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An evaluation framework for forestry R & D: an application to the ENFOR program

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by

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Foreword

ENFOR is the acronym for the ENergy from the FORest (ENergie de la FORêt) program of the Canadian Forestry Service. This program of research and development is aimed at securing the knowledge and technical competence to facilitate in the medium to long term a greatly increased contribution from forest biomass to our nation's primary energy production. It is part of the federal government's efforts to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The ENFOR program is concerned with the assessment and production of forest biomass with potential for energy conversion and deals with such forest-oriented subjects as inventory, harvesting technology, silviculture, and environmental impacts. (Biomass Conversion, dealing with the technology of converting biomass to energy or fuels, is the responsibility of the Renewable Energy Division of the Department of Energy, Mines and Resources). Most ENFOR projects, although developed by CFS scientists in the light of program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact ...

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Abstract

Evaluation of R&D programs is a topic of growing importance for government research managers. This report presents an economic evaluation framework for the ENFOR program, which is a government R&D program intended to conduct research on issues associated with the utilization of forest biomass for energy. It begins with reviewing the question of whether economic evaluation of R&D is possible, reviews the existing literature, and outlines possible methods. Finally, an economic evaluation approach is recommended.

Résumé

L'évaluation des programmes de R.-D. est une question qui intéresse de plus en plus les gestionnaires gouvernementaux. L'auteur présente un cadre d'évaluation économique pour le programme ENFOR, programme gouvernemental de R.-D. portant sur l'utilisation de la biomasse forestière à des fins énergétiques. Il commence par analyser la possibilité d'effectuer une évaluation économique de la R.-D. Il passe ensuite en revue la documentation existante sur le sujet. Il présente diverses méthodes utilisables à cette fin et il indique l'approche qu'il recommande.

Contents

Tables

Figures

Chapter one

Introduction

Background

Research and development (R&D) activities are universally recognized as inherently uncertain processes. They often involve long time-horizon results which are notoriously difficult to predict, links between different phases of R&D which are not well understood, subtle interrelationships between projects, and diffuse potential users. Yet, like all types of investments, R&D should be expected to pay back dividends in terms of demonstrable benefits, however these benefits may be defined or measured. This is as true for publicly funded R&D as for research undertaken in the private sector, although judging the benefits of public R&D is inherently more difficult. Evaluation of R&D programs is consequently a topic of growing importance for government research managers. It is also a topic that poses formidable difficulties for analysts.

This study is concerned with approaches to evaluating, primarily in economic terms, research activities funded under the ENFOR Program. ENFOR (Energy from the Forest) is an acronym referring to a renewable energy research, development, and demonstration program. This program began in 1978 and is administered by the Canadian Forestry Service and sponsored by the Government of Canada. In general terms, the program is intended to conduct research on issues associated with the utilization of forest biomass material for energy, in order to encourage substitution of biomass for fossil fuels. Originally, ENFOR comprised two distinct subprograms: Biomass Production and Biomass Conversion. However, in 1983 the Department of Energy, Mines and Resources assumed responsibility for the Conversion Program. Thus ENFOR now consists of research activities concerned with biomass production issues.

Overall study structure and emphasis

In July, 1984, McDaniels Research submitted an unsolicited proposal to undertake a three-phase study dealing with ENFOR program planning and evaluation (McDaniels Research 1984a). At that time, it was hoped that the ENFOR Program would continue for a number of years. Thus, the original emphasis of the study was to provide a data base and analytical framework that would use economic criteria to help program managers make decisions about what types of new projects to fund. The overall objective was to help achieve the maximum expected benefits from program expenditures.

A brief description of the original objectives and approach for each of the three phases is provided below:

Phase I: Development of a data base regarding the supply and costs of forest biomass fuels in regions of Canada. With this information, supply curves for different sources of biomass fuels would be estimated on a regional basis. The supply curves would be useful outputs on their own, and would also form part of the basis of the decision modeling work of subsequent sections.

Phase II: Development of a decision-making model to assist in estimating the benefits to be derived from biomass production research projects. The decision model would rely on the supply curves discussed above to indicate the size of benefits (in the form of cost savings) associated with successful innovations in bioenergy technology, and on decision analysis (decision trees) to summarize in a probabilistic manner the uncertainties underlying research and development in bioenergy.

Phase III: Application of the decision model to an example set of specific questions or issues to be determined by the ENFOR committee.

Phase I of the study was successfully completed in July, 1985 (McDaniels Research 1985), and copies of the report are available from the Canadian Forestry Service.

As the Phase II study was about to begin, changes in federal priorities mandated that the ENFOR program activities would diminish in coming years. Program emphasis was therefore placed on completing research already in progress, with a few new projects to be undertaken. Consequently, an analytical framework for project selection (planned for development in Phase II) would have had only limited usefulness.

The detailed proposal prepared by McDaniels Research for the Phase II study had anticipated the possibility that ENFOR activities may be considerably reduced. Thus the proposal indicated the study would consider both *ex post* research evaluation methods (analysis after projects are completed) as well as *ex ante* project evaluation methods (analysis for selecting new projects). A final decision regarding the relative emphasis to be given to each of these concerns was to be decided once the study was under way.

In March of 1986, the Canadian Forestry Service decided that emphasis should be placed primarily on *ex post* evaluation methods, since the program was to be considerably scaled down. Moreover, ENFOR managers expected that an overall program evaluation study would eventually be undertaken for ENFOR. It was therefore decided that a study to develop methods for *ex post* economic evaluation of ENFOR projects would be useful as input for an eventual program evaluation exercise.

The main reason for the emphasis on economic criteria as the basis for *ex post* evaluation of ENFOR research projects is the conceptual link between ENFOR research and federal economic policy objectives. One of the chief objectives of ENFOR has been to help foster increased utilization of forest biomass as a substitute for fossil fuels. Interfuel substitution is essentially an economic decision, where the relative costs of possible fuels are compared to select the most inexpensive option. Moreover, Canada's fundamental rationale for encouraging renewable over fossil fuels is a desire to avoid the economic cost of imports, and the economic risk of supply disruption. Thus ENFOR research activities was undertaken to achieve economic objectives. This point is discussed in greater detail in Chapter Two.

Despite this justification for reliance on economic criteria, it must be recognized that many of the research projects funded by ENFOR cannot be readily evaluated in economic terms. A considerable share of ENFOR research involve activities such as analyzing the environmental impacts of using forest biomass for energy, or gathering data for forest biomass inventories. These types of research projects are not readily linked to new products or processes that can be valued monetarily. Moreover, it should be recognized that economic evaluation of R&D projects is a highly uncertain process, even for research projects in which the link to economic outputs is clear. These issues are discussed further in Chapter Three. Such problems suggest there may be a need to consider other program objectives and evaluation criteria, aside from economic ones, in developing an evaluation framework for ENFOR.

Study objectives

After extensive discussions with the Scientific Authority, the following objectives have been established for this study:

1) The study is to review the conceptual feasibility of conducting *ex post* economic analysis of ENFOR research projects, as a means to quantify the potential economic benefits of ENFOR research projects that have been completed.

2) If the approach seems conceptually feasible, the study is to review the literature regarding *ex post* economic evaluation of R&D projects, and recommend methods for conducting this analysis.

3) The study should discuss the role of these economic evaluation methods within any subsequent program evaluation process that may be undertaken for ENFOR.

4) As a supplement to the economic methods, a brief review of the issues and approaches to evaluation of R&D on the basis of noneconomic criteria would also be useful. However the emphasis should be placed on economic criteria.

In a sense, the objectives of the present study are similar to an "evaluation assessment" (or "pre-evaluation") as called for in the Treasury Board guidelines for program evaluation (Canada Treasury Board 1981). However, the study differs from an evaluation assessment in many respects. Briefly, an evaluation assessment study is intended to set an agenda for a program evaluation, by reviewing program objectives and activities, outlining evaluation options, and recommending a preferred approach. In the case of the ENFOR program, two factors suggest that a complete evaluation assessment may not be required. First, the program is to be considerably scaled down, so many program evaluation questions need no longer be considered. Second, because the program in question is an R&D activity, many of the evaluation concerns are fundamentally different from those in other types of programs (Canada Treasury Board 1984). Thus, while the present study considers some of the questions associated with an evaluation assessment, it should not be considered an evaluation assessment *per se*.

Finally, it is important to emphasize the prospective nature of this research. Very few other studies have been undertaken that apply economic criteria to evaluate federal R&D programs in Canada. In the course of interviews with program evaluation managers in various departments undertaken for this study only one *ex post* economic evaluation was identified, which had been completed for the Department of Agriculture (Ulrich and Furtan 1985). Examples of noneconomic research evaluations were found in a few ministries, notably the Departments of Fisheries and Oceans and Energy, Mines and Resources and the National Research Council. But in general, the practice of evaluating R&D programs is still in its infancy in Canada, as evidenced by the fact that Treasury Board released only an "exposure draft" of a document discussing R&D evaluation in late 1984 (Canada Treasury Board 1984). Thus, in a very real sense, this study is an exploration of the possibilities for *ex post* economic evaluation of R&D.

Study organization

The remainder of this study is organized in the following manner. Chapter Two discusses the objectives and activities of the ENFOR Program, in order to set the context for the subsequent discussion of economic evaluation methods. Chapter Three addresses the question of whether it is possible to evaluate R&D programs in economic terms. After reviewing the evidence, the answer is a qualified "yes" for some types of projects. Chapter Four reviews the literature regarding *ex post* economic analysis of R&D programs, and outlines possible methods. In Chapter Five, an economic evaluation approach is recommended, and a list of specific steps and requirements is provided. Chapter Six discusses approaches to noneconomic evaluation of certain ENFOR activities. Finally, Chapter Seven provides some brief conclusions and recommendations for implementation.

Chapter two

ENFOR objectives, activities, and evaluation issues

Overview

A first step in developing an evaluation framework for ENFOR research is a brief review of the ENFOR program itself. The program's objectives must be established and its activities documented. These topics are considered in the following two sections. After that, key issues for *ex post* evaluation of ENFOR projects are considered. A brief review of a Treasury Board guide to evaluation of R&D projects will indicate some broad areas of interest. Then a recap of ENFOR objectives will be used to identify key evaluation criteria. In sum, the intent of this chapter is to establish the overall context for development of specific evaluation methods in subsequent chapters.

ENFOR objectives

Review of objectives

A review of program documentation was undertaken to identify the stated objectives of the ENFOR Program. The earliest statement of program objectives that was located was made by Mr. Alastair Gillespie, then Minister of Energy, Mines and Resources, who in 1978 announced a package of renewable energy policy initiatives "to encourage large-scale development of energy from the forests and other forms of organic material, or biomass, as a substitute for oil, gas and even electricity" (Gillespie 1978). This announcement did not refer to ENFOR by name, but did discuss a $40-million federal program for research, development, and demonstration in forest biomass and other biofuels. The stated physical objective of *all* programs announced at that time (including grants, e.g., the FIRE program, and loan guarantees) was to double the contribution of biomass to national primary energy supply in order to reach a 7% contribution by 1984.

Subsequent ENFOR summaries and reviews are consistent in their statements of program objectives. A typical version is found in a review of ENFOR accomplishments by R.C. Dobbs, which cast ENFOR's objective in these terms: "Its aim is to develop knowledge and technical competence to facilitate a markedly increased contribution from forest biomass to Canada's primary energy supply" (Dobbs 1981). The periodic *ENFOR Review* publications (1980-1985) identify the program's overall objectives in similar language.

Dobbs (1981) also provides two "aims" or sub-objectives for the ENFOR Production program:

1) To determine the potential of Canada's forests to supply, without harm to the environment, biomass for conversion to energy.

2) To develop the forest management practices and systems required to realize the potential energy contributions of forest biomass.

These two aims are in turn subdivided into four general "problem areas," or areas of research interest, each with its own specific sub-objective:

1) *Biomass availability*
   Objective: To determine the amount of biomass in Canadian forests, and to estimate its potential contribution to the nation's energy requirements.

2) *Environmental impacts*
   Objective: To assess the potential environmental impacts of intensified biomass production and harvesting for energy purposes.

3) *Biomass harvesting*
   Objective: To develop and test methods and systems for harvesting, processing, and delivering forest biomass for conversion to energy.

4) *Intensive silviculture*
   Objective: To develop and test methods and systems for increasing biomass production (Dobbs 1981).

Discussion

One sees from the foregoing discussion that facilitating substitution of biomass for conventional energy sources is the program's overall objective, while specific aspects of the program have sub-objectives cast in operational or physical terms. Yet, this begs the question of why greater reliance on biomass in place of oil, gas, and electricity is a desirable public objective - a question which must be answered in order to provide a basis for an ENFOR program evaluation. It is unusual to see a government attempting to encourage substitution of one resource in place of another. In our market-based economy, government typically lets the prices of resources provide information to consumers, who then make their own decisions about which resource to use. What is so different about biomass, or indeed all renewable energy, that it merits special encouragement?

This is a question that goes to the heart of Canadian energy policy throughout the 1970s and early 1980s. During that time, a number of policies were introduced to reduce Canada's dependence on conventional energy resources, particularly imported oil (e.g., Canada, Energy Mines and Resources 1980). In an evaluation of the Department of Energy, Mines and Resources' FIRE Program, McDaniels Research (1984b) provides an extensive discussion of the economic basis that underlies the Canadian energy strategy during that period. Briefly, that report argues that off-oil and import substitution initiatives were based on the perception that reliance on imports was becoming increasingly costly and uncertain, and thus to encourage the development of indigenous energy resources would likely be a less expensive and more secure means of meeting energy demands. McDaniels Research (1984b) argues that the stated objectives of import substitution and self-reliance were really restatements of the federal government's underlying pursuit of improved economic efficiency (i.e., putting resources to their best use by minimizing costs). In sum, economic efficiency, along with its companion objective, income redistribution, were the fundamental policy objectives of Canadian energy strategy throughout the 1970s and the early 1980s, and indeed, continue to be the fundamental objectives today.

What are the implications of this objective for the design of an ENFOR evaluation framework? The chief implication is simply that any evaluation should recognize that the potential for improving economic efficiency was the fundamental motive of the federal government in undertaking this research program. It was believed that by providing new resource information and investigating new techniques, the adoption of biomass energy would be accelerated, because it was hoped that biomass would be shown to be economically viable in specific applications. Rapid adoption of biomass would in turn reduce reliance on conventional energy resources, particularly imported oil, and thus achieve the expected gains in economic efficiency[1].

