultimate user. The estimation of rates of diffusion for the many routes through which new technologies travel is a major research task in itself.

The report has four sections in addition to the introductory section. Section 2 begins with definitions of terms and a discussion of the different perspectives or objective functions of research groups developing and applying new technologies. The need for measures of benefits and costs arising from the introduction of new technologies is described, as well as the importance of discounting costs and benefits to an equivalent time basis for purpose of comparison. Section 2.2 provides a survey or overview of three selected methods or techniques for evaluating and comparing alternative R&D investments.

Two case studies of building technologies are developed in sections 3 and 4. The first, described in section 3, provides estimates of the net savings impact from a past research effort in the development of an improved asphalt shingle for sloped roofing. The life-cycle costs of the improved shingle are compared against the life-cycle costs of the traditional shingle it displaced. Net savings and the internal rate of return are computed for the actual quantity of the improved shingle that was installed during the period from 1962 to 1974. Furthermore, that part of dollar savings that appears attributable specifically to CBT's research activities is estimated.

The second case study, described in section 4, deals with reduced-size venting (RSV), a type of venting for sanitary drainage systems that utilizes smaller vent pipes than those currently permitted by plumbing codes. This case study shows the estimated net dollar savings in venting costs over the period from 1975 through 1985 if RSV were incorporated into building codes and implemented in construction of single-family residences.

Assumptions about material life, the appropriate discount rate, the rate of diffusion of new technologies in the building community, and the impact of CBT's activities on that diffusion rate are necessary for carrying out the case studies. The bases for these assumptions are described in sections 3 and 4. To provide the reader with as broad a perspective as possible, sensitivity tables of cost savings are presented in the shingle case study for several values of the factors to which cost savings appear sensitive and for which the selection of values is controversial.

Section 5 concludes the paper with a summary and suggestions for further research.

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Economic evaluation methods are needed to allocate funds most efficiently among competing research projects.

2. METHODS OF EVALUATION

2.1 TECHNOLOGICAL CHANGE AND IMPACTS

Before reviewing alternative methodologies for evaluating impacts of technological change, it is useful to define carefully some concepts relating to technology so that a common perspective will be shared by authors and readers. It is also useful to consider the definitions and measures of benefits and costs, since they may be defined and measured differently by decision makers, depending upon whether their organization is public, private, or non-profit.

2.1.1 Definitions and Perspective

The measurement of economic impacts of R&D to improve the allocation of research funds is the subject of this paper. Impact can be defined as the influence or effect that introduction of a new technology has on the economy. Consider the following examples: new technology may affect an individual in terms of a new job and higher income, a community through a higher tax base, and a nation through a higher GNP and employment rate. *Social impact* is used here to denote the total net effect on the nation at large. The term is used synonymously with *social economic impact,* although the former term is sometimes construed in a broader context to incorporate more effects than are usually covered under the term "economic." Social impact, as used here, covers a variety of influences or effects, the benefit and cost consequences of which can be quântified in some manner.

In section 1 we described the need for measuring impacts in terms of allocating resources most efficiently and defending budgets. These activities require research managers to identify the objective functions for their organizations and to plan the products which will be produced and the resources which will be allocated to their production. *Objective functions* describe what objectives or goals a given organization is trying to optimize. Associated with objectives are constraints, both in terms of resources and in terms of institutional limitations or requirements. For example, a Federal agency doing research on the prevention of a communicable disease might have as its objective function the minimization of time taken to develop an effective immunization, subject to the constraints of a fixed annual and long-term budget, a fixed number of research staff and existing facilities. On the other hand, a private business firm's research department might have very different objective functions and constraints. A drug firm, for example, might seek to develop a vaccine that is most likely to result in the greatest profit to the firm, taking into account resource constraints. A research project is undertaken because it contributes to achievement of an organization's objective function.

Research can be considered in two forms. *Basic research* is for the purpose of increasing scientific knowledge, whereas *applied research* is concerned with a practical application of basic research findings. The *development* part of R&D puts the research findings into practice, and may include the design of and experimentation with particular products. There is a continuum of activity beginning with basic research and ending with the development of a product. Just where along that continuum applied research begins and is then replaced by development is not clear, although the sequence of research and then development is generally accepted.[3] A sharp demarcation among research, applied research, and development is, in any case, not crucial to this study. The significant point for using the evaluation techniques discussed here is that resource allocations apply to that type of R&D which leads in a direct way to a tangible product whose impact can be measured.

Technology has been defined as "society's pool of knowledge regarding the industrial arts."[4] It includes knowledge concerning physical and social phenomena. Research and development contribute to this "pool of knowledge." The state of technology at any given time controls what can be produced with existing resources. Associated with any given technology is a *production function* that shows the maximum rate of output that can be obtained for given inputs. Any advances in technology that result in the capability of producing a new product or of making a given product in a new way is called *technological change,* which results in a change in the production function.

Invention and innovation are also closely connected to technological change. Invention has been defined as "a prescription for a new product or process that was not obvious to one skilled in the relevant art at the time the idea was generated."[5] *Innovation* is the application of an invention, the result of which is a new good, service, or process. A new technology is not implemented until an innovator takes the risk of production.

Diffusion is the spread of an innovation throughout the economy. An estimate of the rate of diffusion is usually needed to measure the impacts of R&D.

Some of these concepts can be made clearer with a graphical illustration. Figure 2.1 shows two functions (labeled T_1 and T_2) that represent the same level of output (could be a measure of service, performance, or physical output) provided by two different technologies. These functions describe graphically the different combinations of capital and labor required to produce the same level of output with technologies T_1 and T_2.

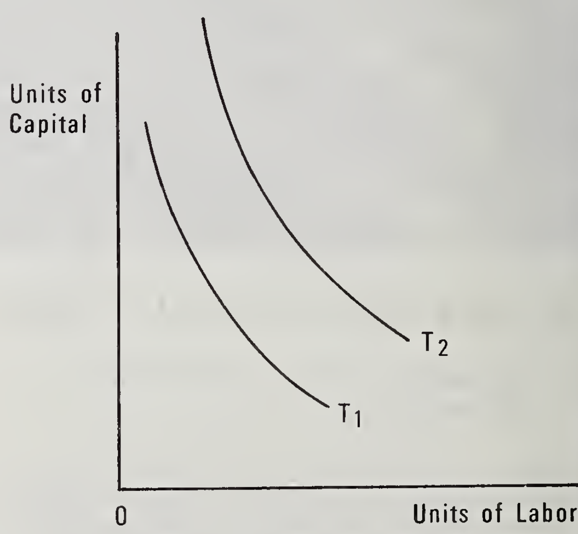

FIGURE 2.1 *Technological change.*

[3] For a more complete description of these terms, see Daniel D. Roman, *Research and Development Management,* pp. 4-5, and Edwin Mansfield, *Research and Innovation in the Modern Corporation* (New York: W. W. Norton & Co., 1971), pp. 1-3.

[4] Mansfield, *Research and Innovation,* p. 2.

[5] ibid., p. 11.

Since the level of output is equal for T_1 and T_2, we see that the technology embodied in T_1 is a more efficient technology than that in T_2. That is, the combination of capital and labor resources necessary to produce the given level of output is smaller for T_1 than T_2. A change in technology which results in less capital and labor required to produce a given output could be represented by a shift in functions from T_2 to T_1.[6] The case studies in section 3 examine two building technologies to see whether, in fact, production functions have changed as a result of research, such that the same or greater performance or outputs can be produced with a less costly combination of resources.

Graphical analyses can also be used to describe the influence of various factors on the extent of diffusion of an innovation among potential users. Figures 2.2 and 2.3 show the relationship between the probability of adoption of an innovation and several characteristics of that innovation. In figure 2.2, for example, A_1 and A_2, which designate two different innovations, show a direct relationship between the probability of adoption and the proportion of firms already using the innovation (degree of saturation). Figure 2.2 also shows that the probability of adoption is higher at every level of saturation for A_2 than for A_1, because A_2 is a more profitable innovation. Figure 2.3 shows a higher probability of adoption of an innovation requiring a smaller investment (B_2) than one requiring a larger investment (B_1), other things being equal.[7]

On *a priori* grounds, these are the relationships that one would expect. Because risks of introducing a new technology generally diminish as market saturation grows, one would expect increased adoption as experience and information increase. Likewise, the more profitable the investment in a new technology appears to be, the greater the compensation for anticipated risks of undertaking that investment. Finally, it seems reasonable to expect firms to be more reluctant to commit large amounts (particularly when they have difficulty raising large capital amounts) than small amounts to undertaking new technologies.[8] Based on these and other factors relevant to a particular innovation, the diffusion process could vary considerably.

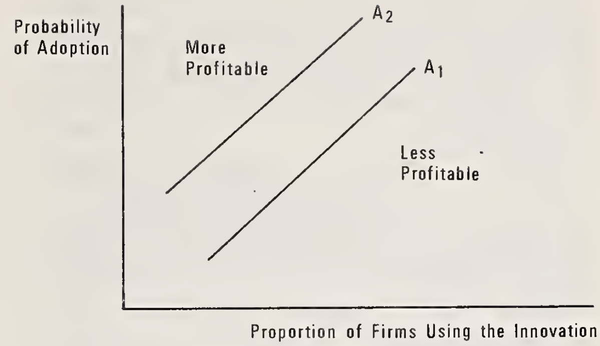

FIGURE 2.2 *Probability of adoption as function of saturation and profits.*

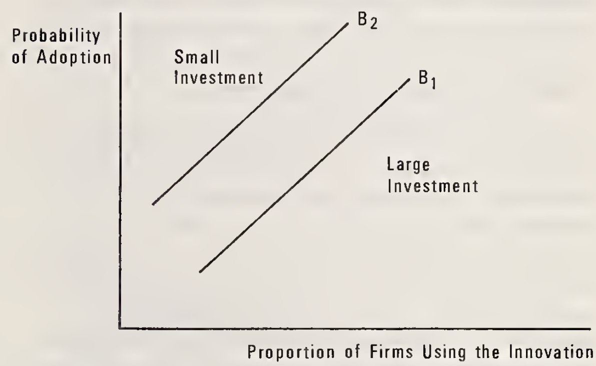

FIGURE 2.3 *Probability of adoption as function of saturation and size of investment.*

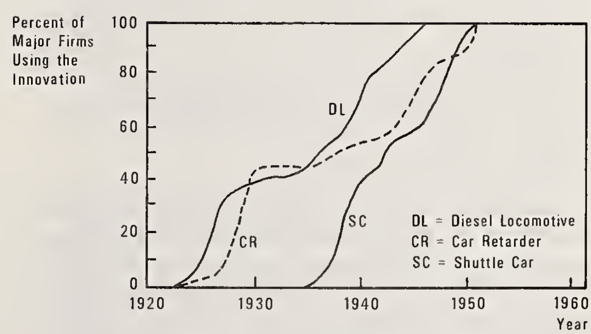

FIGURE 2.4 *Diffusion over time.*

Mansfield has charted the percentage of major firms adopting an innovation for 12 products in four U.S. industries—iron and steel, bituminous coal, brewing, and railroads. Figure 2.4 illustrates how diffusion patterns vary among innovations by tracing the percentage of acceptance of major firms of three of the 12 products Mansfield investigated.[9] He reached two general conclusions. First, diffusion of a new technique is *slow.* It took one-third of the 12 new techniques 20 years or more to be adopted by the major

[6] Figure 2.1 by construction indicates that the more efficient technology requires less capital and labor to produce the same output. Other examples of more efficient technologies might result in less of just one input and the same quantity of another, or, even more of a lower-priced input accompanied by less of a higher-priced input to achieve the same output at lower cost.

[7] For a more complete discussion of these diffusion graphs, see Edwin Mansfield, *Microeconomics: Theory and Applications* (New York: W. W. Norton & Co., 1975), pp. 480-485.

[8] See Edwin Mansfield, *Industrial Research and Technological Innovation: An Econometric Analysis* (New York: W. W. Norton & Co., 1968), pp. 136-154, for a deterministic econometric model that confirms these diffusion relationships.

[9] ibid., p. 134.

firms in that industry, and only one-fourth of the techniques made it in 10 years or less. Second, the rate of diffusion varied widely among techniques. The average time required for half of the firms to introduce the innovation was 7.8 years, but their range varied from 0.9 to 15.[10]

The estimation of the rate of diffusion of a new technology is a critical step in evaluating the future impacts of current or proposed research. The need for information on diffusion will be discussed further in section 2.1.2.2.

2.1.2 Data Needs

Specific elements of information are needed to evaluate alternative research opportunities. Here we discuss the general data requirements for evaluation, before surveying in section 2.2 the selected methodologies.

2.1.2.1 Benefit and Cost Measures

Social benefits (sometimes called national benefits) of a given research project can be defined as the increase in monetary and nonmonetary values of goods and services to the nation (all of society) which results from having that project as compared with not having the project. Thus social benefits include all types of positive features, for all project beneficiaries, no matter how widespread throughout the nation. Note that the savings of resources as a result of technological change may also be considered a benefit under this definition. That is, when resources are saved due to achieving the same output or performance with a new technology, more goods or services can be produced with a given budget. (See the discussion relating to fig. 2.1.) The increased value resulting from the new technology can be approximated by the resource or cost savings which are available for the production of additional goods and services.

Local benefits, on the other hand, are defined as the increase in monetary and nonmonetary values of goods and services to a group smaller than the nation (however that group is defined) which results from having a project as compared to not having it. These benefits may accrue, for example, to an individual, a private firm, or to a local government unit.

A similar distinction can be made between social and local costs. *Social* costs are the total increase in monetary and nonmonetary burdens resulting from having a project as compared to not having it. *Local* costs are those same types of burdens, but only those that accrue to the individual, firm, or group from whose perspective we are examining the project.

The relationship of benefits and costs determines how desirable a project is for the nation or for the institution which undertakes the R&D project. From the standpoint of the organization conducting a project, benefits and costs must be considered in terms of their relevancy to the organization's objective function, and the economic efficiency of that project will depend on its cost and contribution to the organization's objective function.

[10] ibid., pp. 133-136.

Innovations in building technology are used in this report as case examples for illustrating potential benefits and costs. There are several kinds of benefits that may result from introducing new building technologies. One type of potential benefit is safer buildings. Greater safety results when new information (which may be embodied in the updating of standards and codes) brings about modifications in materials or building processes which reduce their hazardous characteristics. Safer buildings result in reduced injuries and/or sickness. Consequent benefits accrue to building users or tenants through reduced injuries and lower medical bills and less time lost from work. Similar benefits might accrue to workers involved in the construction phase of the building. Benefits from better health and safety in buildings might also accrue to building producers and building operators in the form of fewer liability claims, cheaper insurance, and less property loss.

A second type of benefit that might arise from an improved building technology is the increased productivity of occupants that carry out the functions of their job in a building and of construction workers who build the structure. A new lighting system in an office building might enhance productivity as measured by fewer labor hours required for tasks requiring intensive reading. A new labor-saving technique might increase worker productivity in the construction of the building.

A third type of benefit from advancement of building technology is more cost-effective buildings. With new technology, a specified level of building performance might be attained with a new, cheaper material, for example. Or better performance, in terms of increased reliability and durability, might be attained with a new process that costs no more than the currently used process. Increased performance per dollar spent means greater economic efficiency, which can result in decreased costs of production or operation for any one of the participants in the construction process or some combination of them. Thus the developer, contractor, owner/operator, and building user are potential beneficiaries.

Note that the second and third catagories of benefits listed above may be described as reductions in costs of delivering a given product or service, and that these items might be listed either as benefits or as negative costs. In the computation of net benefits, it makes no difference whether a cost savings is deducted from costs or added to benefits, although in the computation of benefit-cost ratios, it does make a difference. (The appropriate classification of cost savings will be discussed in sec. 2.2.)

In addition to efficiency effects of new technologies, the research community is also interested in redistribution effects. That is, in addition to knowing whether benefits are greater than costs for a research and development project, it is important to know how those benefits and costs are distributed. This redistribution of income issue is of interest to manufacturers of building materials, for example, in that the introduction of new technology products may affect their business profits. Incomes could be redistributed from one set of manufacturers to another, from manufacturers to consumers, from manufacturers to installers, or in many other ways. Income redistribution issues are identified here because they are important in considering new technologies. They are outside the scope of this report, however, and are therefore not discussed further.

The measurement of benefits and costs is usually made in dollar terms. By nature most costs are expressible in dollars, such as the costs of research and development, of new equipment required for producing new products, and of developing a new market. However, not all benefits are easily measured in dollar terms. Where an objective of a firm is growth or power, for example, it is difficult to measure the dollar value of meeting that objective through research and development. The value of lives saved from technological innovations in buildings is also difficult to measure in dollar terms. Establishing values for such difficult-to-measure benefits is one of the greatest challenges in determining the economic impact of technological change. Where such objectives as power and safety exist side-by-side with the more conventional objective for the firm of maximizing profits and for the government of minimizing costs of reaching certain performance levels, the tradeoffs of benefits and costs for every research plan should at least be identified or described in words if not measured quantitatively. Project planners will have a more complete perspective of research benefits and costs if both monetary and nonmonetary items are displayed.[11]

Economists are making progress in the measurement of benefits from technological change. Zvi Griliches' 1958 landmark article on the social returns of hybrid corn provided an approach to measuring the benefits of new technologies in agriculture.[12] Edwin Mansfield has applied a similar approach in exploring social and private rates of return from industrial innovations.[13] A brief overview of their conceptual approaches to measuring benefits is given here to acquaint the reader with what has been done to measure successfully the benefits from technological change.[14]

Both researchers rely to some extent on measures of consumers' surplus in determining benefits from technological innovations. "Consumers' surplus" is an economic term defined as that amount which a consumer would have been willing to pay for a good or service beyond what he is required to pay by the market. Figure 2.5 shows the economist's conventional demand-supply model for determining the price and quantity of a given good or service. The cross-hatched triangle represents the amount of consumers' surplus; i.e., the difference between the willingness-to-pay in aggregate for all units up to Qe (the area under the demand curve) and the costs of 0Qe units (the rectangle with area Pe·Qe).