In sum, an ENFOR evaluation should at least conceptually be based on the potential or realized economic benefits the research has produced. The next questions to consider are whether the nature of ENFOR research activities lend themselves to such an economic evaluation, and if not, what other objectives and criteria provide an appropriate basis of an evaluation. These topics are considered in subsequent sections of this chapter, while evaluation methods are explored at length in subsequent chapters.

ENFOR activities

Only a brief overview of ENFOR activities is required here, because the periodic *ENFOR Review* publications provide a comprehensive record of these activities. The emphasis in this section is on general patterns of budget allocation, rather than discussion of specific research projects or the ENFOR management process. Detailed descriptions of research projects are found in the *ENFOR Review* (ENFOR, various years), while a summary of program management is presented in Dobbs (1981).

Table 1 summarizes the total annual expenditures of the ENFOR Program since its inception in 1978 through 1986-87. Data for years before 1983 consider the ENFOR Production Program only. The table subdivides these annual expenditures into three categories: project costs, program administration, and other costs. "Project costs" refers to expenditures on contact and in-house research, while "program administration" refers to expenditures on overhead activities such as management expenses, travel, publication of reports, and similar items. One sees that annual expenditures reached their peak in 1982-83 and declined sharply after 1984-85. The program is scheduled to operate at a reduced level past 1986-87.

Table 2 and subsequent tables in this section were derived from a 1983 report by Dendron Resource Surveys Ltd., which provided a review of the ENFOR Production Program (Dendron Resources Surveys Ltd. 1983). These tables present data on program expenditures, disaggregated in various ways, based on information regarding program expenditures and commitments

[1] We do not pursue here the market failure considerations that necessitate federal support for renewable energy generally, and in particular mandate federal support for renewable energy research and development. The first set of market failure considerations is discussed in McDaniels Research (1948b), while the second is considered in McDaniels Research and Quantalytics (1986).

Table 1. ENFOR production program expenditure summary (nominal dollars)

Fiscal year	Project costs	Program administration	Other costs[1]	Total
1978-79	586 000	30 000	30 000	646 000
1979-80	1 275 000	123 000	50 000	1 448 000
1980-81	2 110 000	221 000	50 000	2 381 000
1981-82	2 848 900	245 600	50 000	3 144 500
1982-83	3 468 800	319 700	50 000	3 838 700
1983-84	3 131 200	326 000	75 000	3 532 200
1984-85	2 206 000	248 000	197 000	2 651 000
1985-86	751 300	113 700	197 000	1 062 000
1986-87	512 400	132 500	197 000	841 900

Source: ENFOR Program administration records.

(1) Other costs include capital spending and IEA contribution.

through January, 1983. Although these data omit the last 3 years of ENFOR activity, they are nevertheless useful, for two reasons[2]. First, the majority of total program research expenditures are accounted for in these data; second, subsequent years' expenditures generally follow the patterns outlined in these tables, according to program managers.

Table 2 summarizes research project expenditures by Canadian Forestry Service research establishments. Projects included in this summary are listed in Appendix 1 of Dendron (1983). A brief explanation of the project selection process that forms the basis of these allocations may be useful. The choice of projects to be refunded by the ENFOR Program is determined at two levels. First, at annual meetings the individual Canadian Forestry Service establishments typically propose specific projects and establish their research priorities. Then, the ENFOR Committee of the Canadian Forestry Service either accepts or rejects these proposals and makes its own proposals as well.

Table 2 indicates there has been a relatively even distribution of funds between establishments, with minor exceptions. The high expenditures at the Great Lakes Forest Research Centre are explained by that establishment's role in equipment development. More typical is the Newfoundland Forest Research Centre and the Pacific Forestry Centre which have received about the same levels of support (Dendron Resources Surveys Ltd. 1983).

Table 3 presents research expenditure disaggregated into subject classifications. This table is more detailed than that usually provided for ENFOR allocation summaries; projects are typically divided into four general classes (biomass availability, biomass harvesting, environmental impacts, and intensive silviculture) corresponding to the program's sub-objectives noted earlier. This table clearly reveals the research areas given priority by the program: development of new harvesting equipment and methods to estimate biomass quantities. These two categories account for over 50% of ENFOR project expenditures during the relevant period.

Table 4 rearranges these expenditures into a different set of categories. One sees that general research and development accounted for nearly half the project expenditures. Finally, Table 5 presents project expenditures by Canadian Forestry Service establishment and by the type of contractor. Here it is apparent that the vast majority of funds were contracted to private sector firms, ranging from small consultants to the Forest Engineering Research Institute of Canada (FERIC).

The picture that emerges from these tables is of an R&D program with the following features:

1) the majority of funds were spent on contracted research projects;

(2) During this study, a request was made for information to update Dendron's tables through 1986. ENFOR Program managers complied with project-by-project summaries of expenditures, which unfortunately were not organized in as detailed a manner as Dendron's tables. It seemed both expedient and desirable to adopt Dendron's more detailed summary for the purposes at hand.

Table 2. Total ENFOR project expenditures by research establishment (1978-1983)

Establishment	Expenditures[1]	Percent
Newfoundland Forest Research Centre	1 218 800	10.4
Maritimes Forest Research Centre	725 900	6.2
Laurentian Forest Research Centre	1 021 900	8.8
Great Lakes Forest Research Centre	2 350 800	20.1
Northern Forest Research Centre	1 336 700	11.5
Pacific Forest Research Centre	1 380 000	11.8
Petawawa National Forestry Institute	1 778 300	15.2
Forestry Statistics and Systems Branch	560 000	4.8
Canadian Forestry Service Headquarters	263 100	2.3
Canadian Forestry Service Headquarters (Forest Engineering Research Institute of Canada)	800 000	6.9
Canadian Wildlife Service	232 500	2.0
Total	11 668 000(2)	100.0

Source: Dendron Resources Surveys Ltd. (1983).

[1] Nominal dollars, summed over 1978-83.

[2] The inconsistency between this total and the data in Table 2.1 is not readily explained. It could possibly be attributable to the fact that Dendron employed estimates for the 1983-84 fiscal year. A second possibility is that Dendron did not accurately disaggregate the total annual expenditures into research and administration.

2) there was regional balance in allocations across CFS establishments;

3) development of methods for biomass inventory and new harvesting equipment was emphasized;

4) it was largely reliant on private sector contractors.

Given the importance of economic performance as an objective for ENFOR research, it is interesting to note that relatively little of the program's budget has been allocated to economic analysis of the role that forest biomass could or should play in Canada's energy supply. Dendron (1983) also observed the relative lack of economic analysis as a component of ENFOR research, and urged a greater role for economic concerns.

It should be mentioned that ENFOR is not alone in its relative lack of economic analysis as a component of its research projects. A similar observation could be made for virtually any of Canada's renewable energy R&D programs, even though they all share the same fundamental economic efficiency rationale. Indeed, the ENFOR program has sponsored studies with a strong economic component (e.g., McDaniels Research 1982; Intergroup Consulting Economists Ltd. 1981); the same cannot be said for some other renewable energy R&D programs.

Evaluation criteria

Overview

When considering the design of an evaluation framework for an R&D program, initial attention should be directed to the Treasury Board's discussion paper entitled *Evaluation of Research and Experimental Development Programs* (Canada Treasury Board 1984). This report carries on in the same vein as the Treasury Board's previous guides to the program evaluation process and departmental functions (Canada Treasury Board 1981). It begins by outlining the basic program evaluation process, and then discusses an array of relevant questions to be considered in an R&D program evaluation.

If the present study were specifically designed as an evaluation assessment of an ongoing program, we would at this point consider a number of the generic R&D program evaluation questions that are raised in the Treasury Board discussion paper (and briefly summarized in Table 6). However, since the ENFOR Program is scheduled to be curtailed after 1988, many of the questions raised in the Treasury Board paper (e.g., regarding program rationale, delivery mechanisms, level of resources, alternatives, and so forth) do not merit careful consideration here. Rather, we must focus on key issues that are relevant for the purpose at hand.

Table 3. Total ENFOR project expenditures by subject (1978-1983)

Subject	Expenditures[1]	Percent
General		
Planning, objectives, policy	117 800	1.0
Socioeconomic studies	158 070	1.4
Biomass availability		
Development of methodology	3 143 540	27.0
Estimation of supply	901 180	7.7
Growth and yield		
Modeling, growth estimation, compilation	230 530	2.0
Intensive silviculture		
General	40 000	0.3
Silvicultural treatments		
Intensive culture, plantations	253 650	2.2
Fertilization, nitrogen fixation	427 900	3.7
Regeneration, reforestation	180 100	1.5
Development of planting equipment	18 100	0.2
Biomass harvesting and transportation		
Reviews, cost summaries, theory	153 947	1.3
Operational trials, production studies	1 387 520	11.9
Development of new equipment	2 724 400	23.3
Environmental impacts		
General theory, studies	899 050	7.7
Nutrient budget	644 180	5.7
Climatic effects	68 300	0.6
Wildlife	232 500	2.0
Conversion of biomass		
Theory, cost summaries	57 233	0.5
Totals	11 638 000	100.0

Source: Dendron Resources Surveys Ltd. (1983)
[1]Nominal dollars, summed over 1978-83.

Objectives as a basis for evaluation

In our view, the key issue to be considered here is the effectiveness of the ENFOR program in meeting its fundamental objectives. Judging from the policy statements and discussion in previous sections, the chief fundamental objective has clearly been to:

> "Improve economic performance by providing research necessary to enhance the displacement of fossil fuels with forest biomass, based on the expectation that biomass would become an economically attractive energy alternative in certain applications."

Yet, as will be seen in subsequent sections, it is impossible to expect that all ENFOR activities lend themselves to direct economic evaluation in terms of improvement in efficiency. Some of the sub-objectives of the ENFOR Program, such as studying the potential extent of the biomass resource, or the environmental effects of biomass harvesting, can only be linked to the economic performance of biofuels in an indirect and tenuous manner. In that case, a second, related objective might be summarized as follows:

> "Provide information relevant for public decisions about biomass energy utilization, which can be directly linked to potential economic benefits of biomass energy."

Table 4. Total ENFOR project expenditures by project type (1978-83)

Project type	Expenditures[1]	Percent
Research and development (excluding equipment development)	5 803 100	49.7
Equipment development	2 725 500	23.4
Demonstrations, operational trials	1 499 600	12.9
Reviews of literature, summaries recompiliations of data	771 900	6.6
Cost analyses, economic feasibility studies	517 300	4.4
Policy and priority statements	350 600	3.0
Totals	11 668 000	100.0

Source: Dendron Resources Surveys Ltd. (1983).
[1]Nominal dollars, summed over 1978-83.

Finally, recalling Dobbs's 1981 statement, a third objective can be inferred as follows:

> "Build expertise within the Canadian private sector, universities, and governments regarding forest biomass utilization for energy."

Both the second and third objectives listed above are clearly related to the first. The federal government's interest in background information about biomass, and in building expertise in biomass, stem from the potential economic efficiency gains that were expected to be derived from biomass when ENFOR began. The second and third objectives are listed separately because the links to economic benefits would be so indirect for these aspects of the program that they require separate evaluation criteria, as discussed below.

Evaluation criteria

Given the fundamental objective and two related objectives that have just been established, what are the criteria to be used in judging whether these objectives have been achieved as a result of ENFOR activities?

Conceptually, selecting a criterion for evaluating progress toward the fundamental economic objective of improved economic performance is straightforward. Some type of economic benefit/cost criterion would ideally be appropriate for evaluating the components of ENFOR research that can be directly linked to economic outputs. However, in practice, implementing an economic criterion to analyze research outputs is a formidable task. Extensive discussion will be required in the following chapters before specific methods for economic evaluation of certain kinds of ENFOR research are presented in Chapter Six.

Evaluation criteria for the second objective are even more difficult to establish. Conceptually, the second objective (providing relevant background information) could be evaluated on the basis of the contribution, or "value," of new information generated by ENFOR research to public decisions about biomass energy policy. Chapter Five provides a conceptual discussion of the "value of information" approach to evaluating research. In practice, this approach would be impossible to implement as a practical evaluation criterion. Thus Chapter Seven discusses noneconomic methods for evaluating research outputs.

Finally, the third objective (building Canadian expertise) is perhaps the easiest for which to specify evaluation criteria. It too is considered in Chapter Six.

Table 5. Total ENFOR project expenditures, (Nominal dollars) by nature of contractor (1978-1983)

Establishment	Private sector	Universities	Federal organizations	Provincial organizations	In-house acivity	Other	Total
Newfoundland Forest Research Centre	1 173 700				45 100		1 218 800
Maritimes Forest Research Centre	368 400	290 000		62 500	5 000		725 900
Laurentian Forest Research Centre	924 800			97 100			1 021 900
Great Lakes Forest Research Centre	2 350 800						2 350 800
Northern Forest Research Centre	1 264 900	71 800					1 336 700
Pacific Forest Research Centre	1 168 200			211 800			1 380 000
Petawawa National Forestry Institute	585 200	1 078 300		106 600		8 200	1 778 300
Forestry Statistics and Systems Branch	165 000		395 000				560 000
Canadian Forestry Service Headquarters	134 100		129 000				263 100
Canadian Forestry Service Headquarters (Forest Engineering Research Institute of Canada)	800 000						800 000
Canadian Wildlife Service	232 500						232 500
Totals	9 167 600	1 440 100	524 000	478 000	50 100	8 200	11 638 000

Source: Dendron Resources Surveys Ltd. (1983).

Table 6. Generic issues in evaluation of R&D programs

Program rationale

- Are the policies or programs the R&D program supports still necessary to meet the socio economic needs of the country?
- Do the conditions that give rise to the program still prevail?
- Are the mandate and objectives of the R&D program consistent with the policies it supports?

Program delivery

- Could the R&D program be restructured so as to be more efficient, either by greater contracting out or greater in-house research?
- Could R&D supported by contributions be more effectively supported by grants, and vice versa?

Operation delivery

- Is the level and distribution of resources adequate?
- Is the size, structure and organization of the R&D program suitable?
- Is the management style appropriate?
- Is the R&D being effectively delivered to the potential users?

Impacts and effects

- Has the probability of achieving the intended objectives changed since the program's inception?
- Is the R&D program perceived as useful by its clients?
- Does the program have a clearly defined clientele?
- Has the program contributed to the training of researchers?

Objectives achievement

- Is the R&D program producing high-quality research?

Conclusions

This chapter has outlined some important considerations that are crucial to designing an evaluation framework for ENFOR R&D. The program's fundamental objectives have been discussed, its activities summarized and evaluation criteria have been introduced. The tasks of developing specific evaluation methods to address these criteria are approached in subsequent chapters. Before that, however, Chapter Three considers a more basic issue: whether economic analysis can be fruitfully applied to evaluate research and development activities.

Chapter three

Can R&D be evaluated in economic terms?

Before embarking on a review of detailed ENFOR evaluation issues, clarification of the conceptual relevance of economic analysis applied to R&D is in order. Thus, Chapter Three considers the following question: "Can R&D projects be evaluated in economic terms?" In answering this question, much of the discussion is drawn from an excellent report recently completed by the Office of Technology Assessment of the U.S. Congress, entitled *Research Funding as an "Investment": Can We Measure the Returns?* (Office of Technology Assessment 1986).

The R&D process

For many years the R&D process was viewed as a linear model, in which innovations began with advances in basic research, that led in turn to applied research, development, and finally a marketable product. This view of the R&D spectrum allowed one to conceive of all research and new knowledge as contributing to a progression that led to economic outputs; consequently, research could be directly or indirectly tied to economic gains. Figure 1, drawn from Bennett and Jaswal (1980), summarizes this progression and the relevant features of these R&D stages, while Table 7, drawn from Organization for Economic Cooperation and Development (1975), provides working definitions of basic, applied, and developmental research.

It is probably accurate to say that analysts have abandoned the linear model that sees a simple progression from basic research to applied research to product development. Instead, they realize that the distinctions between phases are at best ill-defined, that highly successful basic or applied research may never lead to marketed products if necessary linkages do not exist, and that the process often moves in reverse, beginning with recognition of a market need that calls for applied or even basic research. Nevertheless, analysts still believe that scientific research plays a vital role in technological progress and consequently in economic growth (Office Technology Assessment 1986).

Although the notion of a linear progression is flawed, the concept of different phases of R&D, roughly divided into basic, applied, and development, is still useful. These are perhaps best viewed as a continuum with basic research at one end and product development at the other, with no clear divisions between the phases. Such a continuum of research phases will prove useful in later sections where the feasibility of economic analysis is discussed.

Economic returns to R&D

Several trends have combined in recent years to make public decision makers more interested in economic and other quantifiable measures of research success. Technology is becoming an increasingly essential component of economic competitiveness. At the same time, budget constraints are forcing ministries to reevaluate spending and to look for ways to compare the

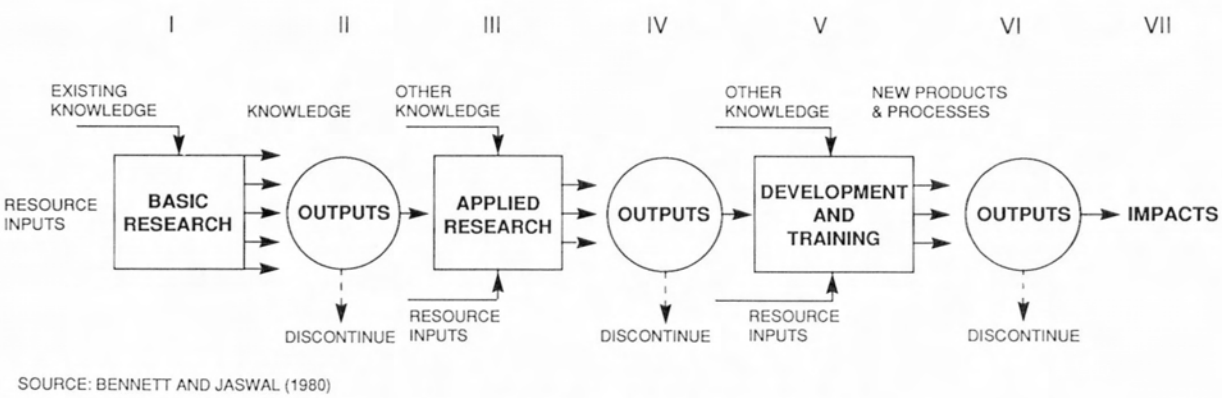

Figure 1. A linear research and development model

Table 7. Definitions of research categories

Basic research

- Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

- Basic research analyzes properties, structures, and relationships with a view to formulating and testing hypotheses, theories or laws.

- The results of basic research are not generally sold but are usually published in scientific journals or circulated to interested colleagues. Occasionally, basic research may be classified for security reasons.

Applied research

- Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.

- Applied research is undertaken either to determine possible uses for the findings of basic research or to determine new methods or ways to achieving some specific and predetermined objectives. It involves the consideration of the available knowledge and its extension in order to solve particular problems. In the business enterprise sector the distinction between basic and applied research will often be marked by the creation of a new project to explore any promising results of a basic research program.

- The results of applied research are intended primarily to be valid for a single or a limited number of products, operations, methods, and systems. Applied research develops ideas into operational form. The knowledge or information derived from it is often patented but may also be kept secret.

Experimental development

- Experimental development is systematic work, drawing on existing knowledge gained from research or practical experience, that is directed to producing new materials, products and devices, to installing new processes, systems and services, and to improving substantially those already produced or installed.

Source: Bennett and Jaswal (1980), citing Organization for Economic Cooperation and Development (1975).

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value of widely divergent government programs; quantification of program success offers the hope for an objective measure that could simplify decisions about priorities for increasingly complex scientific research (Office of Technology Assessment 1986).

An appealing approach to research evaluation would be to view federal research spending as an investment that should produce a measurable economic return. Yet how valid is this metaphor? One way to judge its appropriateness is to review the experience with economic evaluation of the productivity of R&D, both in the private sector and for public research, at the national level and in individual industries.

Econometric studies at the national level

Private R&D investment. Over the past three decades, many economists have attempted to investigate the effects of private research expenditures on technological change and the growth of productivity. Their basic approach employs the notion of a production function that separates inputs to the economy into three groups: capital, labor, and "other factors." The "other factors," or residuals category, includes influences that affect the efficiency of resource use, such as scientific knowledge, technological advance, managerial expertise, economies of scale, or others. In the 1950s, economists recognized that these residual factors have a major influence on economic growth. This notion has provided the basis for numerous studies of the effects of technological change on productivity (Griliches 1979). The U.S. Office of Technology Assessment report (1986) provides a clear summary of this research, which is abstracted below:

> "In the late 1950's economists began to include R&D expenditures (assumed to be a rough

indicator of technological advance) as an input to their productivity calculations, along with capital and labor. Numerous studies found a strong correlation between R&D spending and productivity growth. Looking at R&D as an investment, economists sought to measure its rate of return. Fellner (1970) calculated a 31-55% rate of return for the entire economy. Terleckyj (1974) estimated a 29% return to firm-financed R&D. Mansfield (1965) estimated 40-60% return in the chemical industry and Link (1982) estimated 21% in the petroleum industry.

"More recent in-depth studies confirm the correlation between private R&D spending and productivity increases. For example, a 1974 study by Terleckyj, which analyzed the productivity of entire industries, found that an industry's rate of productivity increase is directly related to the amount of its own R&D and to the amount of R&D carried out by its supplier industries (Terleckyj 1977). Mansfield refined previous work on 20 manufacturing industries by dividing R&D into its basic and applied components. He found a 'strong relationship between the amount of basic research carried out by an industry and the industry's rate of productivity increase during 1948-1966' (Mansfield 1980). In a further study of 37 innovations Mansfield compared the return on R&D for those innovations to the firm making the investment (the 'private return') with the return to society as a whole (the 'social return'). He found a median private rate of return of about 25%, but a median social return of close to 70% (Mansfield 1982)."

As the Office of Technology Assessment report indicates, these studies are representative of the strong and consistently positive correlation found between privately financed R&D and productivity growth in the manufacturing industries. They suggest that econometric analysis of private R&D spending produces estimates useful in evaluation and planning. However, the wide range of rates of return to R&D spending reflects the tentative and hypothetical nature of the methodologies. Each study works with different assumptions and definitions. Results are most definitive and consistent for private spending within one firm or industry, where it is easiest to define and measure inputs and outputs (Office of Technology Assessment 1986).

Social return often exceeds the private rate of return, as a company doing the R&D cannot reap all the benefits from its work. One industry's R&D can produce substantial benefits to other industries and other sectors of society, a difficult output to quantify. In studies by Mansfield and others, the social rate of return was two or more times the private rate of return (Mansfield 1980; cited in Office of Technology Assessment 1986).

In examining the applications of these economic models it should be kept in mind that they are only hypothetical constructs that attempt to describe complex events. One important shortcoming is that the models reveal correlation, not causality. Second, the models do not reveal the path by which R&D investment leads to productivity improvements. Third, the treatment of R&D as "residual" weakens the proof of relationship, since it is entirely possible that other components of the residual exist, but have not been included in the analysis. Finally, the production function approach of neoclassical economics is an hypothesis about the way the world works; it has not been proven that such production functions exist or take the form assumed by economists. For all these reasons the returns on private sector R&D investment reported above should be viewed with caution (Office of Technology Assessment 1986).

Public R&D investment. Econometric approaches have been less successful in establishing a return on publicly funded R&D, particularly at the national and industry levels. Unlike the strong consistently positive correlations found between privately financed R&D and productivity growth in the manufacturing industries, only weak and inconsistent correlations have been found for federally funded R&D. In a 1975 study, Terleckyj found that for the 20 manufacturing industries he studied, "the coefficients for government financed R&D are not statistically significant, and the coefficient for government financed R&D performed in industry is actually negative" (Terleckyj 1977). A decade later Terleckyj reported subsequent studies that confirmed weak indicators and the small effects of government-funded R&D (Terleckyj 1985, cited in Office of Technology Assessment 1986).

Measuring the effects of public R&D spending is far more complex than measuring R&D spending in the private sector. Tracing outputs through the long and nebulous path from basic research to commercial product is especially difficult. A company does research aimed at a specific product or market, controls the entire product development process, manages its marketing, and has a clear record of inputs and outputs. Federal research managers do not target R&D so sharply, have virtually no say in private sector decisions to develop a product, and have no influence and often little knowledge of what is happening in the market (Office of Technology Assessment 1986).

Terleckyj attributes the failure to find a return on U.S. federally sponsored industrial R&D to the fact that "government funded industrial R&D is a public good and therefore is used by all users to the extent where its marginal product is zero." Therefore, according to Terleckyj, its contribution to productivity cannot be observed statistically by traditional techniques and approaches (Terleckyj 1985; cited in Office of Technology Assessment 1986).

The inability to find a meaningful correlation between government funded R&D and productivity increases in the economy as a whole have led economists to examine more closely the indirect impact of federal R&D on privately funded industrial R&D. As the Office of Technology Assessment study indicates, of the research done in the past 6 years government R&D expenditures have been, in most cases, positively related to private R&D expenditures. One reviewer reported a "general impression that Federal R&D is a complement to private R&D efforts," but found a lack of "very good conceptual models of how federal R&D affects private R&D incentives" (Office of Technology Assessment 1986).

Effects of public R&D within specific sectors. Despite the problems in linking government R&D expenditures to productivity improvements in the economy as a whole, studies have shown sector-specific productivity improvements, and measurable economic returns, from certain government R&D programs. This sections looks at analyses of public R&D support of agriculture, a sector where long and heavy dependence on public R&D financing in the U.S. has made it feasible for economists to estimate inputs and rates of return. A brief discussion of R&D returns in other sectors is also provided.

Agriculture is perhaps the best documented of all sectors regarding the economic effects of specific R&D activities. Many studies have been carried out in the past three decades, beginning with Griliches' classic 1958 study of hybrid corn technology (Griliches 1958a). All but one of the studies have shown a very high internal rate of return on public sector agricultural research, as can be seen in Table 8. The studies summarized in Table 8 show rates of return that vary from a low of 21% to a high of 110%, with the vast majority in the 33 to 66% range. Public sector agricultural research has generally been considered to have been a significant success (Office of Technology Assessment 1986).

What are the factors that make agriculture R&D such an attractive public investment? Nelson (1982) summarizes the characteristics that have contributed to this success:

1) Farming is an atomistic industry and farmers are not in competition with each other. Differential access to certain kinds of technological knowledge, or property rights in certain technologies, are not important to individual farmers. This fact means that farmers have little incentive to engage in R&D on their own behalf and opens the possibility that the farming community itself would provide the political constituency for public support of R&D.

2) The U.S. agricultural extension system marshalled that support and put the farmers in a position of evaluating and influencing the publicly funded applied R&D. The system is highly decentralized. The regional nature of agricultural technology means that farmers in individual states see it to their advantage that their particular technologies be advanced as rapidly as possible.

3) A combination of (1) an evolving set of agricultural sciences based in the universities and supported publicly, and (2) applied research and development also publicly funded but monitored politically by the farming community, has made public support of agricultural technology successful. Where private companies are funding significant amounts of innovative work and the industry is reasonably competitive, it is in the interest of the farmers as well as the companies that public R&D money be allocated to other things. A reasonably well defined division of labor has emerged between publicly and privately funded applied research.

One can add a number of other relevant points to this list. First, agriculture has a tradition of experimentation and measurement of results that dates back to Mendel, the father of genetics. Second, the results of any given agricultural experiment are usually known within one or two growing cycles, typically 1 or 2 years. Third, the extension system assures that innovations are adopted rapidly.

Studies of the returns to public R&D in other selected sectors are also summarized in the Office of Technology Assessment report (Office of Technology Assessment 1986). Briefly, Mowery's review of U.S. government support for the aviation sector indicates substan-

Table 8. Studies of the economic returns to agricultural research in the U.S.

Author (Date)	Commodity	Time period	Rate of Return (%)
Griliches (1964)	Aggregate output	1944-59	35-40
Peterson (1967)	Poultry	1915-60	21
Evenson (1968)	Aggregate	1949-50	47
Cline (1975)	Aggregate	1939-48	41-50
Knutson and Tweeten (1979)	Aggregate	1949-58	39-47
		1959-68	32-39
		1969-72	28-35
Bredahl and Peterson (1976)	Cash grain	1969	36
	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
Davis (1979)	Aggregate	1949-59	66-100
		1964-74	37
Evenson et al (1979)	Aggregate	1868-1926	65
		1927-50	95 (Applied R&D)
		1927-50	110 (Basic R&D)
		1948-71	45 (Basic R&D)
Davis and Peterson (1981)	Aggregate	1949	100
		1954	79
		1959	66
		1964	37
		1969	37
		1974	37
Norton and Davis (1981)	Cash grain	1969	31
	Poultry	1969	27
	Dairy	1969	56
	Livestock	1969	30
	Cash gain	1974	44
	Poultry	1974	33
	Dairy	1974	66

Source: Office of Technology Assessment (1986).

tial net benefits accruing as a result of public research. According to Mowery (1985), the "total factor productivity in this industry has grown more rapidly than in virtually any other U.S. industry during the post-war period." The returns to health care research are also reviewed in the Office of Technology Assessment report, with the chief conclusion being that evaluating such research is greatly complicated (if not thwarted entirely) by the issue of setting comparable economic values on well-being, illnesses, and life span (Office of Technology Assessment 1986). Finally, a study by Hertzfeld of the economic benefits due to spillovers (externalities) from NASA space research is also summarized. Hertzfeld (1985) concludes that macroeconomic analysis of the indirect effects of NASA R&D spending "is difficult at best, and perhaps impossible." Microeconomic analysis of NASA R&D effects fared somewhat better, although Hertzfeld stressed that "economic returns are not the primary reason for space investments," and that therefore "no economic measure or calculation can, by definition, encompass the entirety of the return to space investment" (Hertzfeld 1985).