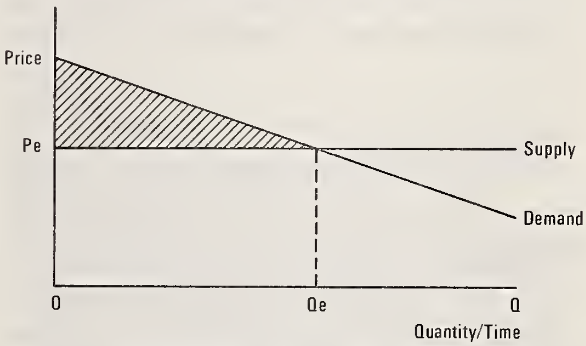

FIGURE 2.5 *Consumers' surplus.*

A simple model which follows the Griliches and Mansfield method for measuring benefits from a new industrial technology is shown in figure 2.6. The introduction of the new technology is assumed to shift the supply from S_1 to S_2 as a result of lower production costs to the producers using the new technology.[15] The price (P) of the product in whose manufacture the technology is used will decrease from

[11] For a description of one method that can be used to evaluate alternative projects given multiobjectives with incommensurable outputs, see Harold E. Marshall, "Cost Sharing and Multiobjectives in Water Resource Development," *Water Resources Research,* Vol. 9, February 1973, pp. 2-4.

[12] Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *The Journal of Political Economy,* LXVI (February-December, 1958), pp. 419-431.

[13] Edwin Mansfield, "An Exploratory Study of Social and Private Rates of Return from Industrial Innovations," a paper presented at the meetings of the Eastern Economic Association on October 26, 1974.

[14] For a step-by-step description of Griliches' and Mansfield's methods, see their papers cited above.

[15] For purpose of illustration, supply is assumed to be perfectly elastic; that is, the supply function is perfectly flat or horizontal.

P_1 to P_2, and the quantity demanded will increase from Q_1 to Q_2. The measure of benefits from introducing the new technology is the increase in consumers' surplus that results from the decreased price; i.e., the dollar value of P_2RTP_1 (shown as the dotted area in fig. 2.6).

Mansfield extends his measure of benefits to incorporate the profit that is earned by the innovator of a new technology. If we designate the profit to the innovator per unit of industry output using the innovation as r (the difference between P_2 and P_2–r in fig. 2.6), we can depict the profit earned on the innovation as the cross-hatched rectangle equal to $r \cdot Q_2$ (i.e., the area bounded by P_2–r, K, R, and P_2). Thus, according

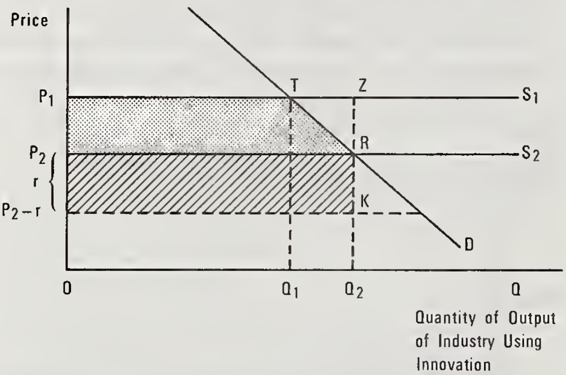

FIGURE 2.6 *Consumers' surplus measure of benefits.*

to Mansfield, the total benefits resulting from the introduction of an industrial innovation would be measured by the value of the area bounded by P_2–r, K, R, T, P_1. If the innovator of a government R&D project is unable to collect profits from, for instance, patent rights, the area P_2RTP_1 alone might be an appropriate measure of benefits from a new government-induced technology. This measure would underestimate social benefits to the extent that private users of the new technology might reap greater profits after than before the innovation.

Benefits derived from cost savings in new building technologies are closely related to the consumers' surplus measure. That is, as supply shifts from S_1 to S_2 in figure 2.6, the area P_2RZP_1 represents what would be saved by consumers in the purchase of Q_2 units if they were bought at P_2 rather than P_1. This value is close to that of consumers' surplus (it exceeds the consumers' surplus measure of benefits by the amount TRZ), and could in fact be identical to it if quantity demanded were constant in that range of prices. The less responsive is quantity demanded to price change (i.e., the more inelastic is demand), the smaller will be the area TRZ. In the case studies of sections 3 and 4, we take this approach in calculating the expected benefits from cost savings from new technologies in roofing and plumbing.

2.1.2.2 Time and Rate of Discount

In order to measure benefits and costs correctly, research administrators need additional elements of information. Much of this information is related to the flow in time of benefits and costs. The rate of diffusion of new technology (see sec. 2.1.1), for example, must be known in order to predict the time flow of benefits. For an *ex post* evaluation (e.g., shingles in sec. 3), documenting the rate of diffusion is not a great problem, but for an *ex ante* evaluation (e.g., RSV in sec. 4), predicting the rate at which a new technology will be adopted is one of the most difficult tasks. Considerations in predicting the diffusion rate include the examination of any constraints, such as consumer attitudes, labor union demands, or patent restrictions that would affect a technology's implementation. For a change in building technology, for example, one of the most important factors to consider is the set of building codes and standards. Predicting the diffusion rate requires a careful analysis of all of the institutions which affect the adoption of a new technology.

Time is also important in selecting the period (sometimes called time horizon or life cycle) over which a research project's benefits and costs are to be measured. The stream of benefits from research, even more so than for most other investments, generally comes in the distant future. The analyst who is evaluating alternative research projects must select time horizons that are consistent with the objective function of the firm or agency and that will allow valid comparisons with other investments. Furthermore, the analyst must be aware of possible obsolesence of any given technology so that future benefits are not estimated beyond the innovation's competitive life span.

Another time-related factor that must be established for accurate evaluations of research projects is the rate of discount. Cost savings, increased revenues, and research and development expenses occur at different points in time. Because dollars received or spent at different times are not equal in value, it is necessary to convert the streams of benefits and costs to a common time basis. This process is called discounting. For example, $1,000 invested at 8% will return $1,080 at the end of 1 year. Thus $1,080 received 1 year from now would be equivalent to $1,000 held today, because that $1,000 could be invested today to return $1,080 in a year. Benefit-cost analysis is sensitive to the discount rate that is selected for converting costs and benefits that are dispersed over time to time equivalent figures. Thus analysts must be careful to select the appropriate rate and make their reasons for choosing that rate known. The procedure and formulas for discounting can be found in most engineering economics textbooks.[16]

2.2 SURVEY OF EVALUATION METHODS

To allocate limited resources efficiently among alternative research projects, R&D managers need a method for measuring and comparing benefits and costs associated with those projects. Three such methods—benefit-cost, internal rate-of-return, and payback analysis—are described in this section.

The intent of this survey is to familiarize the reader with these three approaches and their advantages and disadvantages in different applications. These three were selected because they are used widely; they are logically straightforward and relatively easy for a research manager to understand; and they are theoretically and practically sound when applied properly.[17]

The selected methods have many features in common. For example, each requires estimates of benefits and costs, assumptions about diffusion rates of new technologies, and assumptions about time horizons. Furthermore, they all can be used to measure the economic performance of an investment made either by a government agency, university research group, or by a private firm.[18]

There are, however, important differences among the three methods. Benefit-cost analysis, for example, provides an evaluation measure in terms of dollars and/or ratios; the internal rate-of-return method, in terms of a percentage rate of return; and the payback method, in terms of time. The benefit-cost and internal rate-of-return methods measure benefits and costs over the entire life of a project; the payback method generally includes less than life-time benefits and costs. Each of the three methods is described in sections 2.2.1 through 2.2.3. Case illustrations in building technology of two of the three techniques will be presented in sections 3 and 4.

2.2.1 Benefit Cost[19]

Benefit-cost[20] analysis is a general term used to describe two economic evaluation measures: (1) net benefits and (2) benefit-cost ratios. The net benefits measure is useful for determining the efficient scale or level of investment in any given project, and for choosing among mutually exclusive projects. The benefit-cost ratio is useful for choosing among projects that are not mutually exclusive. Both measures are useful for determining whether to accept or reject a given project.

Graphical analyses can be used to demonstrate how the most efficient[21] scale or level of resources to be allocated to a new technology project is found by an analysis of net benefits. Figures 2.7 and 2.8 illustrate that net benefits, the difference between total benefits and total costs, are maximized at Re, that level of R&D where marginal benefits equal marginal costs.[22]

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[16] For descriptions of discounting, see Gerald W. Smith, *Engineering Economy: Analysis of Capital Expenditures,* 2nd ed. (Ames, Iowa: The Iowa State University Press, 1973), and Eugene L. Grant and W. Grant Ireson, *Principles of Engineering Economy,* 5th ed. (New York: The Ronald Press Co., 1970).

[17] There are other approaches to evaluating alternative investments, but this survey is limited to the selected three. For descriptions of these three methodologies and others, see Ajit K. Dasgupta and D. W. Pearce, *Cost-Benefit Analysis: Theory and Practice* (New York: Harper and Row, 1972), pp. 159-173; and Rosalie Ruegg et al., *Life-Cycle Costing: A Guide for Selecting Energy Conservation Projects for Public Buildings,* NBS BSS113 (Washington, D.C., National Bureau of Standards, 1978).

[18] In applying these methods to evaluate investments of private, profitmaking organizations, the effect of taxes should be taken into account. Because of its focus on the evaluation of government projects, this report does not treat income tax effects. For a description of income tax considerations, see Gerald W. Smith, *Engineering Economy,* pp. 191-267.

[19] The benefit-cost explanation presented here is designed to give the decision maker a general understanding of how this technique of evaluating R&D can be applied. For more thorough treatments of benefit-cost analysis, see the following: Dasgupta and Pearce, *Cost-Benefit Analysis: Theory and Practice;* Otto Eckstein, *Water-Resource Development: The Economics of Project Evaluation* (Cambridge, Massachusetts: Harvard University Press, 1965); Stephen A. Marglin, "Objectives of Water-Resource Development: A General Statement," Chapter 2, *Design of Water Resource Systems,* by Arthur Maass et al. (Cambridge, Massachusetts: Harvard University Press, 1962), pp. 17-87; E. J. Mishan, *Cost-Benefit Analysis: An Introduction* (New York: Praeger, 1971).

[20] Benefit and cost figures discussed here are assumed to be in present value terms. That is, some rate of discount has been applied to all benefits and costs over the life cycle of the project to put them on a time equivalent basis, as discussed in section 2.1.2.2.

[21] Efficiency as used in this study can refer to the welfare of a government agency, academic research institution, firm, or society as a whole, depending on assumptions regarding whose objective function or set of benefits and costs is being evaluated. An increase in efficiency results if an additional investment in R&D results in benefits that exceed the marginal investment. A decrease in efficiency results if an additional investment in R&D generates benefits less than the amount of the marginal investment. (Cost effective is often used synonymously with efficient in this context.)

[22] The following assumptions are made in the benefit-cost model shown above: the total benefit and cost functions are continuous and increasing functions of the level of R&D; the first and second order derivatives of both functions exist for the range of levels of R&D under discussion; and the total benefits function increases at a decreasing rate and the total cost function increases at an increasing rate.

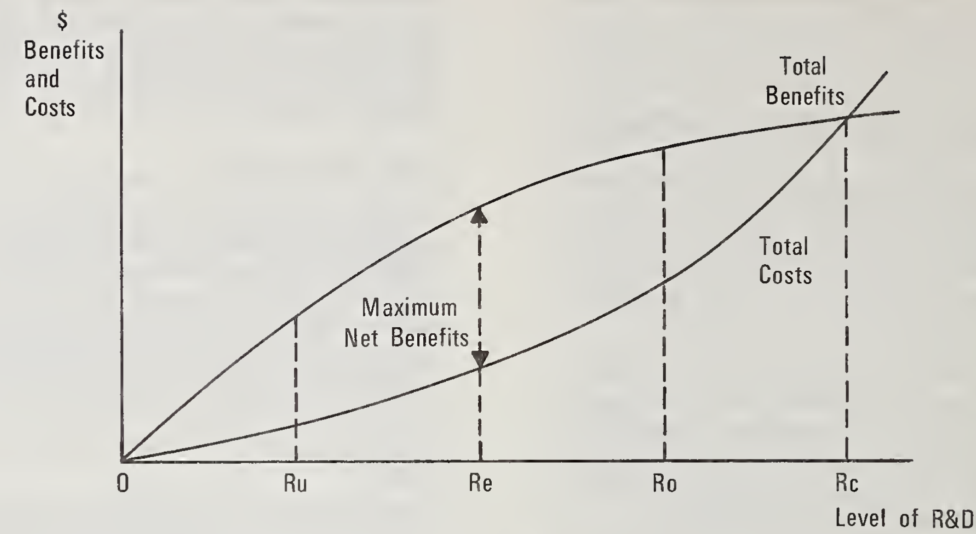

FIGURE 2.7 *Maximum net benefits from R&D in relation to total benefits and costs.*

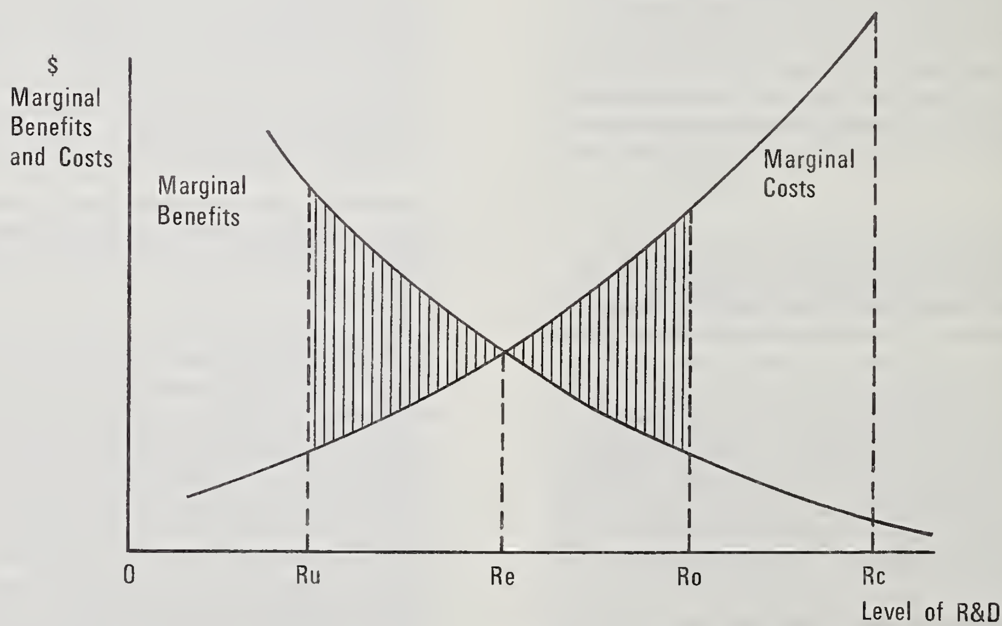

FIGURE 2.8 *Efficient scale of R&D as determined by marginal benefits and costs.*

Undertaking more R&D than Re, the maximum level, would be an overallocation.[23] This can be seen by inspection of figure 2.7, where net benefits at Ro are less than net benefits at Re, and by inspection of figure 2.8, where marginal costs exceed marginal benefits beyond Re. The net benefits foregone by this overallocation at Ro can be measured by the cross-hatched area to the right of Re in figure 2.8.[24] Undertaking less R&D for a given project than Re, say Ru, results in an underallocation of resources. Again by inspection of figure 2.7, we see that net benefits at Ru are less than at Re, and by inspection of figure 2.8 we see that marginal benefits exceed marginal costs at every level of R&D between Ru and Re. The potential net benefits forgone by this underallocation at Ru is indicated by the cross-hatched area to the left of Re in figure 2.8.[25]

The R&D manager might properly point out that the outputs of R&D are not very predictable, and that to estimate the marginal benefits and costs associated with different levels of R&D in order to arrive at the most efficient level for a given technology might be difficult. This analysis can be useful, however, even where estimates of benefits and costs are rough. Note in figure 2.7 that net benefits are positive for the amount of R&D indicated from zero to Rc; that is, the benefits are greater than the costs of R&D. Thus in general terms, an analyst would consider a project efficient or cost effective at levels of Ru and Ro as well as Re, because benefits exceed costs. In absence of complete information, the decision to accept or reject a given project might rest simply on whether or not benefits exceed costs, even while recognizing that the project may not be at its most efficient scale. This is the approach taken in sections 3 and 4 where the net benefits from introducing a heavy shingle and from developing reduced-size venting are computed to see if they are positive.

In comparing projects against one another on the basis of the maximum benefits for a given budget expenditure, a project which is overallocated or underallocated in itself might still be more efficient than an alternative project. However, we stress that the most efficient scale of or level of resource allocation to R&D is at Re for any given project, and that more or less R&D production represents wasted resources.[26]

Another problem for which the net benefits measure is useful is in choosing the most efficient project(s) from a set of mutually exclusive alternatives.[27] Selecting one project means rejecting the other(s). An example would be the choice between research on two innovative approaches to a new production process when only one approach can be followed due to budget, personnel, project interdependence, facility, or other constraints. The objective is to choose the project that will yield the greatest net benefits while meeting funding and other constraints.

Dasgupta and Pearce classify the choice of time for undertaking a single project, i.e., whether to begin the project now or to delay it, as a special case of mutual exclusion. They advocate the maximization of net benefits as the appropriate criterion for this case also.[28] Choice of project scale may also be regarded as a case of mutual exclusion, in that choosing one size precludes choosing alternative project sizes for the same purpose.

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[23] It is assumed throughout this paper that, for any given level of research and development, costs are being minimized, that is, each level of R&D is being provided with the least-cost combination of resources.

[24] The complete discounting formula for measuring the present value (P.V.) of net benefits of investments in R&D for a given scale of R is the following:

$$\text{P.V. of net } B(R) = \sum_{t=1}^{N} \left[\frac{B_t(R) - C_t(R)}{(1+i)^t} \right],$$

where

B_t = benefits in year t,
t = years 1 through N,
C_t = costs in year t, and
i = discount rate.

[25] For a theoretical discussion and application of benefit-cost analysis to a building technology problem, see Robert E. Chapman and Peter F. Colwell, *Economics of Protection Against Progressive Collapse,* National Bureau of Standards Report, NBSIR 74-542, September, 1974.

[26] An assumption that is implicit in our designation of Re as the most efficient scale is that the cutoff benefit-cost ratio at the margin is 1.0; i.e., that the highest benefit yield available at the margin is just equal to the cost of investment. However, in the case where a very limited budget has to be allocated among a large number of high payoff opportunities, this common assumption may not be appropriate. If carrying one or more projects to the scale where their marginal benefit-cost ratio is 1.0 means foregoing other projects whose marginal benefit-cost ratio is greater than 1.0, then the collection of projects should be scaled so that benefits produced are the same for the marginal dollar of expenditure on each project. In this case, the maximum efficient scale of each of the projects would be less than Re in figures 2.7 and 2.8.

For a thorough discussion of cutoff benefit-cost ratios and how they alter efficient scale and project choice decisions, see Marglin, "Objectives of Water Resource Development: A General Statement," pp. 164-177.

[27] Note that, when alternative projects are examined with these criteria, the assumption is made that the individual project scales have been previously determined.

[28] Dasgupta and Pearce, *Cost-Benefit Analysis: Theory and Practice,* pp. 160-163.

Another choice that decision makers must make is among a set of project alternatives that are not mutually exclusive. Choosing one project does not preclude selection of the other projects. Although the objective continues to be the maximization of net benefits for the available budget, ranking and choosing projects with the net benefits measure will not necessarily result in the maximization of net benefits for a given R&D budget. The benefit-cost ratio method is recommended for this type of problem. Table 2.1 shows that the net benefits and benefit-cost ratio criteria may indicate different choices, and that basing the choice on the latter measure will result in maximum net benefits.

Table 2.1 COMPARISON OF RANKINGS BY NET BENEFITS AND BENEFIT-COST RATIOS

	$1,000			
Project	Benefits (B)	Costs (C)	B-C	B/C
1	300	200	100	1.50
2	200	120	80	1.67
3	140	80	60	1.75

If we assume a budget of $400,000 or larger, all projects would be selected if higher returns were not available from alternative investment opportunities. But assuming the budget is limited, say at $200,000, not all projects can be developed. Applying the net benefits criterion (i.e., taking the projects with the highest net benefits value) would result in the selection of Project 1 with net benefits of $100,000. On the other hand, if we pick projects on the basis of the benefit-cost ratio, we would take first Project 3 and then Project 2, but not Project 1, and net benefits for the same $200,000 cost would rise to $140,000. Thus, it is clear from table 2.1 that, for projects that are not mutually exclusive, the net benefits criterion cannot be relied upon to yield the maximum net benefits under a budget constraint. In this case a gain of $40,000 ($60,000+$80,000–$100,000) could be realized by selecting projects on the basis of the benefit-cost ratio rather than on the basis of the net benefits rule.[29]

[29] Note that using benefit-cost ratios instead of a net-benefits measure to rank mutually exclusive projects may result in losses in net benefits. For example, a project costing $160,000, with benefits of $200,000, results in net benefits of $40,000. This project would be preferred on economic grounds to a project costing $90,000 with benefits of $120,000 and net benefits of $30,000. However, if the benefit-cost ratio were used as the selection criterion, the second (and less efficient) project with benefit-cost ratio of 1.33 would be chosen over the first (more efficient) project with a benefit-cost ratio of 1.25.

2.2.2 Internal Rate of Return

The internal rate of return is that compound interest rate which will discount net benefits of an investment to zero; i.e., that rate at which discounted total costs and total benefits are equal. In contrast to the net benefits method of evaluation, which calculates the net dollar value of an investment based on a given minimum rate of return (i.e., a specified discount rate), this method finds the rate of return which makes the net dollar value of the investment equal to zero.

The rate of return is usually calculated by a process of trial and error, whereby net benefits from an investment are calculated for various discount rates until the rate at which net benefits are reduced to zero is discovered.[30] As a very simple example, consider the calculation of the internal rate of return on a project which is to research, develop, and bring to a state of marketability a new technology in artificial lighting. Assume the new technology will reduce the energy requirement per lumen/m^2 of lighting delivered to 20% below the energy requirement of the existing counterpart lighting system, and that the investment costs for R&D are $1,000,000 to be expended in the current year. Assume further that once developed, the purchase and installation cost of the new system will be the same as for the existing system, that the total energy savings will amount to $300,000 a year, and that it is expected that the new technology will likely become obsolete after 10 years.[31]

The objective is to find that rate of return (i) which will equate discounted benefits and costs as shown in equation 2.1:

$$C = B_t \left[\frac{(1+i)^N - 1}{i(1+i)^N} \right]. \tag{2.1}$$

Substituting our problem values of $1,000,000 for C, $300,000 for B_t, and 10 for N, we find the value for i which will solve the equation.

[30] For a more thorough treatment of the internal rate-of-return evaluation method, see, for example, Dasgupta and Pearce, *Cost-Benefit Analysis: Theory and Practice,* pp. 164-168; Grant and Ireson, *Principles of Engineering Economy,* pp. 109-134.

[31] In order to focus on the concept of internal rate of return, we neglect in the above example the complicating factors which may enter into an analysis, such as fuel price escalation, differences in purchase prices and lives of new and old technologies, the process of diffusion of the innovation throughout the economy, and, for a private research firm, tax considerations.

The bracketed term in equation 2.1 is called the uniform present value factor. By visual inspection of tables of discount factors,[32] we find that the factor that solves equation 2.1 is 3.333. We then look in a table of uniform present value factors to find the interest rate for which the factor is equal to, or approximately equal to, 3.333. If we are working without the benefit of a comprehensive set of discount tables, the i for which the uniform present value factor is exactly equal to 3.333 may not appear in the tables. We can, however, closely approximate it by calculating the net present value for those rates included in the factor tables which appear to bound the correct i and interpolate between the two rates. In this case, for instance, if our tables of discount factors were available for interest rates in increments of 5%, we would select 25% (for which the uniform present value factor is 3.571) and 30% (for which the uniform present value factor is 3.092) as trial i's. Applying the uniform present worth factor for 25% results in net present value benefits equal to \$71,300 (i.e., \$300,000 (3.571)–\$1,000,000=\$71,300). Applying the factor for 30% results in net present value benefits equal to –\$72,400 (i.e., \$300,000 (3.092)–\$1,000,000=–\$72,400).

For i=25%, net present value benefits are positive; for i=30%, net present value benefits are negative. Thus, for some discount rate between 25% and 30%, total present value benefits are equated to total present value costs. By interpolation,

$$i = .25 + .05 \frac{\$1{,}071{,}300 - \$1{,}000{,}000}{\$1{,}071{,}300 - \$927{,}600}$$

$$= .25 + .05 \frac{\$71{,}300}{\$143{,}700}$$

$= .275$, or expressed as a percentage, 27.5%.

To decide whether or not to undertake this investment, the expected rate of return of 27.5% is compared with the research organization's minimum acceptable rate of return. If it were a project being considered by a Federal laboratory, for example, the appropriate rate for comparison generally would be 10%.[33]

The calculation of the rate of return can be quite cumbersome when a number of cost benefit items are included in the equation. However, a computer program can be used to facilitate the calculations as was done in the case studies in sections 3 and 4.

In section 2.2.1 four kinds of investment decisions were discussed for which the decision maker may need a method of evaluation—determining the efficient size of investment for a given project, choosing among mutually exclusive projects, choosing among projects that are not mutually exclusive, and determining whether to accept or reject a given project. Let us consider the internal rate-of-return method as a criterion for addressing these problems, noting that in general a higher rate of return, or yield, is more desirable than a lower rate.

With respect to the sizing problem, the internal rate-of-return method can be used to size projects efficiently, although there may be more room for confusion in its use than in the use of the net benefits criterion. To determine the most efficient size of a given project, the internal rate of return would be calculated for increments of investment in the project. The project would be expanded up to the point that the rate of return on the incremental investment is just equal to the investor's minimum acceptable rate of return.[34]

Confusion, which may result in inefficient sizing, may arise because the rate of return on the total investment for a larger-sized version of a project may be less than that on a smaller-sized version of the same project, causing the smaller to appear to be more efficient. However, as long as the rate of return on the difference between the larger and smaller versions exceeds the minimum acceptable rate, the larger version is the more efficient choice.[35]

[32] Tables of discount factors are tabular solutions to the discounting formulas which are used to move values in time so that they may be compared on an equivalent basis. (See sec. 2.1.2.2.) The factors are computed for a range of discount rates and time, and are included as a statistical appendix in most engineering economics textbooks. (See for example, Grant and Ireson, *Principles of Engineering Economy*, pp. 594-627.)

[33] Executive Office of the President, Office of Management and Budget, Circular A-94, "Discount Rates to be used in Evaluating Time Distributed Costs and Benefits," March 27, 1972.

[34] This assumes that the internal rate of return is a continuous and decreasing function of the level of R&D investment.

[35] The same kind of problem exists with use of the benefit-cost ratio criterion to size projects, in that the more efficient sized project may have a lower ratio on the total investment than the less efficient sized project. This reflects the fact that the incremental ratio usually declines as the investment is expanded, the most efficient scale when there is no budget constraint being that for which the incremental ratio has declined to 1.0. It follows that the ratio on the overall investment declines as the investment is expanded toward the most efficient level. To avoid this problem, the net benefits measure is recommended for sizing projects.

The same problem may arise in using the internal rate-of-return criterion to select among other mutually exclusive projects.[36] That is, if applied to total costs and total benefits, rather than incremental costs and incremental benefits, it may result in the choice of a project with a higher internal rate of return, but with lower net benefits than the alternative projects. The net benefits criterion therefore is preferred to the internal rate-of-return method for this kind of decision.

For use in selecting among alternative, non-mutually exclusive projects, when the available R&D budget is limited, the rate-of-return criterion is comparable in effect to the benefit-cost ratio, both of which would generally[37] result in a valid ranking and both of which are recommended over the net benefits method. Alternative investments with rates of return larger than the minimum acceptable rate are ranked in order of their comparative rates, with the higher yielding projects preferred. For determining whether to accept or reject a given project, the calculated rate of return is compared with the investor's minimum acceptable rate of return to determine if the project's rate of return is higher.

The major criticism of the internal rate-of-return method is that it is subject to a possible problem in computation. Namely, there may be either no rate-of-return solution or multiple solutions under certain circumstances.[38]

2.2.3 Payback

A popular measure of an investment's desirability is its payback period, known variously as the payout, payoff, recovery, or break-even period. This is the measure of the number of years (or other unit of time) required for the invested capital to be offset by the resulting yearly net benefits.[39]

[36] Recall that it is assumed that the mutually exclusive situation is restricted to the selection of one project from alternative potential substitute projects and does not take into account the possibility of other projects which might compete with the group of mutually exclusive projects.

[37] The validity of rankings is qualified because of the possibility of computational problems with the internal rate-of-return as described in the last paragraph of this section, and because of the benefit-cost ratio may vary depending on whether certain effects are treated as a benefit (numerator of the ratio) or as a negative cost (denominator of the ratio).

[38] Multiple solutions may result because the internal rate-of-return is in essence the solution to a polynomial equation, which if of degree n, will have n roots, i.e., n solution rates. An example of a type of investment which gives rise to multiple solutions is one characterized by a net benefits stream which is first negative, then positive, and finally negative again.

[39] For an in-depth treatment of the payback criterion, see Grant and Ireson, *Engineering Economy: Analysis of Capital Expenditures,* pp. 347, 528-529; Educational Facilities Laboratories, *The Economy of Energy Conservation in Educational Facilities* (New York: EFL, Inc., 1973), pp. 67-68.

Although the payback measure may provide useful information for evaluating an investment, it has shortcomings as a general criterion of economic efficiency, both from the standpoint of sizing a project and of choosing among alternative projects. The shortcomings stem from two sources: (1) problems in the method of calculation which is popularly used, and (2) conceptual limitations of the measure.

The popular method of calculating payback is to relate the average yearly net inflow of cash to the first cost of the investment, on a before-tax basis and neglecting the opportunity cost of capital (and often, other items of costs). This "short-cut" version of payback is called "simple" payback method, and it may be expressed as follows:

$$\underset{\text{(in years)}}{\text{Payback Period}} = \frac{\text{First Cost}}{\begin{array}{c}\text{Average Yearly Benefits}\\ \text{Minus Average Yearly Costs}\end{array}}. \quad (2.2)$$

Using this approach, for example, the payback period for an investment of $1,000,000 in R&D for an improved fire detection system, which is expected to save 200 users $500 per year each in net operating costs, would be calculated as follows:

$$\text{Payback Period} = \frac{\$1{,}000{,}000}{200 \times \$500} = 10 \text{ years.}$$

But the payback period when calculated in this manner is the number of years required for the net before-tax cash flow from a project to equal zero, when the opportunity cost of capital is 0%. For any positive opportunity cost, this method of calculation does not correctly indicate the period of time before costs will be recovered. For example, if an opportunity cost of money of 10% were taken into account, the investment to develop the improved fire detection system would never recover the investment.

A second problem in using a simple payback measure is that the method fails to distinguish between projects with benefit and cost streams which vary over time. For example, let us examine projects A and B described in table 2.2. Both require a first cost of $20,000, but the benefit streams for A and B differ. Although they cost the same and yield the same in undiscounted terms (i.e., their simple payback period is the same), B has a higher present value of net benefits ($1,525, evaluated with a 10% discount rate) than A ($698, evaluated with a 10% discount rate) because of its larger return in the first year.

Table 2.2 ILLUSTRATION OF A SHORTCOMING OF SIMPLE PAYBACK

Projects	First Cost ($)	Benefits ($) Year 1	Year 2	Year 3	Payback in Years	Present Value Net Benefit[a] ($)
A	20,000	5,000	15,000	5,000	2.4	698
B	20,000	15,000	5,000	5,000	2.4	1,525

[a] The present value of net benefits is calculated by finding the total present value of benefits discounted at a 10% discount rate and subtracting first costs from the total.

The shortcomings that result from failure to discount costs can be overcome simply by using a more comprehensive calculation method, called "discounted" payback. This method finds the number of years, R, for which the following equality holds:

$$C = \sum_{j=1}^{R} \frac{B_j - P_j}{(1+i)_j}, \tag{2.3}$$

where

C = initial investment cost,

B_j = benefits in year j,

P_j = costs in year j,

R = break-even number of years, and

i = discount rate.

Where yearly net benefits are uneven, an iterative process can be used to determine the solution. If, on the other hand, yearly net benefits (M) are expected to be about uniform, the following formula can be used to facilitate the calculation:

$$R = \frac{-\log\left(1 - \frac{iC}{M}\right)}{\log(1+i)}. \tag{2.4}$$

The conceptual limitations of the payback measure persist, however, regardless of the method of computation. The chief problem is that the measure does not include costs and benefits beyond the payback year, and, therefore, does not measure the efficiency of an investment over its life. It is often argued that payback does provide an adequate measure of efficiency, in that the analyst can compare the payback period with the expected life of the investment to determine how far beyond the payback time the investment will continue to yield net benefits, and to some extent this is true. However, the subjective element of this procedure often makes it inadequate for comparing the relative efficiency of alternative investments with differing lives and/or differing flows of net benefits. Thus, the other evaluation methods—net benefits, benefit-cost ratio, or internal rate of return—are preferred to the payback method for most economic evaluations of R&D investments.[40]

Despite its limitations, the payback method is useful for evaluating investments under two situations: (1) A rapid payback may be a prime criterion for judging an investment when financial resources are available to the investor for only a short period of time before repayment is required, as would be the case with the speculative investor. (2) Where the expected life of the assests is highly uncertain, determination of the break-even life, i.e., payback period, is helpful in assessing the likelihood of achieving a successful investment.

The first situation appears more relevant to private firms than to government agencies. The second may be relevant to both.

Provided there are no major costs occurring after the time of payback, the discounted payback measure can be used as a rough indicator of cost effectiveness. The measure is not, however, reliable for choosing the most efficient projects from a set of alternatives, although it may provide critical information for project selection when investment funds must be repaid or asset life is very uncertain.

The payback measure seems to be given undue emphasis by both government agencies and private firms, with decision makers preferring very short payback periods. Although giving preference to projects with relatively short paybacks may provide some guarantee of breaking even, it may also lead to a succession of less efficient, short-lived projects.

[40] Myron Gordon has demonstrated that the internal rate of return is the reciprocal of the payback period when an investment earns the same amount indefinitely, and for shorter project lives, that the difference is negligible over a wide range of lives. See Myron J. Gordon, "The Payoff Period and the Rate of Profit," *The Journal of Business*, XXVIII (October, 1955), p. 254.

2.2.4 Summary of Methods

In section 2.2 we have examined three selected methods—benefit-analysis cost (including both net benefits and benefit-cost measures), internal rate of return, and payback analysis. Each of these methods can be applied by a government, university, or firm to evaluate the economic feasibility of R&D investments from the particular viewpoint of that institution. A decision maker might employ these methods to determine if a specific R&D investment is economic to undertake, what level of resources should be allocated to that R&D project (i.e., what scale of investment should be made), and what set of R&D projects should be undertaken from multiple investment opportunities given budget and other constraints.

Each of the methods described generally can be used to decide whether to accept or reject a given project. For other types of investment decisions, however, there are often advantages to using a particular method. The efficient sizing of a specific R&D project and the selection of a project from mutually exclusive alternatives, for example, are decisions best determined by the net benefits method. The choice of projects from among project alternatives that are not mutually exclusive, on the other hand, is guided best by use of either the benefit/cost ratio or the internal rate-of-return method when there is a budget constraint. When the required time for recovering investment funds is critical and/or the life of major project assets is uncertain, the discounted payback method can provide a valuable supplementary measure for both sizing projects and choosing among alternative projects.

Measurements of benefits and costs are required for all of the methods. Collecting sufficiently complete and accurate historical data, along with predicting sufficiently complete and accurate future values, are crucial elements in the application of any of the methods.

A problem common to all of the evaluation measures is the uncertainty surrounding benefit and cost predictions. Although the formulas for the various methods are conceptually correct and generally easy to use, there is considerable uncertainty regarding the values substituted into the formulas. One approach frequently employed is sensitivity analysis, wherein different values of key parameters (such as discount rates, product life, process, and costs) are substituted into the formulas to determine economic payoffs under different conditions. A second approach is to employ mathematical techniques to predict expected values of benefits and costs. If some historical data base exists for constructing a probability distribution, more confidence generally can be placed in these expected values than in single point estimates.