Implications

This brief review of previous studies suggests that the experience with economic evaluation of publicly funded R&D is at best mixed. Clearly aggregate economic analysis of the productivity effects of public R&D have not demonstrated measurable benefits, even though comparable private sector R&D has often been closely linked with growth in aggregate industrial productivity. On the other hand, some sector-specific or even product-specific studies have estimated very high rates of return to certain public R&D activities, particularly in agriculture and aviation. Yet other sector-specific research evaluation studies, such as in health care or space research, have foundered on conceptual or methodological grounds.

What guidance can be drawn from this review, both for the evaluation of publicly funded R&D in general, and for evaluation of the ENFOR program specifically? Discussed below are first, a series of points regarding the overall viability of economic evaluation of public R&D, and second, an assessment of the implications for ENFOR program evaluation.

The following conclusions can be drawn from the previous experience regarding economic evaluation of public R&D.

1) By far the greatest obstacle to placing an economic value on government-sponsored R&D is that improved productivity or producing economic outputs is not the primary justification for most government R&D programs. As indicated in the Task Force Report on federal R&D priorities, the basic justification for public support of R&D is to encourage research that is socially desirable, high risk, or in the national interest (however those terms may be defined), but that is unlikely to be funded by the private sector (Task Force on Federal Policies and Programs for Technology Development 1984). Consequently, for many government R&D programs or research areas, the concept of measuring economic returns is inherently flawed. Examples where program goals can not be linked to economic objectives include basic or applied R&D in the health or space sciences.

2) This does not mean that economic analysis cannot be used in R&D evaluation. For public research programs with specific goals to improve the productivity of particular industries or industrial processes, economic evaluation is not only possible but also important to help set priorities and assess results. Examples of this latter category include agriculture, aviation, energy and transport. In general, the more an R&D program's objectives can be related to government economic goals involving specific industries or outputs, the more amenable it could be to economic analysis.

3) Some methods for assessing the benefits of private R&D seem fundamentally flawed when applied to public R&D. The production function approach, which uses econometric techniques to estimate the importance of various inputs, suffers from a number of problems. First, the technique attempts to measure the aggregate return on previous R&D expenditures, rather than the incremental returns on future R&D, which should be the policy-maker's chief concern. Second, the method emphasizes the comparison of inputs and outputs, while ignoring the complex processes that go on between them. Research cannot result in product development unless each step in the process, from the initial idea to the market, is successful (Office of Technology Assessment 1986). Finally, public R&D spending may be so interrelated with other inputs that it is impossible to precisely measure its effects in econometric studies at the national or industry level.

4) Not all methods can be rejected, however. Those developed to evaluate agricultural research, which involve the estimation of consumers' surplus benefits and benefit/cost comparisons, seem well

suited to measure the benefits of specific product or process innovations. The approach is conceptually that of the social benefit/cost framework, and can rely on actual market data regarding the rates of diffusion as well as cost and benefit information. These methods are reviewed in Chapter Five, and need not be discussed here.

5) The closer a research project is to the product development and marketing end of the R&D continuum, the more readily its benefits can be evaluated in economic terms. Basic research in any field is likely to be far removed from specific markets and processes, while applied research and product development is closer to the eventual market. Thus basic research is less likely, while applied research and development is more likely to be suitable for economic analysis.

6) Uncertainty is perhaps the defining feature of R&D activities; uncertainty is also one of the greatest obstacles to economic analysis. The techniques developed by operations research specialists to conduct economic analyses under uncertainty are conceptually interesting and often applied to R&D in abstract academic papers. But to practically use the techniques of uncertainty analysis, one must be able to quantify, or subjectively estimate probability distributions for key variables, a process that is difficult for many R&D activities (McDaniels Research and Quantalytics 1986). Thus the smaller the uncertainty for a given R&D effort, the more accurate and easier will be any economic analysis. This suggests that *ex post* evaluations, undertaken once R&D efforts are completed, will exhibit less uncertainty about their results than *ex ante* evaluations.

To conclude, one can characterize the Office of Technology Assessment report findings as being quite pessimistic about the viability of applying economic analysis broadly across the whole spectrum of U.S. federal R&D. The only areas in which economic analyses seem appropriate are where program goals can be clearly linked to the economic objectives of improving productivity or creating new outputs in specific sectors, such as agriculture or energy (Office of Technology Assessment 1986). Even in those cases, economic analysis will be more successful when applied to projects at the development end of the R&D spectrum, and will be more accurate when conducted on an *ex post* basis after some of the uncertainties are resolved.

These points are directly relevant to our investigation of methods to evaluate ENFOR in economic terms:

1) As discussed further in Chapter Two, at least part of the objectives of ENFOR are cast in economic terms. Many of the projects funded under ENFOR were specifically intended to contribute to the development of products or processes that could eventually become marketed technology, contributing to forest biomass energy supply. Thus, at least some of the ENFOR projects are closely enough linked to improvement in productivity or creation of marketed products that economic evaluation is conceptually appropriate.

2) The analytical techniques that have been applied for *ex post* evaluation in agriculture and related areas are likely to be the most appropriate for ENFOR evaluations.

3) ENFOR projects at the applied research and development end of the continuum are much more appropriate for economic analysis than projects at the basic research end. For example, one of the major areas of ENFOR research in the early 1980s was the National Biomass Inventory, which involved major research projects in nearly every province (ENFOR Secretariat 1986). Virtually all research for the National Biomass Inventory could be viewed as falling toward the basic end of the R&D continuum, and thus not directly amenable to economic analysis.

4) *Ex post* economic evaluations of ENFOR, as suggested in this study, will involve less uncertainty than *ex ante* evaluations.

Chapter four

Review of methods for economic evaluation

Overview of the issues

Background

Previous chapters have laid the groundwork by indicating that economic criteria are appropriate to gauge whether certain ENFOR objectives have been achieved (in Chapter Two), and that economic evaluation of at least some ENFOR research is conceptually workable (in Chapter Three). The task at hand in this chapter is to review the literature regarding methods for economic analysis of the returns to R&D. Then in Chapter Five, recommended methods for economic analysis of ENFOR Program research are outlined.

Organization of this rather diverse chapter is structured in the following manner. This first section introduces some of the broad issues that arise in applying economic methods to evaluate R&D, and reviews a set of fundamental questions that can be used to narrow the scope of the methods considered. The second section summarizes the application of economic methods to evaluate research in agriculture, with some discussion of forestry and energy as well. Then the third section points out some unresolved issues in economic evaluation of agricultural R&D.

Broad evaluation concerns

Society sponsors public research in order to create new knowledge. Application of this knowledge could result in new technology, new methods or systems, new products, new plant or animal varieties, or new cultural, social, or environmental understanding. These changes could produce net benefits to society through lowering costs, increasing the value of products, raising productivity, reducing risk, or improving social and environmental conditions.

To begin to understand the dimensions of the net benefits associated with research, one must compare the inputs with the resulting outputs. That comparison can perhaps be facilitated by viewing R&D itself as a production process. Research uses scarce inputs (labor, land and capital) to produce an output consisting of new knowledge. To evaluate such production processes, the analyst must, in simplified terms, measure productivity by estimating units of output produced per unit of input. Output is generally best measured in terms of the changes generated by applying the knowledge gained from research. Thus the analyst must evaluate, although not necessarily in dollar terms, the output produced for the inputs required. Of course, this characterization of the process hides many methodological issues, complexities, and pitfalls. Such issues are the topic of interest in this chapter.

If the task is to evaluate the productivity of research, we must consider how this can best be measured. There are two possibilities: physical units and economic units.

Physical productivity. Physical or technical productivity is usually expressed as the quantity of output produced per unit of a particular kind of input. For example, in forestry the productivity of forest land is often expressed as a quantity of cubic metres of merchantable timber per hectare per year.

Simple production functions that use only one input to produce one output are rarely, if ever, valid in the real world. Typically, the production of even a single kind of output requires diverse inputs. Forest land productivity, for example, is usually cast in terms of a particular species, site rotation, age, and set of management practices. This complicates the concept of technical or physical productivity; to characterize the productivity of a process yielding a single output from several inputs, it is necessary to describe the output in terms of each of the input factors. There is no single ratio that characterizes the productivity of such a process.

Many production processes are even more complex, with multiple outputs resulting from multiple inputs. For such processes the concept of physical productivity becomes very complex, particularly since both inputs and outputs are irregular flows over time. Unfortunately, research is almost always this type of production process. The inputs (scientist years, facilities, land, equipment, and knowledge) fed into a research problem area produce a stream of diverse outputs (such as publications of different kinds, aimed at different audiences; talks; demonstrations; and other goods and services). Attempts are often made to characterize the productivity of research activities by some single measure such as publications per scientist-year, or some other output category. A more complete characterization of the process would require a comprehensive set of productivity relationships for the different outputs and inputs. However, the diversity of inputs and outputs would make the resulting set of productivity relationships unwieldy for comparisons between research activities (Risbrudt 1984).

Complex production processes can sometimes be compared by using what might be termed partial productivities. Productivity of such a process is expressed as units of a single type of selected output (such as the number of referreed journal articles, in research) per unit of a single type of selected input (such as per scientist). But then any comparisons made between different production processes should account for the effects that differences in joint inputs or outputs may have on the productivity ratio in question. Taking these joint influences into account can be difficult (Risbrudt 1984).

Quantifying outputs in physical terms is even more difficult. Are the outputs of research the physical things it produces: the publications of research papers, notes, and journal articles; computer programs; workshops; field trips; and other goods and services? Or is it the actual knowledge contained in these physical products? Risbrudt argues that scientific knowledge is by definition the outcome of scientific research, i.e. of investigation conducted with the method and the aim of science. Thus, the primary outputs from the research process would seem to consist of new data, information, and knowledge. In what units are these quantities expressed?

It should be clear that there are no fully accepted approaches for evaluating the productivity of research in physical terms. Any single productivity measure, such as publications per scientist-year, is at best only one element of a multi-dimensional expression of research productivity, the ratio of one of many outputs to one of many inputs (Risbrudt 1984). Perhaps turning to a common unit of measure, such as dollar or economic value, will help clarify this problem.

Economic productivity. Faced with diverse outputs and diverse inputs of a production process, economists would suggest weighting all outputs and inputs with their respective market price-per-unit (or dollar values derived by other means) and perhaps by a time-weighing factor (the interest rate). The quantities of each kind of output, multiplied by the price per unit, establishes the total "value" of that output in common terms, such as dollars. These values for diverse outputs can be summed to get the total benefits from the process. Similarly, the input units multiplied by their respective prices can be summed to obtain the total cost of the process. Then the economic productivity of the process can be expressed as the ratio of outputs to inputs, i.e., benefits to costs. If both benefits and costs are in the same units of value and have been derived using the same value-determining system, then the benefit/cost ratio is an "index number" demonstrating the economic productivity of research activity (Risbrudt 1984).

A brief mention of the principles of social benefit/cost analysis may be appropriate at this point. Benefit/cost analysis is an analytical tool superficially similar to discounted cash flow analysis, although it differs in a number of important respects. Most important is that the analysis takes place from the perspective of society as a whole, rather than that of a private investor. Thus social benefit/cost analysis attempts to determine how a proposed change (in outputs, technology or policy) would affect the well-being of society. To accomplish this task, benefits are measured in terms of the increase in well-being, or economic values to be created by the proposed change, while costs are measured in terms of economic values, or opportunities, foregone. The interested reader will find a more complete discussion of benefit/cost principles in the Treasury Board guide (Canada Treasury Board 1976), or in Mishan (1983).

The benefit/cost ratio would appear to offer a simple indicator by which one could express the efficiency of a production process, including research. But to employ this measure, one must be able to establish comparable unit values, hopefully in dollar terms, for all inputs and outputs. Failing that, then, at the least, all outputs must be valued with a common approach, and all inputs valued with a (perhaps different) common system. If the two valuation approaches differ, then one can no longer express productivity as an index number, but as the ratio of the units of output value per unit of input value (Risbrudt 1984).

Thus, the difficulty in economic evaluation of a research activity arises in trying to establish unit values of the inputs and outputs. Generally, the unit-values of inputs can, to a large degree, be estimated by using market prices for those inputs, assuming the market prices provide a reasonably good approximation of social values. In other words, the assumption would be that in a large part the differences in salary rates appropriately reflect different skill levels that may affect research output (Mishan 1983).

A much more difficult problem arises in attempting to determine a unit-value of research outputs. What are the determinants of such a value? There is no uniform unit of knowledge produced by research (Boulding 1966). Each research production process in unique, as is each output. There is not a market place to which sellers come with uniform new knowledge in order to find willing, fully informed buyers. Indeed, the output from public research has the unusual characteristic that it is typically offered without charge to potential consumers; in that case, establishing a unit-value for research outputs (however defined) that can be valued by society in benefit/cost terms is difficult.

At this point, it may be useful to recall the notion of a continuum of research with basic research at one extreme and product development at the other. If the analyst must rely on values-in-use in order to evaluate research outputs, then clearly an examination of activities at the applied and development end is more feasible. This observation is of course in keeping with the concluding points of Chapter Three.

Emphasis on applied research as the better candidate for economic evaluation raises an interesting distinction. The value of basic research is usually established primarily within the scientific community, often by a small segment of that community within a single discipline. On the other hand, the value of applied research is established outside the research community, and is judged by criteria other than it contribution to scientific knowledge (Gold 1977, as cited in Risbrudt 1984).

The foregoing discussion should indicate that methods for evaluation of research can rapidly become complex. It is therefore important to give careful thought to how the evaluation process should be focussed, in order to concentrate on key issues. Narrowing the focus of the ENFOR evaluation methods is the topic of concern in the following section.

Key questions

All evaluators of research must wrestle with several basic issues before beginning an evaluation. The scope of methods considered can be narrowed, and the chances for eventual success increased by answering a number of questions at the outset.

Perhaps the key question is that of purpose: why evaluate? Who will be the users of the evaluation results, and how will the information be used? Once that fundamental question is answered, several other basic questions can be resolved. These questions outline the desired characteristics of the evaluation. Following Bengston (1983) these questions include:

1) Is the evaluation to be qualitative or quantitative?

2) Is the evaluation to be based on economic or noneconomic criteria?

3) Are there measn to measure the financial, economic or socioeconomic impacts of research?

4) What viewpoint should be taken (agency, regional, national, international)?

5) What level of aggregation is most appropriate (i.e., project, program, commodity, sector or the entire economy)?

6) Is an *ex post* or *ex ante* evaluation most appropriate?

7) what distributional concerns are to be addressed?

8) What impacts are of secondary interest? (e.g., environment, employment)?

Answers to these questions in regard to the ENFOR Program can be derived from the discussion in previous chapters, which in turn is influenced by priorities set by the study's Scientific Authority. The purpose of an eventual ENFOR program evaluation is to provide information to central agencies (e.g., Treasury Board, the Ministry of Finance, the Comptroller General) and to the Canadian Forestry Service regarding the economic benefits of the program. This information will apparently not be used in decisions regarding the continuation of or funding levels of ENFOR, since the program may be slated for termination in 1988. Rather, the information will provide a retrospective assessment of the accomplishments of ENFOR, emphasizing aspects that can be gauged in economic terms.

Such an assessment will be useful for a number of purposes: for informing decision-makers regarding the success of biomass energy research, for helping to guide future decisions about biomass energy R&D, for informing ENFOR program managers about where the returns to their research have been greatest, and to help provide further experience with and perspectives on the economic evaluation of renewable energy R&D.

Answers to the questions regarding the desired characteristics of the evaluation are as follows: the evaluation is to be quantitative, emphasizing the economic effects, and approached from the national viewpoint. The level of aggregation should be that of the project (or sets of projects) so that specific technology applications can be evaluated. Of course, the ultimate interest is in evaluating the whole ENFOR Program. But in order to evaluate such a diverse program in economic terms, the analyst must essentially evaluate each of the component projects. The evaluation is to be conducted on an *ex post* basis; distributional concerns can be addressed where relevant; and secondary impacts should be de-emphasized, although they merit discussion in some contexts.

Existing methods and applications

Agriculture

As indicated in Chapter Three, agriculture is by far the most important area in which economic evaluation of publicly funded R&D has been successfully conducted. The purpose of this section is to review the analytical methods that have been employed for those evaluations. The types of methods discussed here are of course shaped by the nature of the planned ENFOR evaluation; for example, *ex ante* approaches are not discussed to any real extent.

This discussion has greatly benefited from the excellent review article by Norton and Davis (1981) which discusses methods of evaluating agricultural R&D. The interested reader can obtain a more thorough introduction to this topic by referring to their work.

Norton and Davis (1981) suggest a useful taxonomy for classifying the approaches that have been applied in economic evaluations of research. They divide these approaches into two major categories: *ex post* and *ex ante* techniques. *Ex post* techniques are further subdivided into the consumer and producer surplus (CS) approach and the production function (PF) approach. Norton and Davis note that the *ex ante* benefit/cost (BC) approach is conceptually very similar to *ex post* CS analysis, with the major distinction being that the CS approach is apparently static; thus, it does not compare the flows of benefits and costs through discounting. They also note that a BC evaluation is often appended to a CS study by extrapolating suitably discounted benefits into the future, and by calculating internal rates of return (Norton and Davis 1981).

We find the distinction between the CS and BC approaches arbitrary and somewhat confusing. In subsequent sections we refer to the CS and BC approach jointly as CS-BC, based on the premise that all reasonable CS studies should consider the flow of benefits over time, allowing total benefits and costs to be compared through discounting. Discussed below are key elements of the *ex post* CS-BC approach, as we call it, followed by a less detailed discussion of the PF approach.

CS-BC Approach. Earlier sections indicated that because new knowledge cannot itself be valued in market terms, economists are often forced to value the benefits of R&D based on the values-in-use of technological innovations that are created. The CS-BC approach is the archetypical example of that general evaluation principle. The CS-BC approach was pioneered by Griliches, in his seminal 1958 analysis of the benefits of hybrid corn (Griliches 1958b). That work has inspired many subsequent studies that have built on Griliches' framework (e.g., Schmitz and Seckler 1970; Tosterud et al. 1973).

Griliches set out to quantify the changes in consumer and producer surplus that had occurred because of the hybrid corn innovation. To measure these changes he estimated how the supply curve of corn had shifted downward (meaning a given quantity of corn is available at lower cost) due to hybrids. The beauty of Griliches' approach lies in its simplicity: he assumed all benefits of hybrid corn research were realized in the form of increased consumer's and producer's surplus; he handled changes in supply and demand parameters by assumption.

Briefly, consumer's surplus can, for our purposes, be generally defined as the area below a demand curve and above a line indicating the price, in a supply and demand graph. It is the unpriced increment of value that accrues to consumers. Producer's surplus can be approximated as the area below the price line but above the marginal cost curve. Mishan points out that producer's surplus is nothing but a type of factor rent accruing to producers (Mishan 1983). More technical explanations of the different types of consumer's and producer's surplus can be found in Currie et al. (1971). The sum of producer's surplus, consumers' surplus and any other resource rent equals the net social benefits or social surplus of an activity.

Griliches (1958a, 1958b) attempted to calculate the loss in net social surplus (net benefits, in a social benefit/cost sense) that would occur if hybrid corn were to disappear. His analysis assumed that the adoption of hybrid corn shifted the supply curve of corn down and to the right; he then estimated the returns for two polar cases of perfectly elastic supply and perfectly inelastic supply. His approach has the advantage of simplicity in that the calculation of neither supply nor demand elasticities is required.

The literature extending Griliches' approach is enormous. Peterson (1967) generalized Griliches' formula for estimating changes in net social surplus and applied it to poultry. He calculated the case where supply is neither perfectly elastic nor perfectly inelastic and did not require a demand elasticity of minus one as did Griliches' formulae. Schmitz and Seckler (1970) extended the model to take into account the shadow price of labor saved by an innovation. Ayer and Schuh (1972) altered Griliches' model to incorporate a cobweb behavioral assumption for cotton producers in Brazil. Akino and Hayami (1975) used an approach similar to that of Ayer and Schuh to estimate the social benefits of plant breeding research in Japan. Hertford and Schmitz (1977) provided an approach for estimating the net social surplus when the supply and demand curves are linear and the supply curve shift is parallel. Duncan (1972a and 1972b) estimated the benefits of research that increases the productivity of a resource that is an input toward a final product (e.g., pastureland as an input for cattle production). Various studies (Tosterud et al. 1973; Kislev and Hoffman 1978) have measured net benefits by estimating an increase in production and valuing this at a constant price (i.e., assuming a perfectly elastic demand curve and vertical supply curve). Norton and Davis (1981) provided graphs and further details of the methodologies employed in these and other studies.

What comparisons can be drawn regarding the approaches of these various studies? The chief issue is the extent to which they differ in the ways the supply and demand curves are specified, and in the nature of the supply curve shift. The more thorough discussion in Norton and Davis (1981) indicates the functional forms used in the various studies, which should demonstrate their specific differences. Generally, though, Norton and Davis (1981) provide the following comparisons.

There are major differences in the nature of the supply shift assumed. Griliches assumes a parallel shift (horizontal or vertical); Peterson a proportional shift; Hertford and Schmitz a parallel shift; Akino and Hayami a pivoted shift; Lindner and Jarrett (1978) and Rose (1980), four types of shifts. The type of shift assumed is important because divergent shifts result in fewer total benefits to producers than parallel or convergent shifts. Duncan and Tisdell (1971) have shown, for example, that producer returns for research will be negative when research leads to a divergent supply shift and when demand is inelastic (Norton and Davis 1981).

Another area for comparison is in the specification of supply and demand curves. Griliches, Hertford, and Schmitz, and Lindner and Jarrett assume linear supply and demand curves. Peterson assumes a general specification, Akino and Hayami constant elasticity supply and demand curves, and Rose a linear linked supply curve and a linear demand curve. These differences are likely to be of minor importance in determining net benefits, according to Norton and Davis (1981).

A common parameter estimated in most of these studies is K, the percentage change in the price of the good due to the innovation (i.e, P/Pi). Much attention should be devoted to evaluating K since its size is a major determinant of net benefits. In some cases it is easier to measure K as an output effect (horizontal shift in the supply curve) and in others as the reduction in the supply curve. This distinction between a horizontal and vertical supply shift is really an artificial one. When yield increases due to technical change this also means that the same output can be produced at a lower cost (Norton and Davis 1981).

When using a particular formula for a CS approach, one must be careful to use the type of K which corresponds to it. The formula developed by Hertford and Schmitz includes K as a vertical shifter. Akino and Hayami use K as a production function shifter and provide a formula for converting it to a horizontal supply function shifter. Peterson measures K as the proportional change in equilibrium quantity following the supply shift, which is less than Hertford and Schmitz's horizontal distance between the supply curves (Norton and Davis 1981).

Production function approach. The second major approach used in evaluating benefits of agricultural research is the production function (PF) approach. This approach will only briefly be reviewed here. As summarized by Norton and Davis (1981), the basic model of the PF approach has been specified as:

$$Q = A \bullet \prod_{i=1}^{m} \bullet X_i^{B_i} \bullet \prod_{j=0}^{n} \bullet R_{t-j}^{\alpha_{t-j}} \bullet e^{u}$$

where Q = value of agricultural output; A = shift factor X_i = i^{th} conventional production input; R_{t-j} = expenditures on research (and extension) in the t-j^{th} year; B_i = the production coefficient of the i^{th} conventional input; α_{t-j} = the partial production coefficient of research (and extension) in the t-j^{th} year; and u = random error term.

The basic technique is to estimate equation (1) or a similar specification econometrically. The coefficient estimate for M then indicates the change in Q (output) that would occur if R (spending on research) is increased by one unit. In other words, M is an estimate of a partial derivative (or a partial regression coefficient), that indicates the marginal effect on total output, of increased research, holding all else in the regression constant (including input levels for land, labor and capital).

According to Norton and Davis (1981), the major differences between studies using a model similar to equation (1) have been in the specification of the length and shape of the time lag for the impact of research expenditure on output. Early studies, such as the pioneering work by Griliches (1964), used either a single year's expenditure or a simple average of 2 years. However, more recent studies, for example, Evenson (1967, 1968), Fishelson (1968, 1971), and Cline (1975) have developed theoretical reasoning and presented some empirical evidence which lends weight to the use of an inverted 'V'-shaped or 'U'-shaped distribution. The studies also have attempted to empirically determine the appropriate length of this time lag. For example, for the United States, the consensus suggests a mean lag of 6 to 7 years (Norton and Davis 1981).

Cross section data have mainly been used in the estimation of the type of model described in equation (1). Some studies have used the aggregate level of output as their unit of study (e.g., Griliches (1964) and Davis (1979)), while others (e.g., Peterson 1967) have applied the model to different community groups. Studies using time series data have adopted an alternative model specification: the majority have used a Cobb-Douglas productivity function.

In view of Norton and Davis' study (1981), the production function approach has proven to be a useful means of isolating different influences on agricultural production. The effect of research in one area can be separated from education, conventional inputs, or from research in another geographical area. It also allows one to estimate a marginal as opposed to an average rate of return. One of its major limitations is the data required. It is very difficult, for example, to obtain data on production inputs such as labor, machinery, or chemicals applied on individual commodities. Another limitation is the uncertainty involved with projecting past rates of return into the future.

Comparison of CS-BC and production function approaches. Norton and Davis (1981) provide an interesting summary table that compares the features of the various evaluation approaches. Their table is represented here as Table 9. For completeness, it includes a summary of both *ex post* and *ex ante* techniques, even though the latter are not relevant in this context.

Judging from Table 9, the CS-BC approach holds significant advantages over the PF approach for the type of analysis required for the ENFOR Program. The benefits of specific projects or of the whole program can be considered; required data are much less extensive; and the value of a greater variety of research activities can be assessed. Moreover, the results of the PF approach (that is, the marginal contribution of research holding all else in the production process constant) are less relevant for new products such as those under development by ENFOR. Finally, Chapter Three discussed a number of problems with the production function approach that have arisen in aggregate industrial output studies. These shortcomings are also relevant to commodity applications of the PF approach, as in agriculture. In sum, the CS-BC approach as developed in agriculture is the more sound candidate methodology for evaluation of ENFOR R&D activities.

Forestry

Evaluation of research in forestry is a much more recent development than in agriculture. For example, the U.S. Forest Service only initiated a major program regarding evaluation of forestry research in 1984 (Risbrudt 1984). Based on interviews completed in 1985, the Canadian Forestry Service does not typically undertake economic-based evaluations of its research activities. It is thus reasonable to say that methods for evaluation of forestry research are for a number of reasons much less well developed than in agriculture. These reasons include the long lives of trees, differences in industrial structure, and the nature of the agricultural extension system.

A brief review of the objectives and structure of the U.S. Forest Service program evaluation of forestry R&D may be useful. As Risbrudt (1984) indicates, the 5-year program will involve three major tasks:

Task 1: Identify potential users of forestry research evaluations, determine their uses for evaluation results, and specify their information needs.

Task 2: Assess the suitability of existing research evaluation methods for use in evaluating forestry research.

Task 3: Development and adaptation of evaluation methods.

From Risbrudt's description it is clear that the overall purpose is to develop and test the practicality of theoretically sound methods for evaluating forestry research. The implication is that the research managers perceive a need for further research to refine methods, rather than simply adapting methods that have been employed in other contexts.

As a precursor to the new U.S. Forest Service program, a conference was held in 1982 and a book subsequently published discussing methods for economic evaluation of forestry R&D (Hyde 1983). Some chapters of the book reviewed the Norton and Davis (1981) summary of agriculture R&D evaluation methods (discussed in the previous section) and outlined further studies that were planned to apply these methods to forestry. Three such studies have been reviewed and their methods and results are summarized below.

Perhaps the most interesting study was one completed by Bengston (1984), regarding the economic benefits of research activities that developed structural particle board. Bengston's approach follows the CS-BC model pioneered by Griliches (1958); it involves estimating shifts in supply curves of structural wood based on panels because of the lower production and transportation costs of structural particle board relative to plywood. Benefits are estimated on the basis of changes in consumer's and producer's surplus, while research costs are estimated on the basis of publication counts, and an assumed average cost per publication.