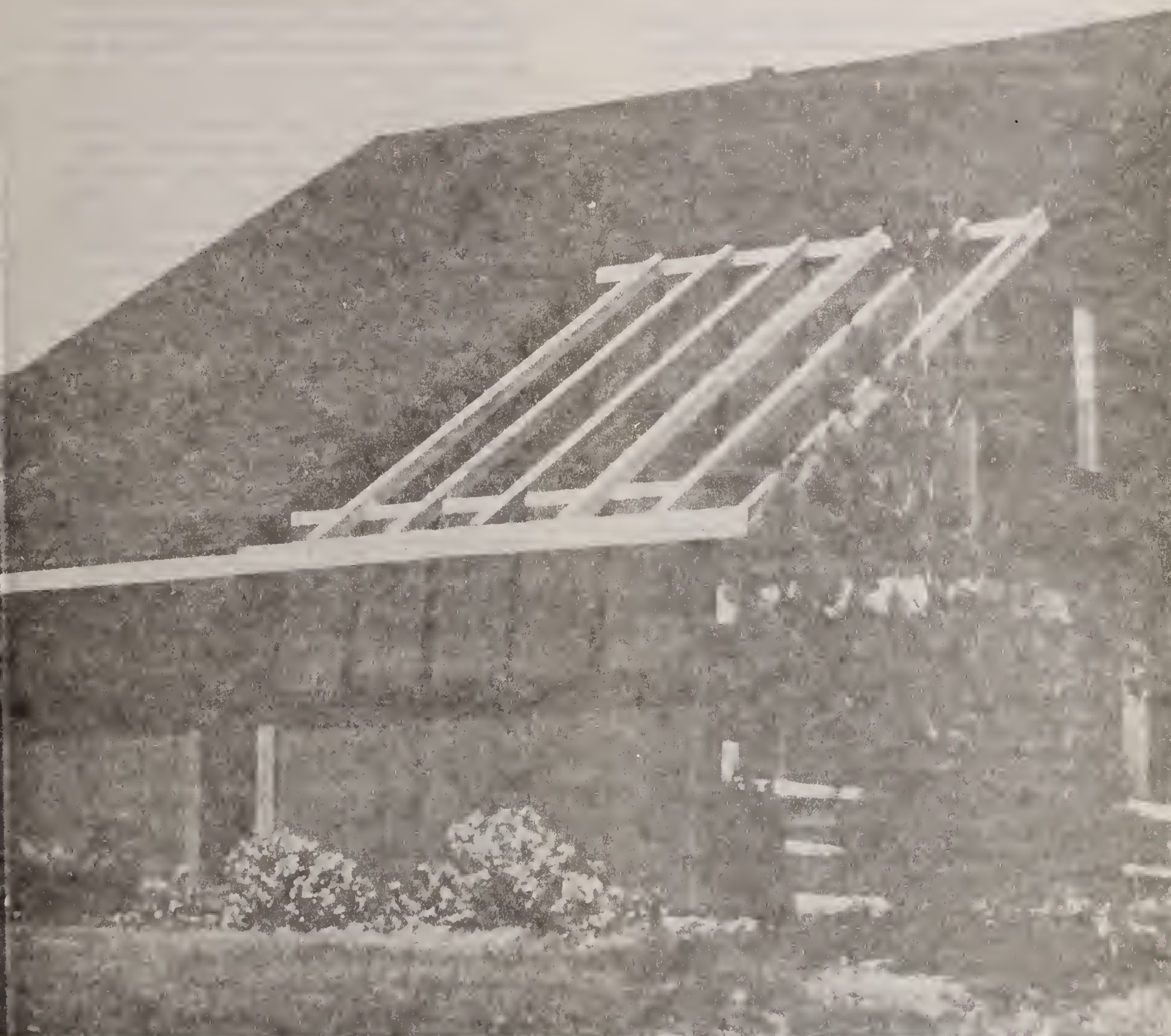
The following case studies in sections 3 and 4 demonstrate not only how to use some of the methods outlined above, but illustrate pragmatic approaches to measuring benefits and costs as well. Both case studies are evaluations of actual research projects which were carried on in the Center for Building Technology (CBT). The first project measures the benefits and costs of developing an improved asphalt shingle for sloped roofing; the second measures the benefits and costs of introducing an innovative sanitary drainage venting system called reduced-size venting, which can be substituted for conventional venting systems in houses.

Two case illustrations are given to demonstrate how to measure impacts under different conditions. The shingles case study describes a building innovation that was voluntarily implemented, took place in the past, and that had some historical data available for analysis. The reduced-size venting case, on the other hand, describes a new building technology that is just being introduced, whose benefits will be accruing in the future, and for which there are no real data for analysis. Measures of both kinds of impacts—those that have accrued in the past and those expected to accrue in the future—are needed to improve resource allocations for R&D.

These particular two cases were selected for study because data were available regarding their research costs and because their benefits were thought to be measurable. The purpose here was to illustrate the techniques and not to make any claims about the "goodness" or "badness" of research investments. No inference can be drawn that all research by the Center for Building Technology has the kind of payoffs described for these two case examples. On the other hand, no claim is made that these two cases are typical or atypical. They serve simply to illustrate the application of the techniques described earlier.

Facing page:

This house has a sloped roof with shingles of the type evaluated in this section.



3. CASE STUDY: 235 SHINGLES[41]

3.1 BACKGROUND

Over 80% of the sloped roofs in the United States are covered with asphalt shingles, and expenditures for these shingles amount to many millions of dollars yearly. Prior to 1962 the type of shingle in predominant use weighed approximately 210 lbs/100 ft^2 (95.3 kg/9.3 m^2) when in place on the roof; consequently this type of shingle is usually referred to as the 210 shingle. The relatively light weight of the 210 shingle contributed to a type of failure called "clawing," which resulted from moisture absorption by the reinforcing organic felt. Clawing led to the need for frequent replacement. The expected life of 210 shingles was approximately 10 years. However, in hot climates their life was sometimes less than 9 years, and it was common for the shingles to fail due to clawing after only 2 to 4 years of exposure. The poor durability was a serious and costly problem not only for homeowners and businesses across the nation, but also for the armed services which use asphalt shingles extensively at military bases.

---

[41] Special thanks are due Robert Mathey, from the Building Composites Program of CBT, who provided assistance and data on roofing shingles.

In face of the premature failure and attendant costs and inconvenience, the Tri Services (a joint organization of the U.S. Army, Navy, and Air Force) asked CBT to investigate ways of solving the problem. In response, CBT carried out field investigations on Federal installations to identify the reasons for the premature failure of 210 shingles; led the development of specifications for a heavier, more durable asphalt shingle; and conducted outdoor exposure studies to validate the new specifications. In addition, CBT staff coordinated work among the various interested parties and promoted the early acceptance of the standards on a voluntary basis.

As a result of its studies, CBT recommended that shingle felts be better saturated so that they contain more asphalt and that the coating on the back of the shingle be significantly increased. Tests showed that greater saturation of the felt and a thicker asphalt coating would provide more protection from moisture penetration into the organic reinforcing felt.

These recommendations were subsequently adopted by the roofing industry. The result was a heavier shingle, weighing approximately 235 lbs/100 ft^2 (106.6 kg/9.3 m^2) in place,[42] and generally referred to as the 235 shingle. By about 1962, the 235 shingle began substantially to displace sales of the 210 shingle. The heavier shingle is not prone to the problem of moisture penetration into the felts, nor the resultant clawing during the expected service life. Consequently, the 235 shingle generally lasts at least 15 years in hot climates and 20 or more years in cooler climates; that is, 5 or more years longer than the 210 shingles. With its longer life, it reduces the frequency and costs of replacement. Approximately 98% of the shingles now used are of the 235 type or heavier types.

Even without CBT's contribution, it is likely that similar improvements would have eventually been made, and that by now most shingles would be of the improved type. However, CBT's research contributed to the development and acceptance of the voluntary industry shingle standard. In the opinion of roofing experts both in and outside of NBS, the availability and extensive use of 235 shingles would have been delayed from 2 to 5 years had it not been for CBT's participation in, and coordination of, the development of 235 shingles.[43]

[42] Minimum weight as given in ASTM Standard D225-65 (reappraised 1970) is 228 lbs/100 ft^2 (103.4 kg/9.3 m^2). American Society for Testing and Materials, *Annual Book of ASTM Standards,* Part 15, Philadelphia, 1974.

[43] According to Harold Whittemore, Managing Director of the Asphalt Roofing Manufacturers Association, CBT's leadership was "absolutely necessary and most essential" in promoting the 235 shingle, and sped up the adoption of 235 shingles by at least "several years."

The price of the various types of similar asphalt roofing shingles generally varies proportionately to their weight. This price relationship reflects the fact that similar type shingles undergo essentially the same production processes, but heavier shingles consume more materials. Thus, the 235 shingle costs more than the 210 shingle. The price per sales square[44] of 235 shingles is about $15 for materials and $20 for labor for the initial installation.[45] The price per sales square of 210 shingles is about $13.40 for materials (i.e., $(210/235) \times \$15 = \$13.40$) and $20 for labor for the initial installation (i.e., the same as for the 235 shingles).[46]

3.2 APPROACH

In this case study, benefit-cost and internal rate-of-return methodologies are used first to measure the social payoff of substituting 235 shingles for 210 shingles, and secondly, to evaluate the efficiency of CBT's investment in the development and implementation of 235 shingles. The evaluations are aimed only at determining the presence or absence of net benefits and positive returns, and does not attempt to determine the optimal investment size, nor to compare the payoffs from these projects with the expected returns on other potential uses of society's or CBT's funds.

As was explained above, the 235 shingle costs more to purchase than the 210 shingle; however, the 235 shingle gives greater service life than the 210 shingle. Both types of shingles give essentially the same performance up until their required replacement. Since it is not obvious which shingle actually costs more per unit of time over its life, the first step in the evaluation is to measure and compare the life-cycle costs of the two types of shingles to determine if, and in what amount, the 235 shingle results in cost savings to the owner of a building on which it is applied.

Total cumulative cost savings attributable to the 235 shingle will be taken as a measure of the gross benefits to society. This approach is consistent with the graphical model of consumers' surplus illustrated in

[44] A sales square—the customary unit by which shingles are sold—is the quantity of shingles needed to cover 100 ft^2 (9.3 m^2) of roofing surface.

[45] The $15 and $20 figures were the approximate costs (ignoring regional differences) of 235 shingles in 1974.

[46] At the time of the second replacement of shingles, it is generally necessary to remove the old shingles before installing the new. Thus the labor cost for the second replacement is usually greater than $20 per sales square. With its need to be replaced more often, the 210 shingle would require more "second replacements" and, hence, a higher average labor cost per installation than would the 235 shingle. This difference is not taken into account in this cost evaluation. Thus the cost savings estimated here will be biased downward from the true values.

figure 2.6 and slightly altered in figure 3.1. The objective of the shingles case study is to measure the dollar value of P_2RZP_1. This is thought to be a fairly accurate measure of social benefits for the following reasons. First, no innovator profits are included because the government cannot reap such profits. Thus, the area below S_2 labeled profits in figure 2.6 is not shown in figure 3.1. Second, consumers' surplus (P_2RTP_1) resulting from the new technology is thought to be close in dollar value to P_2RZP_1. This is due to the fact that the quantity demanded of shingles is expected to remain about the same whether they are 235 or 210 shingles. That is, the total market for shingles during the study period is expected to vary little with the substitution of the heavier shingle.

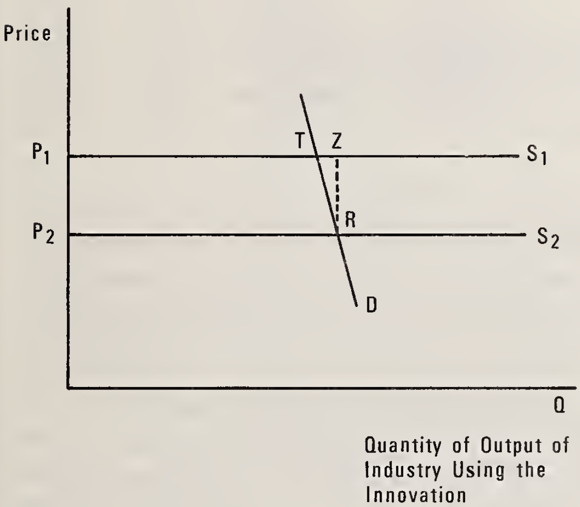


FIGURE 3.1 *Consumers' surplus measure of benefits for 235 shingles.*

This is illustrated by the relatively inelastic (almost straight up and down) demand function in figure 3.1. As the area RZT shrinks, the P_2RZP_1 measure becomes a closer approximation to consumers' surplus, P_2RTP_1. Finally, the price difference (P_1–P_2) between the 235 and 210 shingles is assumed to be the difference in life-cycle costs between the two shingles. Thus multiplying the life-cycle cost differences between the two shingles times the quantity sold would yield P_2RZP_1 as the estimate of social net benefits from the 235 shingles innovation. Total cumulative net benefits of the shingle will be found by subtracting from its gross benefits the total costs of implementing the new shingle. These costs consist of research, development, and dissemination-of-information costs incurred by CBT as well as by other groups with which CBT coordinated its research efforts.[47] The gross benefits to society from CBT participation will be considered as the difference in total gross benefits estimated with and without CBT participation.

Net benefits of CBT will be derived by subtracting CBT costs from gross benefits of CBT participation. In addition, internal rates of return on investment will be calculated, both for society's extra expenditures for purchasing 235 rather than 210 shingles, and for CBT's research investment costs.

Measurement of the impacts of the 235 shingle are based on the period from 1962, when extensive use began, to 1974. Any benefits or costs occurring after 1974 are not taken into account. All costs and benefits are brought forward in time to 1974 dollars.

3.3 GROSS BENEFITS OF 235 SHINGLES

The first step in the evaluation is to compare life-cycle costs of the two types of shingles in order to identify any cost savings (benefits) to consumers of one over the other. Ultimately the objective of the evaluation is to determine if the additional $1.60 which consumers must pay in order to obtain a sales square of shingles with 5 more years of life is a worthwhile investment.[48] By computing life-cycle costs in terms of the annual costs of a unit of each type of shingle and then comparing them, the annual per unit savings of a 235 over a 210 shingle can be derived. The measure of annual savings per unit of shingle is necessary to calculate the value of the expected stream of savings which will accrue to consumers over the 13-year period from the quantity of shingles sold in each of the 13 years. These 13 streams of annual savings are discounted to present value and summed in order to obtain a measure of total present value savings from substituting 235 for 210 shingles over the period 1962 through 1974.

Table 3.1 shows in three parts the computation of annual cost savings from 235 shingles. Part I of table 3.1 shows the calculation of the annual cost of one sales square of 235 shingles. This calculation is based on the assumptions of a combined purchase and installation cost of $35 per sales square, a 15-year life, continuous replacement of the roof (see footnote a, table 3.1 for a discussion of this assumption), and a

---

[47] Other groups that carried out research on and development of the 235 shingle were the Underwriters Laboratories, the ASTM Committee D8, and the Asphalt Roofing Industry Bureau (now known as the Asphalt Roofing Manufacturers Association) and its member companies.

[48] The analysis assumes that the prices of other goods are unaffected by the introduction of 235 shingles, and the gross benefits are assumed to be the shingle cost savings accruing exclusively to shingle consumers.

Table 3.1 CALCULATION OF ANNUAL COST SAVINGS (ACS) TO CONSUMERS FROM SUBSTITUTING A UNIT OF 235 SHINGLES FOR A UNIT OF 210 SHINGLES

I. Calculation of Uniform Annual Cost Per Sales Square of 235 Shingles (AC_{235}), Assuming 15-Year life, Continuous Roof Replacement, and a 10% Discount Rate:[a]

$$
\begin{aligned}
AC_{235} &= (L_{235} + M_{235}) \quad (\text{UCR}, i=.10, N=15 \text{ yrs.}) \\
&= (\$20 + \$15) \quad (.1315) \\
&= \$4.603/\text{SQ}
\end{aligned}
$$

II. Calculation of Uniform Annual Cost Per Sales Square of 210 Shingles (AC_{210}), Assuming a 10-Year life, Continuous Roof Replacements, and a 10% Discount Rate:[a]

$$
\begin{aligned}
AC_{210} &= (L_{210} + M_{210}) \quad (\text{UCR}, i=.10, N=10 \text{ yrs.}) \\
&= (\$20 + \$13.40) \quad (.1628) \\
&= \$5.438/\text{SQ}
\end{aligned}
$$

III. Calculation of Uniform Annual Cost Savings Per Sales Square (ACS_{235}) of Substituting 235 Shingles for 210 Shingles, where $ACS_{235}=AC_{210}-AC_{235}$.

$$
\begin{aligned}
ACS_{235} &= \$5.438/\text{SQ} - \$4.603/\text{SQ} \\
&= \$.835/\text{SQ}
\end{aligned}
$$

---

[a] The formula to calculate the annual cost of one sales square of type k shingles, assuming continuous roof replacements, is

$$AC_k = (L_k + M_k)\frac{i(1+i)^N}{(1+i)^N - 1},$$

where

L_k = labor cost of installing one sales square of type k shingles in 1974 dollars,

M_k = materials cost of one sales square of type k shingles, in 1974 dollars,

i = real discount rate,

N = life of type k shingles, in years, and

$\frac{i(1+i)^N}{(1+i)^N - 1}$ = uniform capital recovery formula.

Note: Rather than continuous replacement, roofing will actually be replaced only as long as the building lasts. If shingle life does not divide building life evenly, i.e., if all of the shingle value is not consumed by the end of use of a building, the annual cost of the shingles will be sensitive to the assumption of continuous replacement versus limited replacement. Annual costs will differ because the salvage value of shingles at the end of building life is generally zero regardless of the "otherwise" remaining life of the shingles. But if shingle life does divide building life evenly, as, for example, in the case of a 30-year building life and 10- and 15-year shingle lives, the annual cost results will be the same regardless of whether continuous replacement or a limited number of years is assumed. Annual costs are here based on continuous replacement, because the choice of building life is somewhat arbitrary and may bias the costs of one shingle type relative to the other, depending on which shingle type the assumed building life corresponds to more closely. For example, a building life of 40 years would favor the 210 shingles, since the fourth installation would be exactly consumed and no life would be lost. On the other hand, building life of 45 years would favor the 235 shingle, since three shingle installations would exactly match building life.

Table 3.2 PRESENT VALUE SAVINGS TO CONSUMERS FROM 235 SHINGLES

Year	235 as % of total shingles[a]	Quantity of total shingles[b]	Quantity of 235 shingles[c]	Annual cost savings/SQ[d] ($)	Annual cost savings/batch[e] ($)	Factors[f]	Present value of annual cost savings[g] ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1962	50	36,606,003	18,303,001	0.835	15,283,005	24.52	374,739,400
1963	60	36,077,904	21,646,742	0.835	18,075,029	21.38	886,444,140
1964	80	40,162,409	32,129,927	0.835	26,828,489	18.53	497,131,910
1965	95	39,748,439	37,808,517	0.835	31,570,111	15.94	503,227,550
1966	95	36,830,053	34,988,550	0.835	29,215,439	13.58	396,745,670
1967	96	42,037,640	40,356,134	0.835	33,697,371	11.44	385,497,910
1968	97	43,306,669	42,007,468	0.835	35,076,235	9.487	332,768,280
1969	97	46,208,524	44,822,268	0.835	37,426,593	7.716	288,783,560
1970	98	45,488,916	44,579,137	0.835	37,223,579	6.105	227,249,950
1971	98	54,588,430	53,496,661	0.835	44,669,711	4.641	207,312,120
1972	98	58,518,259	57,347,893	0.835	47,885,490	3.310	158,500,970
1973	98	63,419,600	62,151,208	0.835	51,896,258	2.100	108,982,140
1974	98	65,956,384	64,637,256	0.835	53,972,108	1.000	53,972,108
						Total present value savings =	$3,921,355,708[h]

[a] Estimated on basis of information provided by the roofing industry.