As discussed in a previous section, the assumed forms of the supply and demand curves, and the nature of the supply shift are the chief determinants of benefits when the CS-BC approach is employed. The interesting twist of the analysis in this study was that it involved changes in the supply and price of a substitute product, which complicated the model. Bengston's model involved analysis of the quantity demanded and prices for structural particle board, and the change in demand for plywood resulting from the introduction, in order to estimate the total changes in social surplus. Lacking econometric supply and demand curves, Bengston approximated the gross annual research benefits through the use of data regarding the price of structural particle board, the price of plywood, and estimates of parameters $\underline{K}$ (the percentage decrease in the price of structural particle board compared to plywood) and $\underline{n}$ (the price elasticity of demand for structural particle board). After annual benefits are estimated, forecasts of prices and quantities are made for future years, in order to calculate the stream of future benefits (Bengston 1984).

A second study by Bengston (1985) outlines an alternative approach to research evaluation that utilizes index numbers. Bengston observes that studies of individual innovations are sometimes criticized because they focus only on highly successful research efforts. His response is to develop an aggregate level approach, comparing the relationship between research and productivity in an entire industrial sector. He employs an index number approach which uses growth in productivity per unit of input to measure the value of resources saved due to more efficient production techniques. Bengston applies this approach to wood products industries through the use of an index he constructs for factor productivity and technical change in the lumber and wood products industries.

By way of illustration, Bengston estimates that had the 1973 output of the U.S. lumber and wood industry been obtained with the techniques and productivity that prevailed in 1958, that output would have cost 38% more to produce (or $4.8 billion 1958 dollars) than was the actual cost in 1973 (in 1958 dollars). This increased productivity (and resulting cost savings) is assumed to be completely attributable to the benefits of wood products research (Bengston 1985).

The final study to be reviewed here is by Westgate (1985) who analyzed the net benefits of research regarding containerized tree seedlings. Westgate adopted a CS-BC approach, along the lines of Bengston (1984), which in turn followed the methodology of Griliches (1958b). Benefits were estimated in terms of the supply curve shift and resulting CS benefits due to the introduction of containerized seedlings, while costs were again estimated on the basis of publication costs and assumed unit costs per publication. The derivation of benefits involved estimating the price of containerized seedlings, the price of bare root seedlings, the quantities of containerized and bare root seedlings, the parameter K (the percentage decrease in the price of containerized seedlings over the price of bare root seedlings), and the parameter n (the price elasticity of containerized seedlings).

In sum, the existing work in forestry emphasizes the CS-BC approach similar to evaluations in agriculture. The current efforts to develop and test new evaluation methods for forestry research suggest that there is room for advancement of these methodologies.

Table 9. Comparison of evaluation approaches

	Ex post approaches			*Ex ante* approaches		
	CS	PF	BC	SM	SI	MP
	Capabilities					
1. Determine distributional effects on consumers and producers at various income levels (benefits and costs)	yes	no	yes	no	yes	no
2. Quantify spillover effects	no	yes	no	no	yes	no
3. Consider secondary impact on employment	yes	no	yes	yes	yes	no
4. Determine effects on relative productivity of input categories	no	yes	no	no	yes	no
5. Evaluate basic research	no	yes	no	yes	yes	no
6. Evaluate benefits to research projects or program	yes	no	yes	yes	yes	yes
7. Consider value of maintenance research	yes	no	yes	no	yes	no
8. Consider economic policy effects	yes	yes	yes	yes	yes	yes
9. Evaluate benefits to aggregate research	yes	yes	yes	no	yes	no
10. Estimate average rate of return	yes	no	yes	no	yes	no
11. Estimate marginal rate of return	no	yes	no	no	yes	no
12. Consider the lags involved research and extension	yes	yes	yes	yes	yes	yes
13. Quantify public sector-private sector interaction	no	yes	no	no	yes	no
Total number of questions approach can address	8	8	8	5	13	3
	Costs					
1. Relative cost in researchers' time	low	interm.	low	interm.	high	interm.
2. Relative cost in scientists' time	low	low	interm.	high	interm.	interm.
3. Relative cost in administr-ators' time	low	low	low	high	low	interm.
4. Relative data requirement	low	high	low	low	variable	interm.
5. Usually requires a computer	no	yes	no	no	yes	yes

Source: Norton and Davis 1981.

Definitions

CS = Consumer and producer surplus
PF = Production function
BC = Benefit/cost
SM = Scoring model
SI = Simulation
MP = Mathematical programming

Renewable energy

Since the mid-1970s, renewable energy R&D has received an enormous amount of attention regarding *ex ante* evaluation of research options. Two factors account for this attention. First, the successive energy crises of the 1970s led to billions of dollars being allocated to renewable energy research. Naturally, questions were asked as to how these funds should be spent. Second, renewable energy R&D entails many diverse, complex, and expensive research options. This variety raises questions about how options should be compared. A review of the literature regarding *ex ante* methods used for renewable energy R&D evaluation in the U.S., as well as an examination of methods for estimating technology costs and market size, is presented in McDaniels Research and Quantalytics (1986). Roessner (1981) also presents an extensive discussion of R&D project selection models that have been employed by the U.S. Department of Energy.

Although the efforts devoted to *ex ante* methods have been formidable, remarkably little attention seems to have been given to *ex post* evaluation of renewable energy R&D. Only one published account of such an evaluation could be located. A recent report by the U.S. Office of Technology Assessment (1986) indicates that the U.S. Department of Energy employed an elaborate, quantitative evaluation scheme to evaluate its Basic Energy Science program in early 1980s. This program was not limited to renewables, but rather they dealt with the gamut of basic research in areas such as physics which were related to energy technologies. Forty small review panels used a formal rating system to evaluate a random sample of projects, based on the criteria of researcher quality, scientific merit, scientific approach, and productivity. However, no economic criteria were considered (Office of Technology Assessment 1986).

In sum, renewable energy R&D evaluation presents a somewhat strange dichotomy. Methods for *ex ante* project selection appear to be very well developed, while methods of *ex post* economic evaluation appear virtually non existent.

Unresolved issues

This section discusses three unresolved issues that have arisen in the course of reviewing the existing studies that employ *ex post* research evaluation methods. The first two involve questions of how the benefits and costs of a given research project should be circumscribed. The third issue is the most open-ended and conceptually demanding. It involves an exploration of how decision theory could possibly be applied to evaluate the information generated by research activities that are far from the product development end of the spectrum and closer to basic research.

Which costs to count?

As Bengston (1983) points out, defining and measuring the relevant costs of research presents some vexatious problems. Most important is the problem of valuing apparently unrelated, or even parallel, research efforts that may have contributed indirectly to that research activity being evaluated. For example, the development of structural particle board was probably facilitated to some extent by unrelated research on the characteristics of hardwood resources in the United States. Should such costs be included in an evaluation of SPB research? Similarly, most agricultural research evaluations have only included the costs of production oriented research extension. This approach will likely underestimate the true costs, since many other types of research (e.g., economics research) ordinarily contribute to the successful adoption of an innovation (Bengston 1983).

It seems clear that the more conceptually appropriate approach is to include the costs of all relevant research that has contributed to an innovation, including unfruitful research efforts. In practice, however, such an all-encompassing approach is almost never adopted. The difficulty arises in defining how a parallel (or an apparently unrelated) research activity has contributed to the development of a given innovation.

A second and contrasting question is how far back to start counting costs. Research always builds on previous work, so the point at which one begins to count costs is somewhat arbitrary (Bengston 1983). Evaluators should solve this problem by only counting research costs that occur after a conceptually relevant starting point for research on the innovation in question, and treating all previous research as sunk costs.

Which benefits to count?

Various chapters of the book edited by Hyde (1983) suggest a case study of research that contributed to the development of the southern pine plywood industry as a test of evaluation methods. The innovation in question was the development of high-speed cutting lathes and lathe changers that veneers from the smaller southern pine logs.

In commenting on this planned case study, Dutrow

(1983) raises an extremely important point that is germane to many research evaluation contexts. Should an evaluation of research regarding the high speed lathe be credited with *all* increases in consumer's and producer's surplus that resulted from development of the southern pine industry? Many factors, particularly economic ones, contributed to the growth of that industry, according to Dutrow. He cites low labor costs, proximity to eastern markets, and a plentiful pine resource as contributing factors. Should not net benefits from that industry be attributed individually to each of these contributing factors, along with the lathe innovation? Dutrow suggests that there would have been little growth in the southern pine plywood industry without those economic and resource conditions. On the other hand, those conditions made the southern forest industry ripe for expansion in general, with or without the plywood industry (Dutrow 1983).

Dutrow is on the right track when he raises the issue of development "with or without" the southern pine plywood industry. A solution to the question can be obtained by careful specification of the "with and without" cases regarding a specific innovation. That is, an evaluation of research on southern plywood technology should begin with a thorough assessment of what would have happened to the southern pine resource had the lathe innovation not been developed. Perhaps a major pulp and paper industry would have developed instead, which would itself be the source of considerable net benefits. The calculation of the net benefits of the plywood technology must take into account all opportunity costs, including foregone opportunities to utilize those resources in other industries.

A related question arises in evaluation of a particular technology that will be applied repeatedly in future projects. Say an innovation occurs regarding containerized seedlings that lowers their costs in all subsequent years. Should that research be credited with the present value of all future cost savings? Does this not raise the possibility of double counting, insofar as future evaluations of containerized seedlings relative to, say, bare root stock, will reflect the lower costs that result from that research?

The answer is straightforward. Indeed, research that creates an innovation lowering the cost of containerized seedlings should get credit for the present value of future benefits in subsequent applications, so long as careful attention is paid to the "with and without" criterion. Then, any future evaluations of the choice between containerized seedlings and any alternative should be based on costs of containerized seedlings at that time. Double counting does not occur because the subsequent evaluations should be based on technology as available when the innovation is made.

The value of information approach: a digression

Previous sections have indicated that because the direct output of research, new knowledge cannot be readily evaluated in economic terms; the analyst must conduct evaluations indirectly, based on the outputs from innovations generated from that new knowledge. This implies that research near the development end of the research spectrum is far more readily evaluated in economic terms than is basic research. Yet, as Mansfield (1981) points out, all research has a potential value, even research that fails to achieve its objectives. That value lies in the scientists' ability to better shape future research because of information learned from previous failures. Similarly, basic research clearly has an economic value, at least theoretically that arises from applying new basic knowledge in subsequent basic and applied research.

Both of these examples suggest a potential avenue for evaluating research that is less clearly linked to product development and innovations: the value of information approach. Decision theory provides a conceptual framework for evaluating the benefits of new information based on the effects of information on subsequent decisions.

The value of information approach might be relevant to an evaluation of the ENFOR Program because the largest single area of research supported by ENFOR involved a national biomass inventory. Those research activities cannot be readily linked to the development of specific products, and thus fall toward the basic research end of the spectrum. Yet the information produced by the biomass inventory is clearly valuable in terms of our understanding of the national biomass resource and its potential role in the national energy economy.

The concept of value of information arises within decision analysis (Behn and Vaupel 1982), which is essentially decision theory as applied to real-world problems involving uncertainty. The following simple example will illustrate the concept. Suppose your local bookmaker offers you the following gamble. He has an urn that contains red and black marbles. An honest mutual friend assures you that the urn contains exactly 100 marbles, and that at least ten are red. The bookmaker offers you the chance to pay $100 in exchange for the opportunity to draw one marble from the urn. If it is red, you win $1000. If it is black, you win nothing. Should you take the bet? The information you have allows you to place the probability of drawing a red marble at a minimum of 10%. Since your estimate of the expected payoff on the bet (.10) ($1000) is equal to the amount you would pay ($100), you would likely only accept the wager if you are "risk neutral" or "risk seeking." But since most people are "risk averse" (unwilling to take even-money bets for large sums), you may hesitate. The bookmaker sees you are wavering. He offers you two options:

(1) Pay $5 and get an opportunity to "sample" the urn by drawing 20 balls and counting the number of red balls in that sample (i.e., obtain imperfect information).

(2) Pay $15 and get an opportunity to count the total contents of the urn to determine the precise number of red balls (i.e., obtain perfect information).

Say you opt for the latter choice, pay $15 and determine that there are precisely 20 red marbles in the urn. You then know the true expected payoff of the bet is $200. The value of knowing the true probability (i.e., perfect information) is equal to the "true" expected pay off ($200) less your prior estimate of expected payoff ($100), less the cost of acquiring the information ($15), or $85. Note that the new information does not eliminate the uncertainty, but rather gives you the best possible probability estimates over the outcome.

One sees that the value of information concept entails a stringent set of decision rules and information requirements in order to be successfully applied. The requirements are:

- a specific decision to be made that involves an uncertain outcome;
- probability assessments over the possible outcomes;
- knowledge of the payoffs of the outcomes;
- an explicit statement of attitude towards risk;
- a willingness to make decisions on the basis of "expected utility" theory;
- the opportunity to purchase new information that will reduce the uncertainty by giving updated estimates of the probability of potential outcomes;
- and, a decision-maker that follows Bayes' Rule to revise estimates once new information is available.

All these concepts are discussed at greater length in Behn and Vaupel (1982).

How relevant is this theoretical construct for evaluating R&D initiatives? In an innovative 1980 article, Norton and Schuh (1981) discuss various methods of evaluating social science research as applied to agriculture. The article provides an example of an evaluation of price forecasts, used by farmers to obtain updated estimates of future commodity prices, as one basis for crop planting decisions. This is the only example that could be located of the value of information approach as applied to R&D. In that example, all the requirements of the value of information approach could be met, by assumption if not in fact. A specific decision by farmers was at hand, and one could construct a prototype framework to analyze decisions regarding the selection of crops for planting in order to maximize the farmer's expected utility. One key assumption is the existence of prior and updated probability distributions regarding prices for commodities as well as other relevant cost and output data.

In an evaluation of ENFOR research, specifically the research comprising the National Biomass Inventory program, the context is not nearly so well suited to a decision analytic approach. It is true that the National Biomass Inventory program has provided new information that can be used to derive probability estimates of volumes and costs of biomass fuels. However, there is no clear-cut, explicit decision to which that information appears directly relevant. The information produced by this program will in general be relevant to broad renewable energy management and policy decisions, but less so to specific decisions about investments or biomass harvests in particular locations. Even if a particular decision context were identified, one would have difficulty in arguing that the decision could or would be made on the basis of expected utility maximization, assuming prior and updated probability assessments. Finally, knowledge of the possible outcomes associated with biomass policy or investment options is at this point difficult to predict, so the returns of various outcomes can only be vaguely estimated.

In sum, while the value of information approach is theoretically relevant to evaluating certain components of ENFOR R&D activities, the analytical framework and the web of assumptions needed to use this approach make it impracticable. We must resort to noneconomic and non-decision analytic approaches to evaluating these basic research activities, as explored later in Chapter Six.

Chapter five

Economic methods for evaluating the ENFOR program

Overview

The purpose of this chapter is to recommend economic methods for evaluating ENFOR research projects. It draws heavily on previous chapters in which methods used for research evaluations in sectors such as agriculture were reviewed. In addition, this chapter draws on previous work completed by the consultants regarding economic evaluation of renewable energy incentive programs and renewable energy policy analysis. Organization of this chapter proceeds in the following manner. The first section discusses the recommended overall approach, while the next section considers important factors in determining the benefits, which essentially involve questions about the nature of demand and supply curves associated with forest biofuel technology applications. In the third section, analysis of costs are discussed. A concluding section draws together these points.

Approach

To begin, the basic approach must be clarified. On the basis of the discussion in Chapters Three and Four, the consultants believe the CS-BC approach should be adopted for economic evaluation of ENFOR Program projects. The reasons for this choice are straightforward: the data requirements are less extensive, a wider range of research can be accommodated, the necessary focus on projects contributing to the development of technology applications is possible, and the conceptual link to new products is more straightforward.

The next issue is the nature of the projects to be analyzed. The evaluation approach should be structured so that it is relevant to *technology applications*, which combine an energy source and conversion technology to produce a marketed (or marketable) energy product (McDaniels and Quantalytics 1986). In the case of the ENFOR program, the energy source will invariably be forest biomass in some form. The technology aspect would refer to technical components that produce some type of usable energy product from biomass. This wood-based energy product could find application in the pulp and paper sector as boiler fuel, as fuel for lumber dryers in the forest sector, for cogeneration of electricity and steam in various contexts, for liquid fuels, or in other applications.

Once the focus on bioenergy technology applications is established, the thrust of the CS-BC analysis becomes clearer. The demand and supply curves of interest are those that describe the price and quantity combinations for a given biofuel source in a given location. ENFOR research relevant to a given biofuel technology application could create an innovation that shifts the supply curve, providing benefits because the quantities demanded become available at a lower price. The issue at hand in this chapter is to recommend methods to evaluate such an innovation.

The approach should be capable of evaluating a single project, or a group of projects, that led to an innovation for a given technology application. Finally, it merits repeating that only certain types of ENFOR-supported projects are potentially amenable to economic evaluation with the CS-BC approach. Other types of projects could be analyzed with noneconomic methods, as discussed in Chapter Six.

Potential benefits of ENFOR

Overview

In Chapter Four we pointed out that analysis of benefits is generally the most troublesome aspect of any R&D evaluation. This difficulty is particularly evident in developing an evaluation approach for the ENFOR program. Perhaps the most concise and direct way to discuss the issues of benefit estimation is as a series of discrete topics, presented below.

Recall that when the CS-BC approach is employed, the benefits of R&D activity are evaluated on the basis of supply and demand curve shifts. Thus the benefits are sensitive to assumptions regarding the nature of supply and demand curves for the good in question. Similarly, assumptions regarding price changes, the elasticity of demand, and the nature of the supply curve shift can also be important. These and other issues are discussed below in the context of ENFOR benefit calculations.

Demand considerations

1) Assumptions regarding the nature of demand curves for biomass fuels are particularly troubling for the ENFOR program analysis. The planned approach to this question when the proposal for this study was first prepared was essentially to ignore demand considerations. We reasoned that because the ENFOR program has since 1982 been concerned only with the production of biomass, rather than its utilization, the benefits should be measured by the *potential* economic benefits arising from downward shifts in biofuel supply curves, while demand curves could be ignored. However, upon close examination, we found this assumption unworkable. The supply curves for biomass fuels would be unbounded upwards (that is, they would show infinite quantities available at infinitely high cost) if demand considerations were ignored completely.

2) Some background will be useful in order to understand the issues affecting demand curves for biofuels. Biomass fuels compete with fossil fuels (primarily heavy oil, natural gas, or coal) and, to a limited extent, electricity. A decision to utilize forest biomass in place of a fossil fuel is largely made on the basis of their relative costs, when all capital and operating costs for the alternative fuels are considered. Thus the rapid increase and subsequent decline in oil prices in recent years have had drastic effects on the demand curves for biofuels. As the price of substitute fossil fuels has fallen, the demand curves for biomass fuels have shifted in and downward, meaning users are willing to pay less for a given quantity of biomass in a given market context. In sum, the demand curves for biomass fuels are as unpredictable as are fossil fuel prices. The implication is, of course, that the benefits of ENFOR R&D are equally as unpredictable.

3) Another factor strongly affecting biofuel demand is that the types of energy users who would likely find it feasible to use forest biomass in place of fossil fuels are relatively few. Moreover, the bulkiness of biofuels means they are expensive to transport. Biofuel demand is thus completely region-specific or even location-specific; demands at one location are quite likely to be completely different from demands in a location only a short distance away. Thus, any rigorous analysis of demand should be conducted on a site-specific basis, taking into account the nature of the users, infrastructures, and the relative fuel costs at each location.

4) Even if it were possible to accurately forecast fossil fuel prices, and even if the regional distribution of demands were carefully modelled, other factors would still make it difficult to project the demand curves needed for a CS-BC analysis of biofuel technological innovations. When conducting a benefit/cost evaluation, the values (or prices) that form the basis of the demand curve for the product should fully reflect the marginal social values of all types of social benefits derived from that product. Part of the challenge of the social benefit/cost approach is to impute market values to outputs or benefits from the innovation, resource change, or proposed policy under analysis, even when those outputs are not valued in conventional markets. Examples of situations where market information is not adequate to value certain outputs include externalities (such as adverse or beneficial environmental effects), or when prices are set by administrative convention (i.e., by government fiat) or by market power (i.e., monopoly) rather than in competitive markets. (See Treasury Board (1976) or Mishan (1983) for a more complete discussion of these problems.)

5) There are three types of potential benefits associated with the utilization of forest biomass energy products, and thus with ENFOR research, that cannot be directly evaluated on the basis of market prices. These are (1) the value of reduced risk of oil import disruption, (2) the value of reduced environmental costs from former waste disposal practices for forest biomass waste, and (3) the value of reduced environmental costs from conventional oil and gas exploration, development, refining, and transport.

6) Briefly, even though Canadian energy prices now reflect world prices, and the price of oil has fallen dramatically in 1986, there is still risk of a future disruption of oil supply and thus there are potential costs of relying on oil imports that are not reflected in the import price. To the extent that using forest biomass reduce the demand for oil imports, biomass products provide unpriced benefits in terms of reduced risk of import disruption costs. However, quantifying these potential benefits is well beyond the scope of this study, and has proven too troublesome to be attempted in previous evaluations of renewable energy incentive programs (McDaniels Research 1984 a,b). The expected utility

of avoiding such costs may be more closely associated with the variance in import prices over the last decade than with their current mean level.

In sum, any benefits from reduced risk of import disruption are too complex to be built into any demand curves for biofuels associated with ENFOR innovations. Further discussion of these conceptual and practical issues is found in McDaniels Research (1984b).

7) The two types of benefits associated with reduced environmental costs are similarly too complex to be treated here. Those benefits are so site-specific and so difficult to treat in marginal terms that they could not be sensibly imputed as part of the social demand curve analysis for a given biofuel technology innovation.

8) The conclusion to be drawn from points 2 to 6 is that analysis of the demand curves for biomass fuels associated with ENFOR innovations is extremely complex. It seems clear that the evaluation of ENFOR R&D must rely on a number of simplifying assumptions in order to proceed. Of course, virtually all the evaluations of R&D activities discussed in Chapter Four also included simplifying assumptions.

9) Two possible, alternative simplifying assumptions that could be made would be to assume that biofuel demand curves are either perfectly elastic at a given price, or perfectly inelastic at a given quantity. Both of these assumptions have been employed in previous evaluations of R&D (e.g., Griliches 1958 a, b), but have been applied to supply curves, not demand curves. As indicated in Chapter Four, a perfectly elastic demand curve implies that no matter how large the quantity, all available supply will be used at the going price. One example would be the demand for wheat from a given farm. Conversely, a perfectly inelastic demand curve implies that no matter how high the price, a specific quantity will always be purchased. An example would be demand for a necessity such as salt. Either assumption would require considerable abstraction before it would appear applicable to biomass energy. Nevertheless, of the two, the assumption of perfectly elastic demand seems more in keeping with the nature of the bioenergy marketplace. The difficulty that arises in implementing this assumption is in selecting the appropriate price at which the perfectly elastic demand curve should be placed.

10) Using a perfectly elastic demand curve requires the selection of the appropriate price, while a perfectly inelastic demand curve requires the selection of the appropriate quantity. Either choice is problematic for biofuels. On one hand, market studies (e.g., Cogeneration Assoc. 1985; Canadian Resourcecon 1983) have indicated that at the margin, in most locations, there is little or no incremental demand for biofuels that remains unfilled at current energy prices. Thus, in many locations the marginal price that incremental biofuel supplies would command is zero. This is evidenced by the vast supplies of unused, relatively good-quality, low-cost hog fuel that pose major disposal problems in the British Columbia interior. Certainly in that region one could not attach a positive price to incremental biofuels. On the other hand, if energy prices had continued to grow at the rates envisioned in the beginning of the 1980s, and if energy resources had been priced on the basis of their marginal social values in Canada over that period, the situation today (1987) would be very different (McDaniels Research 1982). Biofuel demand and utilization would be much higher than current levels, and it seems clear that positive prices for incremental biofuel production would be expected in many locations. This difficulty simply underscores the complexity of ascribing demand curves to biofuels.

11) Perhaps the simplest way of treating demand curves would be to assume a perfectly elastic demand curve at an arbitrarily high price, say \$75 or \$100 per ODt. This approach would be in keeping with the reasoning outlined in the proposal for this study; that is, the ENFOR program has been concerned with biomass production and not with utilization questions. Following that reasoning, the evaluation would be based on *potential* economic benefits that would accrue if biofuel prices and utilization levels become high enough so that the potential cost savings associated with ENFOR innovations can be achieved.

12) A second, more difficult approach would be to employ perfectly elastic and perfectly inelastic demand curves as the two polar cases to bound estimates. The price and quantity levels for these two cases could be set according to market conditions in each region, trying to accommodate the concerns outlined previously as much as possible, and also based on expectations regarding long-term energy market conditions in each region. In addition, the analyst would have to estimate the demand curves based on regional conditions for the

quality and type of biofuel to be produced by the technology associated with the ENFOR research in question. This approach is too complex to be workable in most if not all cases.

13) A third (and the most difficult) method of treating demand issues would be to attempt to estimate downward sloping demand curves for the type of biofuel in question, for each region, for each relevant year. The timing of demands is potentially a major factor in determining benefits, since it is well known that diffusion of innovations does not occur instantaneously. There is an extensive literature on the factors affecting, and the modelling of, the market penetration of renewable energy technologies. Appendix B in McDaniels Research and Quantalytics (1986) provides a detailed review of these issues. This third method, although theoretically the most appropriate, is clearly unworkable in the context of an evaluation of ENFOR research.

14) It seems clear that the analysis of benefits of ENFOR research requires that simplifying assumptions be made when considering the demand for biofuels. The simplest and most pragmatic method is to assume the demand curve is perfectly elastic at some arbitrary high price, such as $75 or $100 per ODt. This method reflects the assumption that the ENFOR program has an objective of increasing biofuel supply, but is not concerned with demand issues.

Supply analysis

1) The analysis of supply curves is potentially more straightforward. The main reason is that the first study of this three-phase research project developed supply curves for various biomass fuels in regions all across Canada (McDaniels Research 1985). That study's findings can be used as the basis for estimating the shapes of existing supply curves. The nature of the shifts in these supply curves due to innovations resulting from ENFOR research can then be handled through assumptions. The process of making supply curve estimates is discussed below.

2) Briefly, the Phase I study developed a computerized method to estimate the quantities and costs of forest biomass fuels available from (typically) five different sources in each region. These sources included mill residues, forest residues, noncommercial stand conversion and the harvest of surplus materials and plantations. The basic approach in the Phase I study required the consultants to estimate probability density functions for the production and transport costs for each of these categories of biofuels. The spreadsheet template developed for the study then calculated the distribution of the quantities available at various total costs for each source.

3) The basis for the required estimates of production costs was an extensive review of over 70 different forest engineering publications dealing with processes and equipment for obtaining biomass fuels from either forest residues or harvests of non commercial stands. The cost estimates presented in these publications were summarized in a data base that comprised an appendix to the Phase I study. Both ENFOR publications and many other reports from the United States and Canada were reviewed for this data base.

4) In the data base, the production processes upon which the cost estimates in a given report were based were also summarized. Thus one can obtain cost estimates (from this data base) for various processes that are appropriate in different terrain or forest types.

5) In the body of the Phase I report, cost distributions for the recovery of biomass fuels from the various sources are provided for each region. These estimates were produced by the consultants and the study's scientific authority, based on a review of the data base or production costs studies. It is important to recognize that these estimates of probability distributions for production costs are subjective, and are based on our review of the information at hand. Of course, these subjective estimates have a major effect on the supply curves for various sources in each region.

6) In order to analyze the benefits associated with an ENFOR research project, one must first identify the technology application that was the intended purpose of that project. For example, a project intended to develop a machine for a particular type of forest residue recovery process would involve a technology application to produce marketed biofuel from a particular type of forest waste.

7) The next step would be to identify the regions in which this technology application could be employed. The factors to consider in identifying these regions would include the type of terrain, the

forest stand type, and the machinery type. These data are summarized in the cost model of the Phase I study, and a broad set of the relevant regions could be identified through sorts of the data files comprising that model. (See Chapter Five of McDaniels Research (1985a) for a brief summary of how these sorts are accomplished.) However, the process of identifying regions where the technology could be employed is complex, and not one that can be conducted entirely by sorting the data bases in the Phase I study. Discussions with Canadian Forestry Service personnel familiar with both the technology and the regions in question would likely also be required to develop the final list.