[b] Total quantity of shingles having a base of dry felt or other organic binder produced in each year. In absence of sales data, it is assumed that the quantity produced is equal to the quantity purchased. The unit of measure is the "sales square" (SQ); i.e., a quantity of shingles sufficient to cover 100 ft^2 ($9.3m^2$) of roof area.

[c] Col. 4=Col. 2×Col. 3. Quantity is stated in number of units of squares sold.

[d] Annual cost savings per sales square as derived in table 3.1.

[e] Col. 6=Col. 4×Col. 5. This is the annual cost savings attributable to each year's production (i.e., batch) of 235 shingles.

[f] Uniform compound amount (UCA) factors computed from the uniform compound amount formula, $(1+i)^N-1$, for a discount rate of 10%. This formula can be used to convert an annual stream of past values to the present.

[g] Col. 8=Col. 6×Col. 7.

[h] No rounding of intermediate results was performed in this and subsequent tables to avoid unnecessary rounding errors.

10% real rate of discount—the rate recommended by OMB for evaluating government investments.[49] The resulting annual cost of 235 shingles is shown to be $4.603 per sales square.

Part II of table 3.1 shows the calculation of the annual cost per sales square of 210 shingles, based on a combined purchase and installation cost of $33.40 per sales square, a 10-year life, continuous roof replacement, and a 10% discount rate. The annual cost of 210 shingles is shown to be $5.438 per sales square.

Part III of table 3.1 derives the annual cost savings (benefits) per sales square of 235 shingles by subtracting the annual cost per square of 235 shingles from the cost of 210 shingles. Annual savings from using 235 instead of 210 shingles are $.835 per sales square.

[49] Executive Office of the President, Circular No. A-94.

The subsequent steps in the estimation of gross benefits from 235 shingles are shown in table 3.2. First, the quantity of 235 shingles purchased each year from 1962 through 1974 (column 4) is estimated by multiplying the estimated percentages of total shingle production comprised of 235 shingles in each year (column 2) times the total number of shingles produced in each year (column 3). (In absence of purchase data, the quantity of shingles produced is used as a proxy for the quantity purchased and applied to roofs.)

Next, the annual savings resulting from the 235 shingles purchased in each year (column 6) are calculated by multiplying annual savings per square (column 5) by the yearly quantity of 235 squares (column 4). For example, the 18.3 million squares of 235 shingles sold in 1962, yielding an annual savings of $.835 each, result in total annual savings equivalent to $15.3 million (in 1974 dollars). This is the amount of savings which accrue in each of the 13 years over the evaluation period 1962 through 1974, as a result of the use of the 18.3 million squares of 235 shingles in place of the same quantity of 210 shingles. The 62.2 million squares sold in 1973, also yielding an annual savings of $.835 each, are estimated to save a total of $51.9 million annually. The $51.9 million in annual savings from these shingles will accrue only during 1973 and 1974, the last 2 years of the evaluation period.

The final step is to convert each stream of annual savings to a present value equivalent (column 8). This is done by applying the uniform compound amount factors (column 7) to the annual cost savings (column 6). The uniform compound amount factors—or the uniform compound amount formula, from which the factors are derived—are appropriate for converting a stream of past annual values to the present, which is the case here. For example, the 18.3 million squares of 235 shingles sold in 1962 yield a total present value savings of $374.7 million over the 13 years.

By summing the present value savings associated with each year's consumption of 235 shingles, we arrive at an estimate of total present value savings (gross benefits) for the 13-year period. It totals nearly $4 billion. This large sum is not too surprising given that millions of squares of 235 shingles are sold each year, and that each square is expected to reduce roofing costs by almost $1.00 annually.

3.4 BENEFITS OF CBT ACTIVITIES

To estimate the gross benefits from CBT research activities, we compare the total present value savings to the consumer over the 13-year evaluation period, with and without CBT involvement. To do this, present value savings from 235 shingles are reestimated, assuming CBT had not been involved. It is assumed that CBT's work with 235 shingles speeded up their application by 3 years. This assumption takes approximately the middle value of our best guess that CBT speeded up the development and use of 235 shingles by 2 to 5 years. Hence, to take into account the lack of CBT influence, the level of production (hence consumption) of 235 shingles is lagged by 3 years. Table 3.3 shows the derivation of total consumer savings from 235 shingles assuming no CBT involvement. Table 3.4 takes the difference between tables 3.2 and 3.3 and shows that the present value of additional

Table 3.3 PRESENT VALUE SAVINGS TO CONSUMERS FROM 235 SHINGLES WITHOUT CBT INVOLVEMENT[a]

Year	235 as % of total shingles, without CBT	Quantity of 235, without CBT	Annual cost savings/SQ ($)	Annual cost savings per batch, without CBT ($)	UCA factors	Present value of annual cost savings, without CBT ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1962-1964	0	0	0	0	--	--
1965	50	19,899,219	0.835	16,615,847	15.94	264,856,640
1966	60	22,098,031	0.835	18,451,855	13.58	250,576,250
1967	80	33,630,112	0.835	28,081,143	11.44	321,248,240
1968	95	41,141,335	0.835	34,353,014	9.487	325,907,000
1969	95	43,898,097	0.835	36,654,910	7.716	282,829,280
1970	96	43,669,359	0.835	36,463,914	6.105	222,612,170
1971	97	52,950,777	0.835	44,213,898	4.641	205,196,700
1972	97	56,762,711	0.835	47,396,863	3.310	156,883,600
1973	98	62,151,208	0.835	51,896,258	2.100	108,982,140
1974	98	64,637,256	0.835	53,972,108	1.000	53,972,108
				Total present value savings, without CBT =		$2,193,064,128

[a] Present value savings in this table are computed exactly as they were in table 3.2, with one exception. It is assumed that without CBT involvement, the quantity of 235 shingles prior to 1965 would have been negligible, and that beginning in 1965 the percentage of the market given each year to 235 shingles would have paralleled that for the period 1962 to 1971 with CBT involvement.

Table 3.4 **PRESENT VALUE SAVINGS TO CONSUMERS FROM 235 SHINGLES DUE TO CBT INVOLVEMENT**

Present value savings from 235 shingles =	$3,921,355,708
(minus)	
Present value savings from 235 shingles without CBT involvement =	$2,193,064,128
(equals)	
Present value savings attributable to CBT involvement =	$1,728,291,580

consumer savings due to CBT involvement are estimated to be about $1.7 billion.

To calculate net benefits to society of 235 shingles, the estimated total present value costs of introducing 235 shingles are deducted from the estimated total consumer benefits of the shingles. To calculate net benefits of CBT's activities, the present value costs of CBT's activities are deducted from these estimated consumer savings attributable to CBT activities.

Most research on 235 shingles, by CBT and other organizations, occurred between 1958 and 1960. Expenditure on research by CBT amounted to between $15,000 and $20,000 during this period. Other organizations are estimated to have spent between $50,000 and $100,000 over the same period. (Although other groups spent more than CBT, it may be recalled that CBT played a key role, in that it led the development of the new standards, coordinated work of the different groups, and promoted acceptance of the standards.)

Converting these amounts to equivalent 1974 dollars requires taking into account not only the time value of money by discounting, but also the effect of inflation.[50] These two operations may be accomplished by first applying consumer price indices to the expenditures incurred between 1958 and 1960, to express the expenditures in 1974 dollars, and then applying the single compound amount discount factor to bring the values forward in time.[51] Adjusted for inflation and expressed in present value terms, the costs of research on 235 shingles amounts to a total of $853,610, of which $142,267 is attributable to CBT, and $711,343 to other organizations.

Table 3.5 derives estimated net benefits by subtracting costs from gross benefits. The net benefits to consumers from 235 shingles are estimated at $3.9 billion, and the additional net benefits to consumers as a result of CBT involvement, at $1.7 billion.[52]

3.5 SENSITIVITY ANALYSIS

Recognizing that the results of the evaluation may be sensitive to the particular assumptions which have been employed, we consider the effects of alternative assumptions regarding shingle life, the discount rate, and other key variables. Each assumption change is described in turn, and then the sensitivity of net benefits to the new value is illustrated in tables 3.6 and 3.7.

The realization of any benefits—in total or attributable to CBT—from the shingle research hinges on a lower life-cycle cost for the 235 shingles. Given that the selling price is higher for 235 shingles than for 210 shingles, that no important maintenance and operation costs are involved for either, and that performance during their service lives is essentially the same, the assumption of a longer service life for 235 is crucial to the findings of positive net benefits and positive rates of return on the investment (sec. 3.6). Therefore, let us first examine the assumption regarding shingle life.

The original estimates of benefits were based on a life advantage of 5 years for the 235 shingles. To find out how much advantage in service life is required to make the life-cycle costs of 235 shingles lower than 210 shingles, the break-even life of 235 shingles can be determined, given the life of 210 shingles. By break-even life we mean that service life of 235 shingles for which life-cycle costs would be equivalent for the two types of shingles. Based on a 10-year life for 210 shingles and a discount rate of 10%, the break-even point was found to occur between 10 3/4 and 11

[50] In converting the annual cost savings to present value terms, as was done in table 3.2, it was not necessary to adjust for inflation, because annual cost savings were stated in 1974 dollars at the outset. Here, however, research expenditures are expressed in 1958-1960 dollars.

[51] To simplify the calculations, it is assumed that all costs were incurred in 1959. To avoid possible understatement of costs, the upper end of the estimated range of expenditures is used. Application of a consumer price index to convert the 1959 costs to 1974 dollars yields $34,060 in costs for CBT and $170,300 in costs for other groups. Multiplying the single compound amount factor, 4.177, by each cost figure yields $142,267 and $711,343, respectively.

[52] Other impacts that might be of interest, such as employment effects and excess profits to some shingle producers, are not treated in this analysis.

Table 3.5 CALCULATION OF NET BENEFITS

A. 235 Net Benefits	
Present value cost savings of 235 shingles =	$3,291,355,708
(minus)	
Present value costs of introducing 235 shingles =	853,610
(equals)	
Present value net benefits of 235 shingles =	$3,920,502,098
B. CBT Net Benefits	
Present value cost savings attributable to CBT = involvement	$1,728,291,580
(minus)	
Present value costs of CBT activities =	142,267
(equals)	
Present value net benefits of CBT involvement =	$1,728,149,313

years. This means that 235 shingles need last not even a full year longer than 210 shingles in order to justify their additional purchase price; furthermore, for any additional life beyond this point they would yield benefits in the form of reduced life-cycle roofing costs. We conclude that the probability of positive gross benefits from 235 shingles is quite high given the very small life advantage required to make them cost-effective, and the fact that 235 shingles often last considerably more than 5 years longer than 210 shingles. Nevertheless, for a more conservative evaluation, we will reestimate present value benefits based on the assumption of only a 2-year life advantage of 235 shingles.

It does not appear necessary to test for sensitivity to the assumed volume of 235 shingles. Since 235 shingles have been in widespread use for a number of years, there is some confidence in the general magnitude of the estimates of quantities of 235 shingles. These estimates are based on actual reports of the annual volumes of total shingle production, and on assessments of the shingle market composition provided by experts in the roofing industry.

Given the uncertainty and controversy regarding the appropriate discount rate, it appears useful to re-evaluate benefits for an alternative discount rate.

The estimation of net benefits is affected by the choice of discount rates in two ways. First, the consumer's preference between a higher priced shingle with a longer life and a lower priced shingle with a shorter life depends upon the discount rate. As the discount rate is increased, the consumer's net benefit per unit of 235 shingle diminishes because he or she becomes increasingly sensitive to the higher first cost and finds the benefits of deferred shingle replacement relatively less attractive, For a discount rate greater than the internal rate of return (32.6% on 235 shingles as computed in sec. 3.6) the consumer will prefer the lower priced 210 shingle, other things equal.

Second, the choice of discount rates affects the conversion of past annual costs and annual benefits to present value equivalents. These amounts are compounded as they are brought forward; the larger the discount rate, the larger the present value of the past savings, and vice versa.

By raising the discount rate in the range from zero to around 32%, the result will be an increase in the estimate of the present value of net benefits, because the increasing effect of compounding past annual savings will more than offset the decreasing of annual cost savings per square. Since the chief concern in this section is not to overestimate net benefits, we reevaluate gross benefits for a very low discount rate of 2%.

The least certain of the assumptions is the length of the lag in acceptance of 235 shingles without CBT involvement, although there is substantial evidence that CBT speeded the adoption of 235 shingles by at least several years. Again, to provide a conservative lower bound estimate of net benefits, we recalculate benefits assuming that CBT's effect was to speed adoption of 235 shingles by only 1 year instead of the originally assumed 3 years.

Table 3.6 SENSITIVITY ANALYSIS: LOWER BOUND ESTIMATE OF PRESENT VALUE BENEFITS FROM 235 SHINGLES[a]

Year	235 as % of total shingles[b]	Quantity of total shingles[b]	Quantity of 235[b]	Annual cost savings/SQ[c] ($)	Annual cost savings/batch[d] ($)	Factors[e]	Present value of annual cost savings[f] ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1962	50	36,606,003	18,303,001	0.406	7,431,018	14.68	109,087,080
1963	60	36,077,904	21,646,742	0.406	8,788,577	13.41	117,860,490
1964	80	40,162,409	32,129,927	0.406	13,044,750	12.17	158,757,650
1965	95	39,748,439	37,808,517	0.406	15,350,257	10.95	168,082,500
1966	95	36,830,053	34,988,550	0.406	14,205,351	9.755	138,569,770
1967	96	42,037,640	40,356,134	0.406	16,384,590	8.583	140,629,020
1968	97	43,306,669	42,007,468	0.406	17,055,032	7.434	126,786,870
1969	97	46,208,524	44,822,268	0.406	18,197,840	6.308	114,792,980
1970	98	45,488,916	44,579,137	0.406	18,099,129	5.204	94,187,196
1971	98	54,588,430	53,496,661	0.406	21,719,644	4.122	89,528,372
1972	98	58,518,259	57,347,893	0.406	23,283,244	3.060	71,245,980
1973	98	63,419,600	62,151,208	0.406	25,233,390	2.020	50,970,660
1974	98	65,956,384 (est.)	64,637,256	0.406	26,242,725	1.000	26,242,725
					Total present value savings =		$1,406,741,293

[a] Estimates are based on the new assumptions of a 2% discount rate, a 12-year life for 235 and a 10-year life for 210.

[b] These data are identical to those used in the original estimates (table 3.2).

[c] AC_{235}=$35 (the cost of purchasing and installing a sales square of 235 shingles)×.0946 (the uniform capital recovery factor for 12 years and 2%)=$3.311; AC_{210}=$33.40 (the cost of purchasing and installing a sales square of 210 shingles)×.1113 (the uniform capital recovery factor for 10 years and 2%)=$3.717; ACS_{235}=$3.717−$3.111=$0.406.

[d] Col. 6=Col. 4×Col. 5.

[e] Uniform compound amount factors for a discount rate of 2% and the number of years indicated by Column 1.

[f] Col. 8=Col. 6×Col. 7.

Tables 3.6 and 3.7 show re-estimated gross benefits based on the conservative set of assumptions outlined above: a 2-year life advantage for 235 shingles (12 years for 235 compared with 10 years for 210), a 2% discount rate, and a 1-year lag in the widespread use of 235 without CBT. (Other assumptions as to the quantity of 235 shingles and the labor and materials costs for both types of shingles are held constant.) Table 3.6 shows the new estimates of gross benefits from 235 shingles *per se,* and table 3.7, the estimates of what gross benefits would have been without CBT involvement. Under the new assumptions, present value gross benefits of shingles are reduced from $3.9 billion (table 3.5) to $1.4 billion, and present value gross benefits of CBT activities from $1.7 billion (table 3.5) to about $200 million (i.e., $1,407 million–$1,208 million). Despite this substantial decrease in estimated gross benefits, they remain impressive in amount.

From these results of the sensitivity analysis, together with the original estimates, we conclude that 235 shingles have had a tremendous impact on roofing costs, resulting in net savings of several billion dollars since their introduction in the early 1960's. We further conclude that CBT activities which promoted the development and use of 235 shingles were directly responsible for millions of dollars of the savings which resulted from lower roofing costs.

Table 3.7 SENSITIVITY ANALYSIS: LOWER BOUND ESTIMATE OF PRESENT VALUE BENEFITS FROM 235 SHINGLES WITHOUT CBT INVOLVEMENT[a]

Year	235 as % of total shingles, without CBT[b]	Quantity of 235, without CBT	Annual cost savings/SQ ($)	Annual cost savings per batch, without CBT ($)	UCA factors	Present value of annual cost savings, without CBT ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1962	0	0	0.406	0	--	0
1963	50	18,038,952	0.406	7,323,815	13.41	98,214,840
1964	60	24,097,445	0.406	9,783,563	12.17	119,071,280
1965	80	31,798,751	0.406	12,910,292	10.95	141,364,500
1966	95	34,988,550	0.406	14,205,351	9.755	138,569,770
1967	95	39,935,758	0.406	16,213,917	8.583	139,164,760
1968	96	41,574,402	0.406	16,879,207	7.434	125,478,480
1969	97	44,822,268	0.406	18,197,840	6.308	114,792,980
1970	97	44,124,248	0.406	17,914,444	5.204	93,224,456
1971	98	53,496,661	0.406	21,719,644	4.122	89,529,840
1972	98	57,347,893	0.406	23,283,244	3.060	71,245,980
1973	98	62,151,208	0.406	25,233,390	2.020	50,970,660
1974	98	64,637,256	0.406	26,242,725	1.000	26,242,725

Total present value savings, without CBT = $1,207,870,271

[a] Estimates are based on the new assumptions of a 2% discount rate, a 12-year life for 235 and a 10-year life for 210, and a lag of 1 year without CBT.

[b] Based on a lag of 1 year.

3.6 INTERNAL RATE OF RETURN ON 235 SHINGLES

Another measure of an investment's desirability, shown in section 2.2.2, is the internal rate of return. It is that compound rate of interest which equates the flow of costs of a project with the flow of benefits. The higher the rate, the larger the net beneficial yield from the investment.

To evaluate with this method the social impact from the improvement in shingles, we calculate the rate of return on the additional investment of $1.60 per sales square of 235 shingles that is paid by the consumer to obtain the additional 5 years of shingle life.[53] Using a process of trial and error, as shown in table 3.8, the rate of return is found to be between 30% and 35%, and by interpolation, it is narrowed to 32.6%.

Compared with other investment opportunities typically open to the consumer, a return of 32.6% appears quite high.

To evaluate CBT's investment in research by the rate-of-return method, we need to find the compound rate of interest which equates CBT's research costs with the benefits from that research, where benefits are measured as the additional savings accruing to consumers due to the earlier availability of improved shingles as a result of CBT research. As shown in table 3.9, the rate of return on CBT's investment is a substantial 70%.

Note that these returns are calculated on one investment—in this case one with a very favorable return. The return on the investment budget for a large R&D program with many projects could be expected to fall below these rates, since some projects are likely to fail completely and lower the average project return.

[53] In the preceding net-benefits evaluation of the value of the shingle investment to society, the total present value of research costs was deducted from the total present value of consumer cost savings to find net benefits to society. In contrast, the rate of return method, as used in table 3.8, evaluates the value of the investment to society solely in terms of a consumer's direct cost savings on one unit of 235 shingle. This discrepancy arises from a simplification in the calculation which, in any case, does not significantly affect the outcome. The rate of return is the same regardless of whether it is calculated on the basis of one unit of shingle or on the basis of the millions that were sold during the period in question. Including total research costs or excluding total research costs from the calculation in this example has a negligible effect on the outcome (the rate is reduced from the 32.6% derived in table 3.8 to 32.2% by including research costs) because the effect of the research costs is swamped by the consumer impact per se. In other evaluations, however, the research costs could be a significant factor and therefore should be included in the determination of the internal rate of return.

Table 3.8 CALCULATION OF THE INTERNAL RATE OF RETURN ON THE CONSUMER'S INVESTMENT IN 235 SHINGLES

Order of steps	Description of steps
1	Where benefits and costs are defined in terms of the *differences* in prices and lives of 235 and 210 shingles, we set net benefits equal to zero and solve for i, the internal rate of return on the investment: $33.40 (UCR,i,10 years)[a]–$35.00 (UCR,i,15 years)=0.
2	Using a trial and error procedure, we calculate net present value benefits for i=30%: $33.40 (.3235)–$35.00 (.3060)=$10.805–$10.710=$.095.
3	Finding positive net benefits for i=30%, we next make the same calculation for i=35%: $33.40 (.3683)–$35.00 (.3539)=$12.301–$12.387=–$.086.
4	Finding negative net benefits for i=35%, we know that the i for which net benefits are zero is bracketed by i=30% and i=35%.
5	By interpolation we now solve for i on the consumer's investment in 235 shingles: $i = 30 + \frac{.095}{.095 + .086}(.05)(100) = 32.6\%.$

[a] (UCR,i,n) is the notation for the uniform capital recovery discount factor, evaluated for a compound interest rate of i, over n years.

Table 3.9 CALCULATION OF THE INTERNAL RATE OF RETURN ON CBT'S INVESTMENT IN 235 SHINGLE RESEARCH

PROBLEM: We wish to find that compound rate of interest, designated i, which equates net benefits of CBT research to zero; i.e., the value of i in the following equation:

$$\sum_{j=1}^{N} B(j) \quad \frac{(1+i)^j - 1}{i} \quad - C(1+i)^y = 0,$$

where

B(j) = Annual consumer savings attributable to CBT from the batch of shingles consumed in year j, which, for the evaluation period 1962 (j=1) to 1974 (j=N), are as follows:[a]

1962	$15,283,005	1969	$771,683
1963	18,075,029	1970	759,665
1964	26,828,489	1971	455,813
1965	14,954,264	1972	488,627
1966	10,763,584	1973	0
1967	5,616,228	1974	0
1968	723,221		

N = 13 years, the number of years during which consumers purchased and consumed shingles; this is the benefits evaluation period.

C = $34,060, CBT's estimated research expenditure adjusted for price inflation, but not stated in present value equivalent.

y = 15 years, the number of years which have elapsed between CBT's research and the end of the period of evaluation.

$\frac{(1+i)^j-1}{i}$ = the uniform capital recovery discount formula used here to find the value in 1974 of annual savings which begin in the past and continue for j years, where j ranges from 1 to 13 and the annual savings are B(j).

$(1+i)^y$ = the single compound amount discount formula used here to find the value in 1974 of a single expenditure, C, made y years ago.

i = that discount rate for which present value benefits of the investment are just offset by present value costs, i.e., the internal rate of return on the investment.

SOLUTION[b]:

i = $.697 \times 100 = 69.7\%$, which can be rounded to 70%.

[a] Annual savings attributable to CBT per batch of shingles are calculated as the difference between estimated actual savings and estimated savings if widespread use had been delayed 3 years; i.e., column 6, table 3.2 minus column 5, table 3.3.

Note that these annual savings per batch are based on a savings per square of $.835, an amount which reflects an assumed opportunity cost of capital (i.e., discount rate) for consumers of 10%. Use of a lower rate of discount would have increased the value to the consumer of the additional 5 years of life, and would, therefore, have raised the estimated consumer savings per square and per batch. Correspondingly, CBT's investment would have shown a higher rate of return than that shown in the above analysis. Conversely, use of a higher discount rate for consumers would have caused them to realize less savings from the 235 shingle with its higher first cost, and would have resulted in a lower rate of return to CBT research than that reported in the above analysis.

[b] Because of the complexity of the above equation, i was solved by a computer rather than manually as was done in table 3.6.

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This scientist is preparing to take measurements of the pneumatic pressure in a reduced-size vent.

4. CASE STUDY: REDUCED-SIZE VENTING[54]

4.1 BACKGROUND

Venting is required for sanitary drain-waste-vent (DWV) systems in buildings to maintain the trap seals of plumbing fixtures. The venting provides protection by maintaining adequate water seals in the traps and thereby blocking the entry of sewer gases, suds, sewage and vermin into the buildings.

Traditional plumbing codes require that venting meet certain prescriptive standards. In the early 1960's, the National Association of Homebuilders (NAHB) proposed a laboratory investigation of Reduced-Size-Venting (RSV), an innovative type of venting which utilizes dry vent pipes substantially smaller in size than those permitted by existing plumbing codes. The

[54] Most of this section, with the exception of the discussion of payoffs on CBT's research in reduced-size venting, is taken from "Cost Savings from Reduced-Size Venting," an article in *Plumbing Engineer* (July-August, 1977, p. 35, and September-October, 1977, p. 45) by Harold E. Marshall, Rosalie T. Ruegg, and Robert S. Wyly. An earlier version also appeared in an unpublished CBT report entitled "Impact of CBT Activities on the Building Community," submitted on March 31, 1975 to Dr. Richard Roberts, Director, National Bureau of Standards.

purpose of the investigation was to test the hypothesis that RSV would be a viable approach to venting. The hypothesis was based on two pieces of information. First, traditional criteria for sizing vent systems were derived from data obtained under hydraulic test conditions that were more severe than what would be expected in service, particularly for one and two-story residential buildings. Preliminary analysis indicated that air requirements in the vents of the DWV systems of these buildings are substantially less than that assumed in the prescriptive requirements of the codes. Second, traditional criteria were based on the assumption that a substantial diameter reduction in vent pipes occurred in service from the accumulation of corrosion products. But with new pipe materials such as thermoplastics and some of the corrosion resistant metals, this assumption became invalid.

Studies by the NAHB, the National Bureau of Standards (NBS), and the Stevens Institute have since shown that RSV can meet the implied essential requirements for *performance* imposed on conventional vent systems in one and two-story houses by the prescriptive requirements of the traditional codes.

The purpose of this case study is to illustrate how to measure net benefits of a new technology by examining the potential cost savings from substituting RSV for conventional venting. Cost savings are expected from reduced materials costs, from reduced labor installation costs, and from reduced overhead and profit charges. No sacrifice in terms of higher maintenance costs, reduced performance, or reduced durability is expected for properly designed and installed systems. Savings from introducing RSV are estimated for single new dwelling units and for groups of new dwelling units nationwide over the next decade. In addition to illustrating how the benefits of research can be measured, the analysis provides useful information to the research community which is concerned about the returns on its investment in plumbing research. This analysis of potential savings is also of interest to builders and contractors, both of whom are eager to cut costs and thereby be more competitive, and to homebuyers, who wish to reduce their costs for a home.[55]

[55] We recognize that, in this early stage of the development of RSV, exact predictions of cost savings cannot be made. Estimates of costs for the different plumbing system designs and some of the other information needed to make precise estimates of cost savings are without detailed empirical verification. However, the estimates of savings developed in this analysis give a reasonably accurate, preliminary view of the economic viability of RSV, in that a conceptually logical model is used to evaluate cost savings, and the underlying assumptions are based on a sampling of expert industry opinion that appears realistic.

4.2 APPROACH

In this case study, a benefit-cost methodology is used to measure the social payoff of substituting plastic RSV for plastic conventional venting. As was the case with the 235 shingles, the evaluation is aimed only at determining the presence or absence of net benefits, and does not attempt to determine the optimal investment size. Furthermore, this case study, unlike the 235 shingles study, focuses on social payoffs exclusively and does not treat payoffs to CBT's investments.

Cost savings per dwelling unit are estimated here in 1975 dollars as the difference in the costs of plastic RSV as compared with plastic conventional venting for particular kinds of dwelling units in specific regions of the country.[56] The consumers' surplus model illustrated in figure 3.1 is the theoretical basis of the cost comparison.

We will conclude that RSV is the more economically efficient technology for venting on a life-cycle cost basis if the following conditions obtain: (1) The costs of RSV must be less than those of the conventional venting system called for by the plumbing code. (2) The performance of RSV must satisfy the minimum performance requirements implied by the traditional code for venting. (3) The durability and maintainability of RSV must be equal to that of conventional systems.

The life-cycle cost savings per dwelling unit from using RSV instead of conventional venting is calculated for plumbing systems in one-story and two-story residences using thermoplastic piping materials. It is assumed that the plumbing system in each new house contains two baths, one kitchen, and one laundry room. (Specifically, the system contains two bath tubs, two toilets, and two wash basins; a laundry tub; a washing machine; a kitchen sink; a dishwasher; a foodwaste grinder; water supply, drainage, and vent (DWV) piping; building sanitary drain; and building sanitary sewer.)

Savings from using RSV are influenced by the kind of pipe material used, as well as by the particular venting design that is required by the code in force. This is because pipe materials vary in cost and because venting designs vary in the amount of dry vent piping they require. Furthermore, some codes require larger sizes of vent piping in some applications than do other codes, resulting in potentially larger pipe size reductions and therefore greater cost savings. The cost savings that are anticipated from substituting RSV for conventional venting therefore increase directly with the price of the conventional pipe, the number of units of dry vent piping required, and the size reductions made possible by substituting RSV.

[56] Costs are expressed in 1975 dollars because that is the year in which this economic analysis was undertaken.

Note that plastic pipe and fittings are assumed in this study for both RSV and conventional venting, rather than copper tube and fittings. Basing the costs on plastic piping results in a lower bound estimate of potential cost savings because the savings are smaller when plastic RSV is substituted for plastic conventional venting than when plastic RSV is substituted for copper conventional venting, other things equal.

The basic configuration of DWV systems utilizing RSV does not differ from standard DWV systems. However, the diameters of the dry vent pipes are smaller than the standard sizes—usually from one to four commercial pipe sizes smaller. (Dry vents are pipes through which only air passes; wet vents, in addition to allowing air to pass, serve intermittently as drains.)

The analysis is based on the following three basic types of venting system designs: (1) a fully individually vented system, referred to here as C1; (2) a wet vented system, referred to as C2; and (3) a stack vented system, referred to as C3. Figures 4.1 through 4.5 show schematically the details of these designs, starting with the simplest, C3, and ending with the most complicated, C1, for one and two-story houses.[57]

4.3 COST SAVINGS

Tables 4.1 and 4.2 show the estimated materials, labor, and overhead and profit savings from introducing RSV in one and two-story houses with each type of venting design. The estimated savings from using plastic RSV in place of plastic conventional venting in a one-story home with venting design of type C1, for example, are $95 in total, comprised of $19 (20%) in materials, $56 (59%) in labor, and $20 (21%) in overhead and profit. Tables 4.1 and 4.2 show that the cost savings per plumbing system from using RSV are greatest when it is applied in two-story homes with venting systems of type C1. This is to be expected because C1 is the most elaborate venting system and thereby provides the largest potential for RSV savings on a per dwelling unit basis. The cost savings from RSV are least when applied in one-story residences with venting designs of type C3, the least elaborate of the systems. The savings from using RSV range from $125 to $46.

To estimate the savings per system from RSV as shown in tables 4.1 and 4.2, the costs of RSV were subtracted from the corresponding costs of conventional venting systems for each design. To calculate the total costs of installing RSV and conventional venting systems, the following cost formula was developed, based on the NAPHCC Labor Calculator:[58]

$$C = (P + F + L)\, F_O\, F_P, \qquad (4.1)$$

where

- C = Total installed costs of a venting system,
- P = Cost of pipe materials,
- F = Cost of fitting materials,
- L = Cost of labor,
- F_O = Contractor's overhead factor (e.g., if overhead charge=15%, then F_O=1.15), and
- F_P = Contractor's profit factor (e.g., if profit=10%, the F_P=1.10).

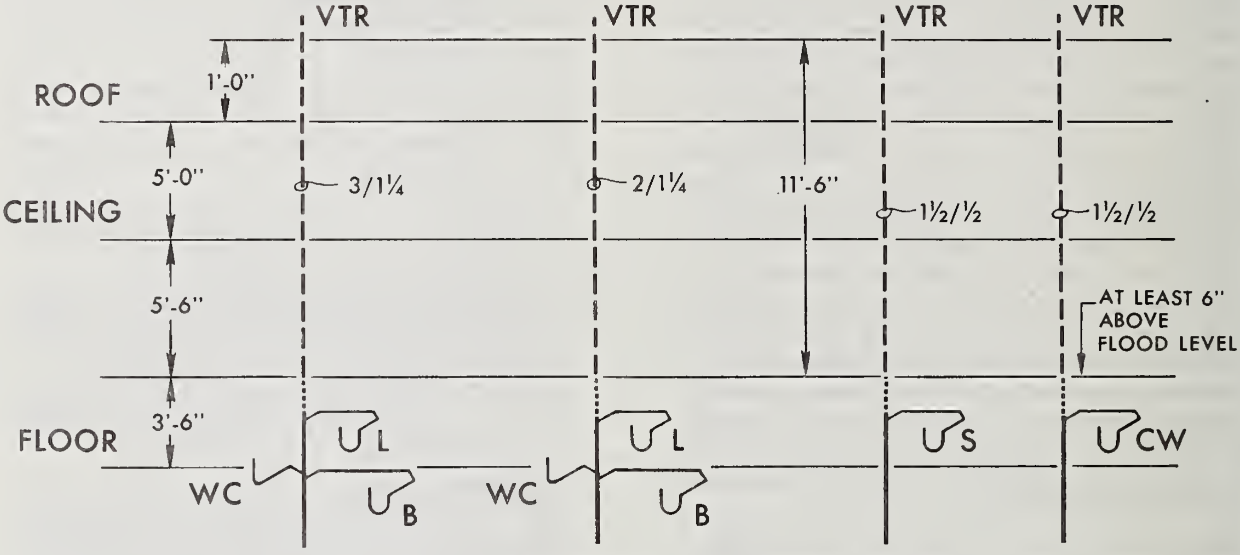
The values for P and F were calculated on the basis of the measurements shown in the schematics in figures 4.1 through 4.5 and on materials list prices. Specifically, the lengths and sizes for RSV pipe and the number and sizes of fittings were based upon the schematics and on NBS recommended design criteria.[59] The system configurations, as well as the sizes and numbers of units for conventional pipe and fittings, were based on the rquirements of hypothetical, average local plumbing codes patterned after the 1975 Basic Plumbing Code, 1975 Standard Plumbing Code, and 1976 Uniform Plumbing Code. Unit Costs of pipe and fitting materials, shown in tables 4.3 and 4.4 respectively, were obtained from plumbing materials and equipment suppliers in the Washington, D.C. area. These national list prices reflect a 30% reduction in retail prices to account for a realistic contractor discount. Multiplying the number of units times their respective unit prices yields the materials costs for RSV and conventional venting for each of the venting designs for one and two-story residences.

The values for labor costs, L, were derived by using the "pipe and fittings.' method of the *NAPHCC Labor Calculator.* Two factors regarding labor savings should be elaborated. First, a national hourly labor rate of $20 was chosen as average. This figure appears large relative to the plumber's wage, but considering that it incorporates supervisory and backup costs not included in overhead, it appears reasonable. Second, although the proportions of total savings attributed to labor (44% to 61%) in tables 4.1 and 4.2 may appear

[57] The designs are not drawn precisely to scale. The purpose is to illustrate approximate differences in the designs and the measurements of pipe sizes, pipe lengths, and number and size of fittings used in calculating savings from substituting RSV.

[58] National Association of Plumbing-Heating-Cooling Contractors, *NAPHCC Labor Calculator,* NAPHCC, Washington, D.C. (1971 with 1975 revisions).

[59] Orloski, M. J. and Robert S. Wyly, *Hydraulic Performance of a Full-Scale Townhouse Drain-Waste-Vent System with Reduced-Size Vents.* National Bureau of Standards Report, BSS60, 1975.

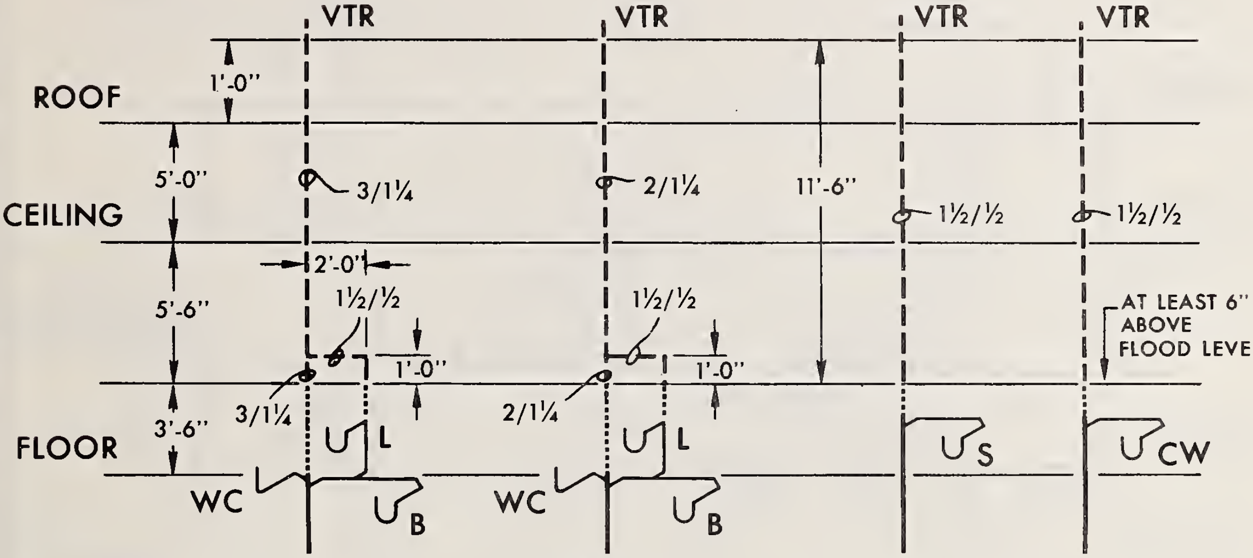


LEGEND:

———	DRAIN OR "WET" VENT
....	STANDARD SIZE DRY VENT
— — —	REDUCED-SIZE DRY VENT
3/1¼	MEANS DRY VENT REDUCTION IN SIZE FROM 3" TO 1¼"

VTR	VENT THROUGH ROOF
L	LAVATORY
WC	WATER CLOSET
B	BATH
S	SINK
CW	CLOTHES WASHER

FIGURE 4.1 *Basic design features for one-story, stack-vented system, C3.*

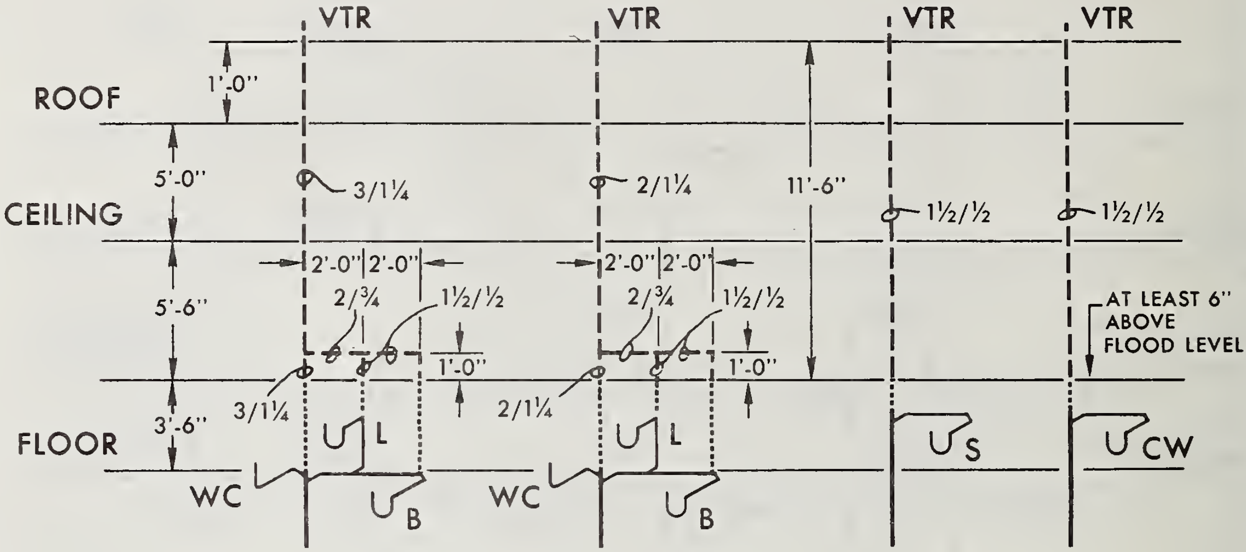


LEGEND:

———	DRAIN OR "WET" VENT
....	STANDARD SIZE DRY VENT
— — —	REDUCED-SIZE DRY VENT
3/1¼	MEANS DRY VENT REDUCTION IN SIZE FROM 3" TO 1¼"

VTR	VENT THROUGH ROOF
L	LAVATORY
WC	WATER CLOSET
B	BATH
S	SINK
CW	CLOTHES WASHER

FIGURE 4.2 *Basic design features for one-story, wet-vented system, C2.*

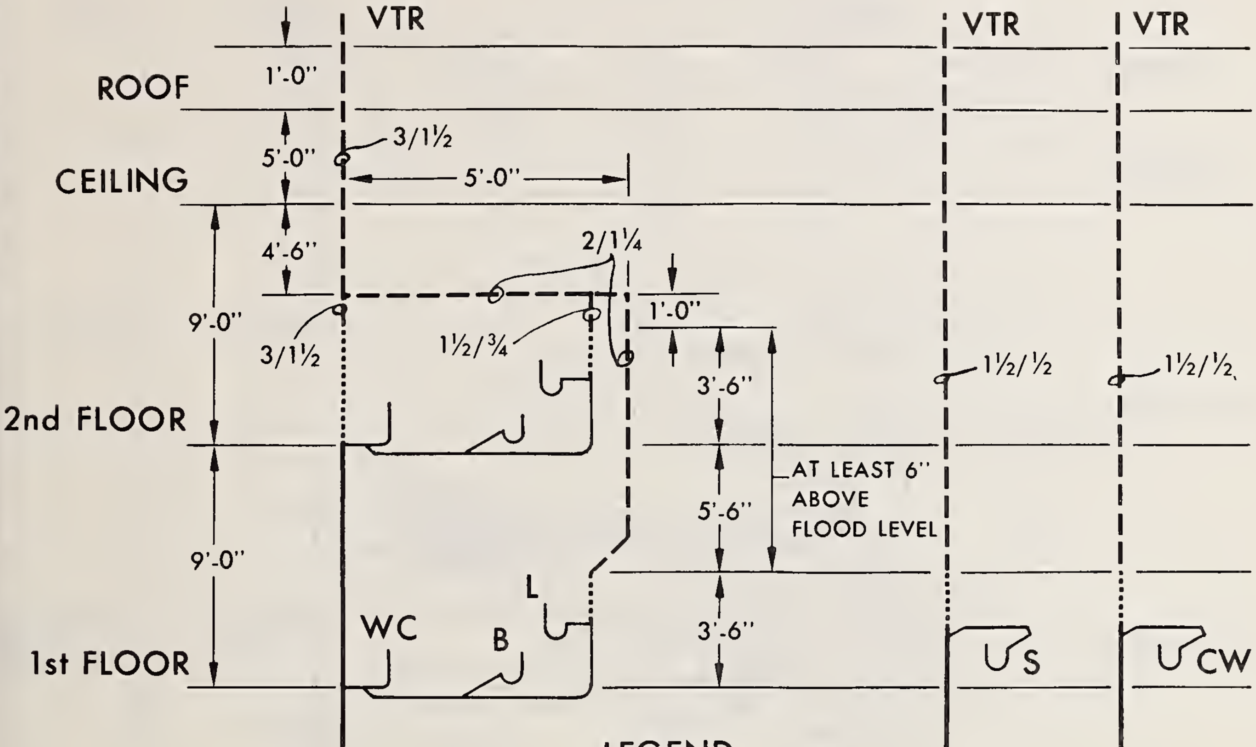


LEGEND:

———	DRAIN OR "WET" VENT
....	STANDARD SIZE DRY VENT
— — —	REDUCED-SIZE DRY VENT
3/1¼	MEANS DRY VENT REDUCTION IN SIZE FROM 3" TO 1¼"

VTR	VENT THROUGH ROOF
L	LAVATORY
WC	WATER CLOSET
B	BATH
S	SINK
CW	CLOTHES WASHER

FIGURE 4.3 *Basic design features for one-story, individually vented system, CI.*



LEGEND:

———	DRAIN OR "WET" VENT
....	STANDARD SIZE DRY VENT
— — —	REDUCED-SIZE DRY VENT
3/1¼	MEANS DRY VENT REDUCTION IN SIZE FROM 3" TO 1¼"

VTR	VENT THROUGH ROOF
L	LAVATORY
WC	WATER CLOSET
B	BATH
S	SINK
CW	CLOTHES WASHER

FIGURE 4.4 *Basic design features for two-story, wet-vented system, C2.*

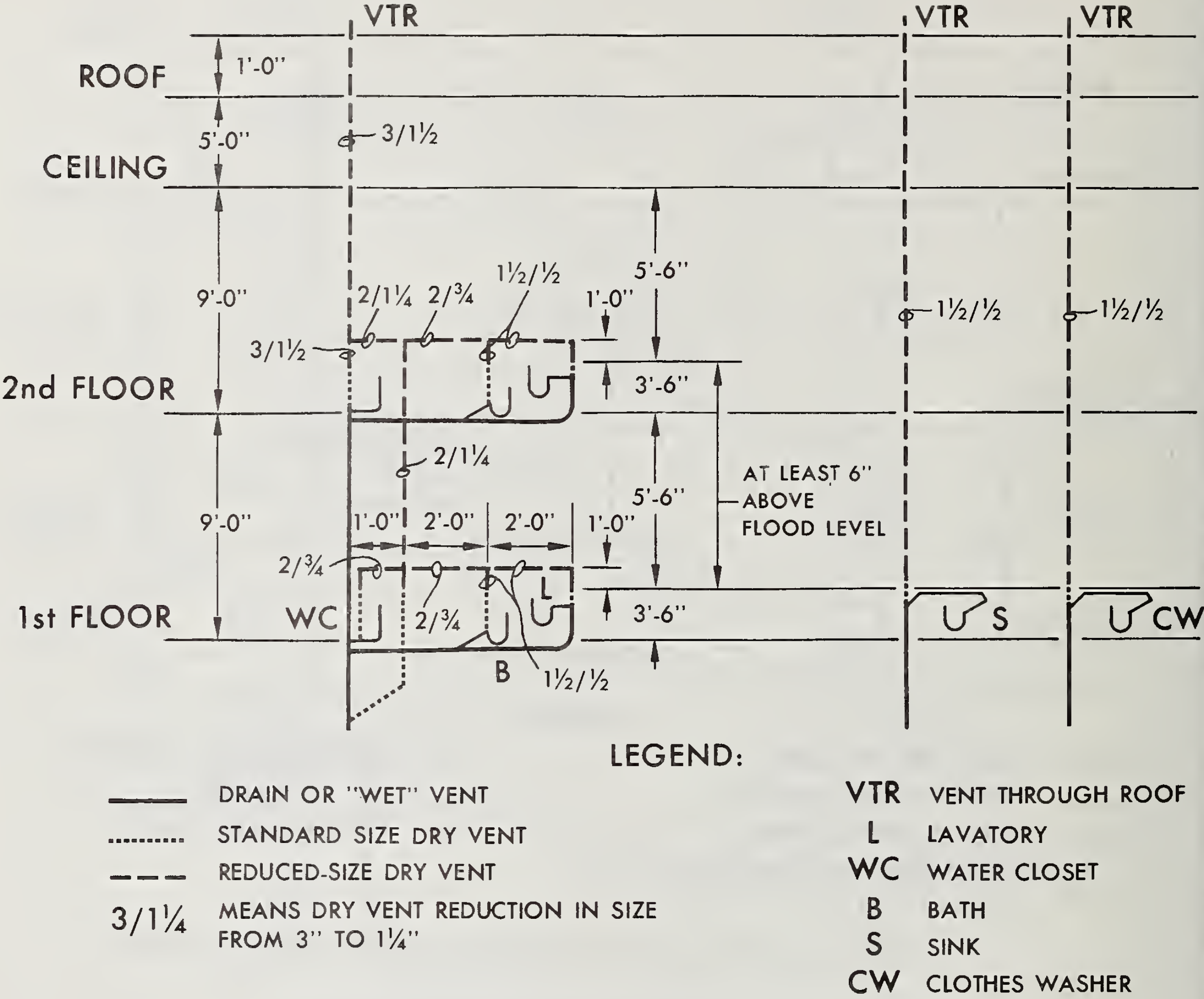


FIGURE 4.5 *Basic design features for two-story, individually-vented system, C1.*

Table 4.1 ESTIMATED SAVINGS FROM RSV PER PLUMBING SYSTEM IN ONE-STORY RESIDENCES

System design	Dollar savings (percentage distribution) Materials	Labor	Overhead & profit	Total
C1	18.65 (20)	56.26 (59)	19.85 (21)	94.76 (100)
C2	17.28 (22)	44.34 (57)	16.33 (21)	77.95 (100)
C3	16.01 (35)	20.22 (44)	9.60 (21)	45.83 (100)

Table 4.2 ESTIMATED SAVINGS FROM RSV PER PLUMBING SYSTEM IN TWO-STORY RESIDENCES

System design	Dollar savings (percentage distribution) Materials	Labor	Overhead & profit	Total
C1	22.73 (18)	76.14 (61)	26.20 (21)	125.07 (100)
C2	21.79 (31)	34.34 (48)	14.87 (21)	71.00 (100)
C3	N.A.[a]	N.A.	N.A.	N.A.

[a] N.A. means not applicable for purposes of this analysis.

Table 4.3 PLASTIC PIPE COSTS BY SIZE[a]

Size in inches	3	2	1 1/2	1 1/4	1	3/4	1/2
Dollar costs per foot	1.36	0.66	0.48	0.41	0.38	0.26	0.20

[a] Cost estimates are based on 1976 list prices of a leading brand of thermoplastic (ABS and PVC) pipe, reduced by 30% for a realistic contractor discount. Costs are for Schedule 40 DWV pipe in sizes 3, 2, 1 1/2, and 1 1/4 inches, and for Schedule 40 water pipe in sizes 1, 3/4, and 1/2 inches.

Table 4.4 **PLASTIC FITTING COSTS BY SIZE**

Size in inches	Dollar costs						
	Coupling	Tee	Cross	90° Ell	45° Ell	Reducing Tee	Reducing Bushing
3	.74	2.59	4.53	N.A.[a]	N.A.	N.A.	N.A.
2	.38	.92	2.77	.58	.55	N.A.	N.A.
1 1/2	.25	.68	1.86	.47	.37	N.A.	N.A.
1 1/4	.25	.60	1.55	.42	.41	N.A.	N.A.
1	.35	.70	N.A.	.54	.70	N.A.	N.A.
3/4	.21	.36	N.A.	.30	.62	N.A.	N.A.
1/2	.15	.29	N.A.	.24	.37	N.A.	N.A.
3×2	N.A.	N.A.	N.A.	N.A.	N.A.	2.00	.78
3×1 1/2	N.A.	N.A.	N.A.	N.A.	N.A.	1.85	1.02
2×1 1/2	N.A.	N.A.	N.A.	N.A.	N.A.	.80	.26
2×1 1/4	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	.54
1 1/2×1 1/4	N.A.	N.A.	N.A.	N.A.	N.A.	.96	.30
1 1/2×3/4	N.A.	N.A.	N.A.	N.A.	N.A.	1.21	.56
1 1/2×1/2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	.56
1 1/4×3/4	N.A.	N.A.	N.A.	N.A.	N.A.	.95	.52
1 1/4×1/2	N.A.	N.A.	N.A.	N.A.	N.A.	.95	.52
3/4×1/2	N.A.	N.A.	N.A.	N.A.	N.A.	.36	.20

[a] N.A. means not applicable for purposes of this exercise.

high, they are consistent with the labor calculation approach outlined in the NAPHCC Labor Calculator. As RSV becomes more widespread, however, it should be recognized that the process for determining contractor bid prices may change to reflect a smaller labor savings component for RSV.

Based on interviews with contractors, the values $F_O = 1.15$ and $F_P = 1.10$ were used for the calculations of overhead and profit. These figures may vary in practice, depending on the type and size of the project as well as on the size of the firm and the business procedures of the plumbing contractor.

The findings in tables 4.1 and 4.2 are generally consistent with results of another study[60] which estimated RSV savings for one and two-story houses with venting system designs similar to C1 and C2. However, estimated cost savings in the other study included a wider range of values ($24 to $151) than did this analysis ($71 to $125).

[60] Dickerson, Donald F., "Procedures for Estimating Economic Benefits and Materials Savings for Plumbing Drainage Systems with Reduced Size Venting," Report by Dickerson/Gladstone/Associates under contract to National Bureau of Standards, 1975.

Thus far the potential cost savings have been examined for specific venting designs in a single house of one or two stories. To determine the potential total impact of RSV on plumbing, it would be necessary to look at the aggregated cost savings over time for all types of buildings that might use RSV.

For the aggregate analysis undertaken here, the estimates of cost savings are limited to an 11-year period from 1975 through 1985. The 11-year period was used because reasonably dependable projections of housing starts were available. The aggregate analysis is confined to privately-owned, one-family houses constructed during this 11-year period. The savings from the possible use of RSV in multi-family residences and commercial buildings, as well as in new plumbing units retrofitted in existing housing, are not included.

The first step in calculating aggregate RSV savings is to estimate the number of plumbing systems in which RSV will be used. It is assumed that each new house (one-story or two-story) will contain a plumbing system as defined earlier. The estimated number of new privately owned, single-family homes to be constructed yearly, which is assumed to indicate the number of new plumbing systems installed yearly, is

Table 4.5 ESTIMATED ANNUAL NUMBER OF NEW PRIVATELY-OWNED, SINGLE-FAMILY HOUSES AND PLUMBING SYSTEMS

	Number of houses and plumbing systems constructed annually							
	Total U.S.A.		Northeast		South		West	
Year	1 story	2 story	1 story	2 story	1 story	2 story	1 story	2 story
1975-1980	750,400	369,600	201,600	190,400	380,800	112,000	168,000	67,200
1981-1985	917,900	452,100	246,600	232,900	465,800	137,000	205,500	82,200

shown in table 4.5 by region and number of stories. These estimates are based on Bureau of the Census population forecasts,[61] Bureau of Census *Construction Reports,*[62] and U.S. Department of Agriculture housing forecasts.[63]

The estimated numbers of housing units and plumbing systems are approximate projections of possible housing demand (rather than actual construction), under the assumption of continued economic growth, moderate inflation, and no catastropic events such as war. Cyclical variations are assumed to be offsetting in the long run, and are ignored in the projections.

The breakdown of housing and plumbing systems by region in table 4.5 is necessary because certain venting designs tend to be used more in some regions than others, depending upon the codes in effect. It is, therefore, necessary to evaluate the relative incidence of codes in order to estimate cost savings.

Local jurisdictions generally adopt one of the widely recognized model plumbing codes which have been developed by various associations of plumbing and building officials, or pattern the local code after one of the models. The IAMPO Uniform Plumbing Code, one of the model codes, is usually interpreted to require venting systems of type C1 in most installations. The BOCA Basic Plumbing Code and the SBCC Standard Plumbing Code, two other popular model codes, are similar to one another in terms of their venting requirements, both allowing all three types of venting for specified types of construction.[64]

The Uniform Plumbing Code is the predominant code for the West. Thus most venting in the West is likely to be of design type C1. The Basic Plumbing Code is probably the predominant code for the Northeast, but the Uniform Plumbing Code and the Standard Plumbing Code are also used in a number of localities in the Northeast. The Standard Plumbing Code seems to be the predominant code for the Southeast. A relatively higher proportion of venting installed in the Southeast is likely to be of the design type C3 and a smaller proportion of the types C1 and C2 than in the Northeast, mainly because a greater percentage of houses in the Southeast are of an architectural design conducive to venting designs of type C3, the simplest type.

Figure 4.6 divides the U.S. into three main regions—Western, Northeastern, and Southeastern—for the purpose of showing the approximate percentages of new homes which will have venting designs of each of the types C1, C2, and C3. The estimated percentages of new plumbing systems in each region that will have each type of venting design are shown in the legend at the bottom of the map.

Given the estimates of new plumbing systems over time (table 4.5), the incidence of the different types of venting designs (fig. 4.6), and the RSV savings per unit (tables 4.1 and 4.2), we could easily calculate the yearly cost savings under the assumption that RSV is applied to all new private houses built from 1975 through 1985. However, it is unlikely that RSV will be this widely adopted in the beginning. It takes time for a new technology to be accepted by the building regulatory system as well as by builders, plumbers, and home buyers. Thus to estimate the future savings of RSV, it is necessary to predict the rate at which RSV will be accepted by code authorities and applied in venting systems, i.e., the "diffusion rate" of RSV.

To develop a proxy for the diffusion rate, we estimated the percentage of new, single-family houses each year in which RSV appears likely to be installed.

[61] U.S. Bureau of Census, *Projection of Population Growth.*

[62] U.S. Bureau of Census, *Construction Report,* Series C25, July, 1974.

[63] Marcin, Thomas C., *The Effects of Declining Population Growth on the Demand for Housing,* U.S. Department of Agriculture, General Technical Report NC-11, 1974.

[64] IAPMO stands for International Association of Plumbing and Mechanical Officials; BOCA stands for Building Officials and Code Administrators International; and SBCC stands for Southern Building Code Congress International.

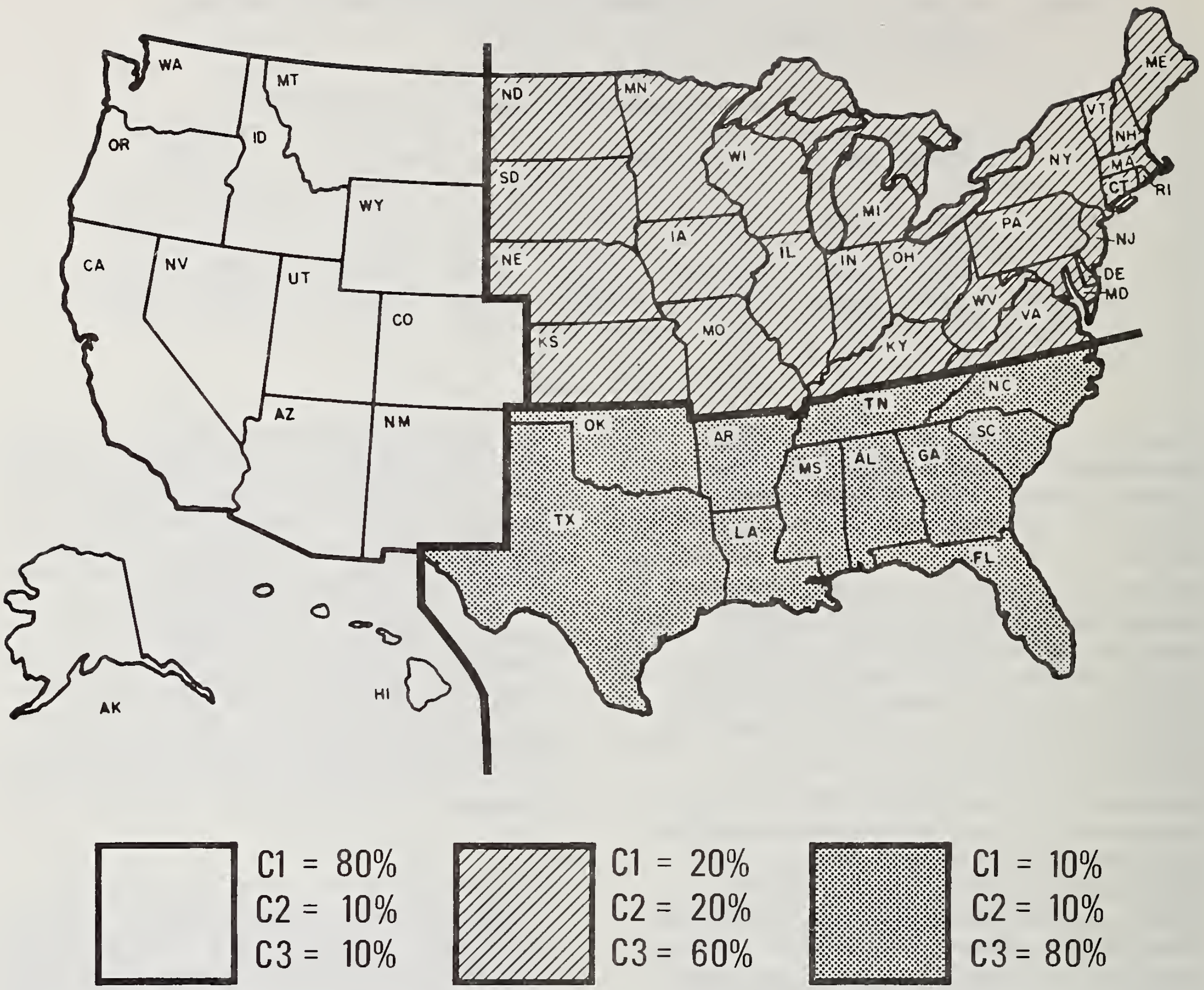


FIGURE 4.6 *Estimated percentage use of the three different types of venting system designs in new houses by region.*

Table 4.6 shows these estimates by region. To derive them, the percentage of new houses in which RSV will be used by 1985 was first forecasted in consultation with experts in the plumbing industry. The percentages of new houses in which RSV will be used in each year from 1975 through 1984 were then estimated on the basis of the 1985 forecast and the following formula:

$$F_j = \frac{\sum_{i=1}^{j} Y_i}{\sum_{i=1}^{n} Y_i} \cdot F_n, \qquad (4.2)$$

where

F_j = calculated percentage of new houses constructed in year j with RSV venting,

Y_i = years from 1975 through 1985 represented by consecutive numbers from 1 to 11, and

F_n = predicted percentage of new houses to be constructed in year n (i.e., 1985) utilizing RSV.

This formula was selected for estimating the percentages of new houses from 1975 through 1985 which will utilize RSV because it appeared reasonably descriptive of the pattern of acceptance of an improved plumbing technology (i.e., a pattern of growing acceptance over time, but at a decreasing rate).

To derive the expected aggregate cost savings from RSV, the savings for each region and house type were first computed separately, taking into consideration

Table 4.6 ESTIMATED YEARLY PERCENTAGES OF NEW SINGLE-FAMILY HOUSES WITH RSV, BY REGION

Year	Northeast	South	West
1975	1	1	1
1976	3	4	2
1977	6	7	5
1978	10	12	8
1979	15	18	11
1980	21	25	16
1981	28	34	21
1982	35	44	27
1983	44	55	34
1984	54	67	42
1985	65	80	50

Source: Percentages for 1985 were forecasted with advice from experts in the plumbing industry. The percentages for 1975-1984 were derived with equation 4.2.

the cost savings from RSV for each of the three types of venting designs, the percentages of houses likely to contain each type of venting design, and the expected percentage of houses utilizing RSV. The savings across all regions and house types were then summed. Table 4.7 shows the estimated total cost savings by region and for the U.S. as a whole if RSV were to be used as assumed during the period 1975 through 1985. The projected estimate of aggregate present value savings, discounted with an interest rate of 10%, is $106.5 million, based on the use of RSV in an estimated 3.9 million single-family residences. The largest single part of these savings is expected from use of RSV in one-story houses in the South.

The present value costs of research and field testing leading up to the introduction of RSV were estimated in both government and private sectors to total $900 thousand. Thus, the social net benefits of RSV are estimated to be about $105.6 million.

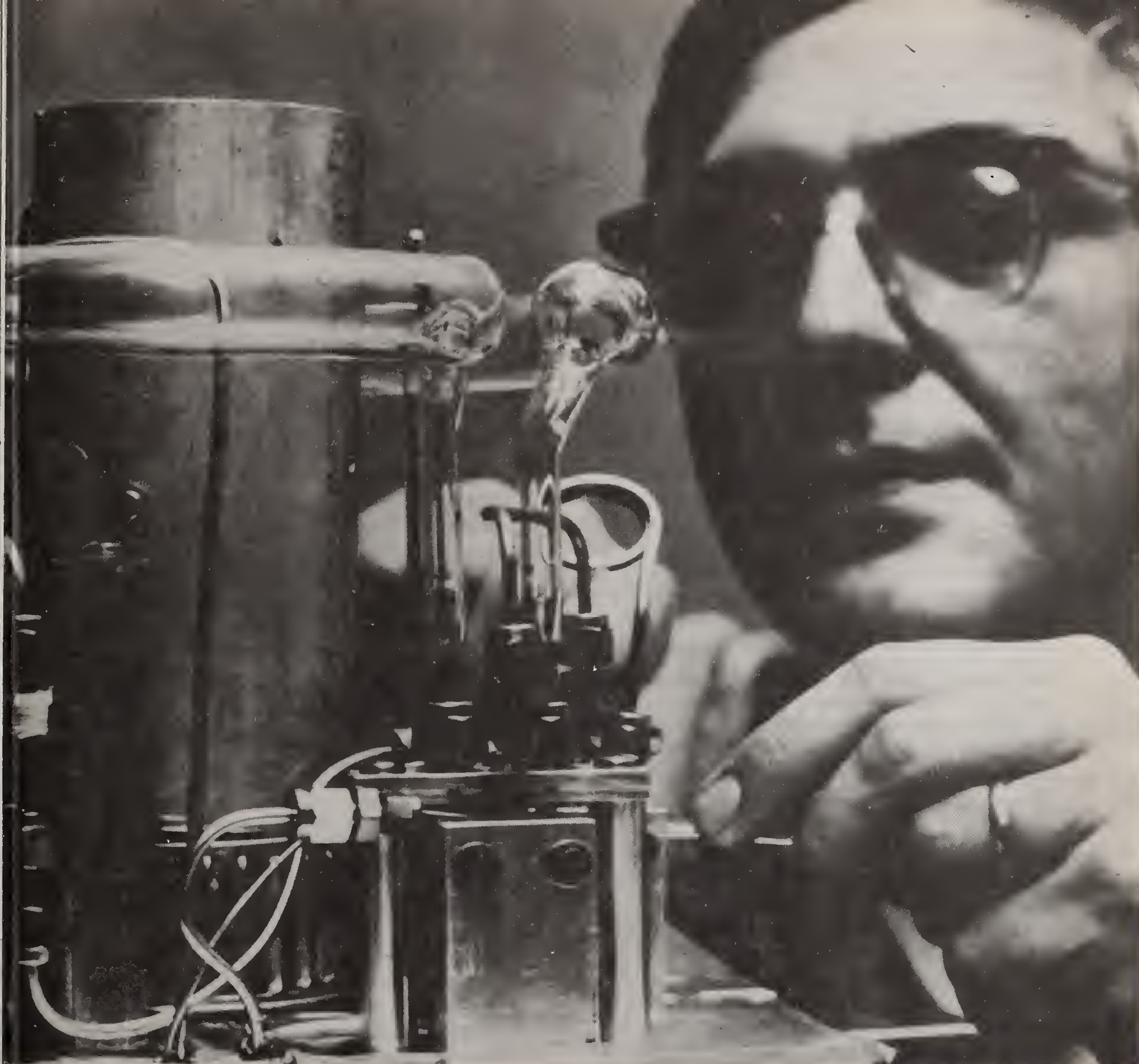
Realization of these potential cost savings depends on how fast code authorities accept RSV in the plumbing codes and how fast builders, developers, contractors, plumbers, and housing buyers implement RSV technology once it is authorized by codes. Greater use of RSV would be promoted by demonstrations that RSV meets the performance requirements of venting and that RSV will save money. It should be recognized, however, that such factors as possible difficulties in obtaining the smaller-sized piping and the special transition fittings, initial lack of installation experience, lack of familiarity with research findings on the adequacy of performance of RSV, inappropriate code content to facilitate proper design and inspection, and resistance to change by labor may retard RSV acceptance and reduce the savings to be realized from RSV over the next decade. However, time will likely reduce many of these barriers to RSV, and one might expect that the combined thrust of greater familiarity, better documentation on field trials, and demonstrated cost savings will establish RSV as a viable venting technique applicable to any type of standard DWV system.

Table 4.7 ESTIMATED POTENTIAL COST SAVINGS FROM USE OF RSV, 1975 THROUGH 1985

Region	Type of house	Number of RSV systems ($1,000)	Present value savings ($1,000,000)
Northeast	1-story	670	20.5
	2-story	633	12.3
	Total	1,303	32.8
South	1-story	1,557	41.5
	2-story	458	4.4
	Total	2,015	45.9
West	1-story	429	18.7
	2-story	172	9.1
	Total	601	27.8
All regions	1-story	2,656	80.7
	2-story	1,263	25.8
	Total	3,919	106.5

Facing page:

This scientist is sweeping dissolved hydrocarbons from sea water.



5. SUMMARY AND SUGGESTIONS FOR FURTHER RESEARCH

5.1 SUMMARY

Expenditures in the United States for research and development (R&D) represent large sums of money, and the R&D community is a major industry in terms of the human and material resources that it controls.

The National Bureau of Standards (NBS), a scientific research agency of the U.S. Department of Commerce, has attempted to improve its resource allocation process by requiring all major operating units to do "microstudies" of their research impacts on society. This report is an outgrowth of the microstudy prepared by the Center for Building Technology (CBT) of NBS, and it incorporates the two case studies on building technology described in the microstudy. The report is presented in a general framework so that it can be adopted for application by any government agency allocating research funds, and in some cases, by universities and private research firms as well.

A formal resource allocation process for research is needed in both the public and private sectors. Research managers need guidelines for research planning so that they can maximize the payoffs from their limited resources. Furthermore, quantitative descriptions of research impacts have become a basic requirement in many organizations for justifying budget requests.

The purposes of this report are (1) to provide research administrators with an examination of alternative methods for evaluating future, existing, and past research projects, and (2) to provide a description of the data needs for evaluating the impacts of technological changes that results from an agency's or firm's applied research programs.

Section 2 provided a definition of terms and a discussion of the different perspectives or objective functions of research groups that develop and apply new technologies. The measurement of benefits and costs arising from the introduction of new technologies was described. Three selected methods of project evaluation—benefit-cost analysis, the internal rate-of-return, and the payback methods—were described and compared in terms of their usefulness in selecting among alternative R&D investments.

Sections 3 and 4 presented two case studies in building technology. The first provided estimates of the net savings and internal rate of return from a past research effort at CBT in the development of an improved asphalt shingle (the 235 shingle) for sloped roofing.

The life-cycle costs of the improved shingle were compared against the life-cycle costs of the shingle it replaced (the 210 shingle). The net benefits (i.e., life-cycle cost savings) to society from having the 235 shingle were estimated to be approximately $4.0 billion in present value terms over the period 1962 through 1974. The part of the total net benefits that can be attributed to CBT were estimated to be about $1.7 billion. The internal rate of return on society's investment in 235 shingle research was estimated to be about 33%. The rate of return to CBT for its investment was estimated to be about 70%.

The second case study deals with the net benefits from research investments in reduced-size venting (RSV), a type of sanitary drainage vent system that utilizes smaller vent pipes than those currently permitted by plumbing codes. The net benefits (i.e., net dollar savings in venting costs) to society from introducing RSV over the period from 1975 through 1985 were estimated to be over $105 million.

5.2 SUGGESTIONS FOR FURTHER RESEARCH

The background work for this report, particularly for the case studies, uncovered additional areas of research that might be of value to government agencies and other institutions that are concerned with an efficient allocation of their research budgets.

One type of research needed is the analysis of past and ongoing innovations to determine their rates of diffusion. Reliable predictions of net benefits or rates of return on proposed research projects cannot be made without some relatively sound basis for predicting rates of diffusion.

A second area of research involves the development of a system of record keeping on completed and ongoing pojects so that benefits of R&D can be correlated with specific actions by the organization, and can be measured in some quantitative manner, preferably dollars.

A third potential area for research is the computation and comparison of private and social payoffs on specific projects to see where government support of R&D is warranted. Projects with high social payoffs, but low private payoffs, are those for which government sponsored R&D might be appropriate.

A fourth topic of research is the determination of government cost-sharing (i.e., grant) formulas for supporting R&D in the private sector in those areas where social payoffs are much higher than private payoffs.

A fifth area of research, and one that would be particularly useful to a large research concern that funds many low budget projects, is the review and assessment of simplified approaches to use in determining the relative economic efficiency of alternative research projects, and the extension of these to fit specific kinds of projects. An approach that is simpler, cheaper, and more quickly applied than the benefit-cost and internal-rate-of-return approaches described here, but generally reliable, would be helpful as an initial screening device for selecting among alternative research projects.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Public and private administrators of research programs are concerned with maximizing the payoffs from their research investments; that is, with allocating their limited budgets most efficiently. Benefit-cost, rate-of-return, payback, and other evaluation methodologies are examined for their usefulness in helping administrators to decide whether to accept or reject research projects leading directly to applications; to plan the scale of these research projects; and to identify priorities among alternative research investments, all of which may be profitable. Data needs for applying these evaluation methodologies are outlined. The net-benefits and rate-of-return methodologies are applied to two case studies involving research in the Center for Building Technology (CBT) of the National Bureau of Standards. The first deals with a heavier asphalt shingle for roofing, and the second deals with reduced-size venting in plumbing. The case studies show high payoffs in these two areas of research, both for society as a whole and for CBT's contribution in undertaking the research. Recommendations from the study are that research funds be allocated on the basis of anticipated payoffs determined through these evaluation techniques, and that benefit and cost data for evaluating new technologies be collected.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Benefit-cost analysis, building technology; economic impacts; economics; efficiency; payback; plumbing; roofing; shingles; venting.

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