8) Once the relevant technology application, fuel source, and regions are identified, the key question becomes: how have the supply curves for the particular source in these regions been affected by the ENFOR research project? At this point, the analyst must review the studies that comprise the basis for the cost estimates in the model. In most cases, these are identified in (or obvious from) the data base. If the ENFOR research project in question is not one of the studies that comprise the basis for the estimates, the process is straightforward. The analyst must review the cost data in the relevant ENFOR project report and assess how the supply curve estimated previously would be shifted as a result of the ENFOR research. If the ENFOR study in question *is* one of the studies providing information for the existing estimate, the procedure becomes complex. One must review the data from the studies other than the relevant ENFOR report, and determine what the estimated supply curve *would have been in the absence of* the ENFOR study in question. After that, the supply curve incorporating the ENFOR study can be used to estimate the resulting supply shift[3]. In practice, few ENFOR studies are likely to fall in the latter category.

9) As discussed in Chapter Four, the assumed nature of the supply curve shift is an important determinant of the benefits in a CS-BC economic analysis of an R&D project. There are various approaches to estimating such shifts, which require varying amounts of data. In the extreme, a complete slate of estimated costs and quantity would be available from the research project, meaning the supply curve would simply be drawn, not estimated. More typical is the case in which only partial data are available, at best providing one or two numbers on a revised supply curve. There are no hard rules to be followed by analysts in estimating supply curve shifts. One suggestion is that a careful review be completed of both previous and new information on the relevant costs. The second and more concrete recommendation is that supply curve shifts be treated as parallel shifts, unless there is evidence to indicate a different approach. As Chapter Four indicated, some previous research evaluation studies have assumed parallel supply curve shifts (Griliches 1958 a,b).

10) It is possible that the results of an ENFOR research project could indicate a supply curve shift upward, not downward, or a supply curve that is more dispersed than previously estimated. These situations would mean that the biofuel product would cost more, or that there is a greater range in costs than previously supposed. These findings would not necessarily mean that the benefits of the research project are negative. Rather, an analysis of the benefits would have to proceed in terms of value-of-information analysis as discussed in Chapter Four, rather than the conventional CS-BC approach.

Gross benefits analysis

1) Analyzing the gross benefits of a research project requires that the demand and supply curve estimates be combined, assuming a perfectly elastic demand curve at an arbitrarily high price such as $100/ODt, and estimating an old and new supply curve. One then obtains the situation illustrated in Figure 2. The *increase* in area under the demand and supply curves due to the shift in supply determines the *potential* gross annual benefits. As discussed previously, these are potential benefits in that they assume demand is great enough to absorb all production with costs up to $100/ODt. This assumption is in keeping with the ENFOR program's focus on biomass production (supply) issues and not on biomass conversion (demand) issues.

2) How should future potential benefits should be

(3) At this point, the reader might ask why the data base and model in Phase I *included* ENFOR studies as a source of information, if that model is to be used to evaluate the benefits of these same projects. The answer is that the Phase I study was originally intended to analyze the benefits of *new* ENFOR proposals, not studies that had already been completed. Chapter One of this report explains the change in study objectives that occurred as this Phase II study was beginning.

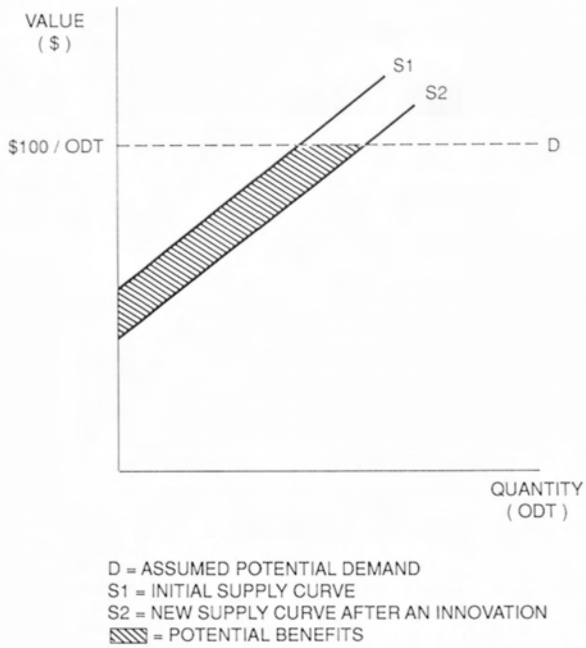

Figure 2. Potential Benefits.

considered? We recommend calculating the discounted present value of this stream of future potential benefits at discount rates of 5 and 10%, in keeping with the Treasury Board guidelines (1976). Discounting should be calculated over the economic life (say, 25 years) back to the year in which the research project began. Benefits should begin the year after the research was completed. Again, it should be stressed that the results will indicate *potential* discounted gross benefits, because, as mentioned earlier, demand is not explicitly considered, and also because the time necessary for the potential innovation to diffuse into the bioenergy marketplace has not been explicitly addressed. Thus, one should *not* view the resulting gross benefit estimates as actual, realized gross benefits in the social benefit/cost sense. Rather, the figures indicate potential benefits that could be realized once demand reaches the assumed level.

ENFOR costs

Analysis of ENFOR project costs is far more straightforward than analyzing benefits, and can be briefly outlined in point form below.

1) As suggested in Chapter Four, the conceptually appropriate approach is to include the costs of all relevant research that has contributed to the development of an innovation, including unfruitful research efforts, that were incurred after a relevant starting point. Research that occurred before that starting point should be treated as sunk costs.

2) Perhaps the best sources of information on the costs for an ENFOR research project (or set of projects) are scientific authorities and principal investigators of projects. These individuals should be contacted to determine whether research projects outside the obviously relevant set indirectly contributed to the technology innovation of interest.

3) The relevant date at which to start counting costs should be the beginning of the fiscal year in which the project started. All costs before that date can be treated as sunk costs.

4) The actual direct budget and years of expenditure for the project or projects in question can be determined from ENFOR records. In addition the indirect costs of contract administration, program organization and administration, as well as information dissemination must be considered. These joint costs can be apportioned to the individual projects as a pro-rated share (based on the ratio of a specific project's direct costs to all projects' direct costs, for the years in question) of the ENFOR program's total annual overhead costs for the years the research project was actively conducted.

5) The discounted present value of direct and indirect costs should be calculated at interest rates of 5 and 10%, discounted to the year in which the project's direct expenditures commenced.

Comparison of benefits and costs

The results of the previous steps can be summarized in two ways: as a benefit/cost ratio (*B/C*), and as a net value (*B-C*). It merits repeating that these summary measures can*not* be viewed as indicative of net social benefits from an ENFOR research project in the conventional benefit/cost sense. Rather, these calculations would reflect *potential* net benefits, not realized net benefits, for reasons outlined earlier.

Conclusions

This chapter has provided a series of instructions for conducting benefit/cost evaluations of ENFOR research projects. Certain simplifying assumptions were required to adapt the CS-BC analytical structure that has evolved in previous evaluations of agricultural research. By far the most important assumption is to the one regarding the nature of demand curves for biomass fuels. This assumption was deemed necessary (and appropriate) because of the complex issues associated with biofuel demand analysis, the current state of the biofuel market-place, and the emphasis of the ENFOR program on supply issues. It should be stressed that this assumption will have a major influence on the results of any subsequent ENFOR evaluations, and on the interpretation of those results.

Chapter six

Noneconomic evaluation methods

Overview

Chapter Two established that while the primary objective of the ENFOR Program is economic, some of the program's sub-objectives cannot be closely linked to economic performance criteria. These sub-objectives include: 1) creation of information to assist in management of biomass resources; and 2) creation of expertise in biomass energy. To evaluate progress towards these objectives, some type of noneconomic evaluation approach is necessary.

The purpose of this chapter is to review methods for noneconomic evaluation of R&D, and then identify the methods that are potentially applicable to evaluation of those ENFOR activities which cannot be evaluated in economic terms. The chapter's organization follows that structure. First, we review methods for noneconomic evaluation, then we discuss their applicability for ENFOR. The treatment is brief, in keeping with our primary emphasis on economic evaluation.

Review of methods

Chapter Three began with a brief discussion of the linear view of R&D, in which basic research leads to applied research, development and a final product. Figure 1 illustrated such a model, while Table 7 provided definitions of its stages. The chapter pointed out some of the flaws in that view of the innovation process, indicating that analysts have generally recognized that it is an incomplete representation of the innovation process. Nevertheless, the notion of a continuum of R&D activities, with basic research at one extreme and product development at the other, remains informative.

We refer to that model at this point because the separate stages in the R&D process have different characteristics, and these characteristics lead to different possibilities for R&D evaluation methods. Bennett and Jaswal (1980), in a report for the Planning and Evaluation Sector of Energy, Mines and Resources Canada, provide a summary of their views on the applicability of various evaluation methods (noneconomic and economic) to different R&D stages. Their table is reproduced here as Table 10. Bennett and Jaswal (1980) provide little justification for their assessments of method applicability, although their views seem inherently reasonable. In essence, they see noneconomic methods such as peer review, citation analysis, and publication counts as most appropriate at the basic research end of the spectrum, and economic methods (benefit/cost analysis) appropriate at the product development end. This is certainly in keeping with the discussion in Chapter Three. Bennett and Jaswal's reference to probabilistic methods would more appropriately be termed "rating scales" or "subjective multiple criteria assessment," given the example they provide. "Probabilistic methods" would more aptly refer to the use of probability distributions to incorporate uncertainty in a benefit/cost framework, or, for *ex ante* evaluation contexts, to the reliance on decision analytic techniques that involve probability.

Another perspective on the applicability of noneconomic evaluation methods to research evaluation is provided by the Treasury Board's discussion paper on evaluation of R&D programs (Canada Treasury Board 1984). That report identifies two key approaches to R&D evaluation:

- an approach to determine client satisfaction; and
- possible approaches to determine quality of R&D.

To determine client satisfaction, the Treasury Board (1984) report recommends client surveys. To determine the quality of R&D, the report recommends various methods including peer review, publication counts, citation analysis, and other indicators such as the number of awards, reports, or patents.

In sum, Bennett and Jaswal (1980) and Canada Treasury Board (1984) suggest similar approaches to noneconomic evaluation of R&D. The reports differ in the taxonomies they use to define R&D evaluation contexts. One could theoretically combine the two sets of recommendations into a three-dimensional matrix that matches methods to R&D stages and evaluation contexts. However, such a matrix could not be reproduced graphically and would add little to the discussion al-

Table 10. Applicability of noneconomic evaluation methods to research stages. The larger the number of asterisks, the more relevant and applicable, and hence more important, is the evaluation method.

Evaluation Method	I Basic Research	II Basic Research Output	III Applied Research	IV Outputs of Applied Research	V Develop-ment & Testing	VI Outputs of Development & Testing	VII Impact on Clients
Peer review - value analysis	***	***	**	**	*		
Client survey	*			**		***	
Cost-benefit				*		**	***
Indicators							
- Patents	*			**		***	
- Publications	***			*		*	
- Citations	***			*			
Productivity			*		***		
Probabilistic methods		*		***			
Organizational characteristics	***		***		**		

Source: Bennett and Jaswal 1980.

ready presented. A more pressing issue is a better description of the key concerns and steps involved in these evaluation methods, as considered below.

Description of methods

The following discussion of methods is largely drawn from Bennett and Jaswal (1980), Canada Treasury Board (1984), and the Office of Technology Assessment (1980).

Peer Reviews. Peer review refers to an evaluation of a program by persons of similar rank in the scientific community, skilled in the disciplines in question. This approach to evaluation is especially relevant for basic research, although it may be used at other stages also, and is normally concerned with an evaluation of quality rather than the effectiveness of the work. The National Research Council in Canada and the National Bureau of Standards in the U.S. both rely heavily on peer reviews (Bennett and Jaswal 1980). Some of the chief concerns in developing a peer review process include:

- identifying knowledgeable peers who are willing to act as reviewers;
- selecting peers who have no conflict of interest (e.g., who do not receive grants from the program or coauthor papers with R&D program professionals);
- developing a suitable rating instrument; and
- ensuring confidentiality.

A multiple criteria approach to peer evaluation has been adopted in several studies. Some of the criteria that could be used in a peer review to rate published articles or reports are (Canada Treasury Board 1984):

- overall research quality;
- raising of important theoretical issues;
- contribution of an important method;
- resolving a recognized controversy;
- contribution of important data;
- leading the field in an appropriate direction; and
- provision of new ideas for other investigators.

Some of the criteria used in evaluations of broad programs and technical functions (such as those of the National Bureau of Standards in the U.S.) include:

- importance and priority of projects;
- quality of staff;
- equipment needs;
- finances;
- relation to mission of the organization.

Peer review seems to be a valuation tool in evaluating the quality of R&D. Because of its subjective nature, it is often used in conjunction with numeric indicators, as discussed in following sections.

Client surveys. This method is especially relevant for evaluation of government R&D, with its multiplicity of objectives and broad spectrum of clients. It is well suited to addressing the question of the usefulness or relevance of R&D.

The objectives of the survey and questions to be posed should be well planned, since this can be an expensive technique. The survey should be concerned with the client's assessment of the usefulness of new information provided by R&D. Some of the assessment concerns include:

- the scientific quality of published information;
- presentation and format, accuracy, accessibility, timeliness, and usefulness;
- availability of alternate sources for the data; and
- monetary value of the information to the user.

There are several data collection methods:

- mail out/mail back;
- interviews;
- telephone surveys; or
- combinations.

Bennett and Jaswal (1980) stress that the procedure to be used should be decided with care, and preferably in consultation with specialists.

Bibliometrics. "Bibliometrics" refers to the use of quantitative indicators, particularly counts of publications, citations and patents, to evaluate R&D in terms of both quality and quantity. The Office of Technology Assessment (1986) provides an extensive discussion of the first and second generation activities comprising bibliometrics. Briefly, bibliometrics arose from the search for ways to study science, apart from interacting with the scientists themselves. Bibliometrics researchers saw the need to study the process, structure, and products of science, through research on the science literature. With the creation of the *Science Citation Index*, the science literature became an enormous data base containing information regarding the interconnections, productivity, and importance of research organizations.

Bibliometric evaluations have grown in number and sophistication since the 1960s, as computer power became more accessible and data bases were expanded. Bibliometric studies are often used in conjunction with peer reviews, in a process sometimes termed "convergent indicators" (Office of Technology Assessment 1986). Some of the key concerns in bibliometric studies involving various measures (e.g., publications, citations) are discussed below.

Publication counts. A common technique for judging the performance of an R&D program is to simply count the number of papers produced during the relevant period. While this is a straightforward procedure, it has some important drawbacks which reduce its effectiveness as an evaluation method:

- the counts reflect quantity more than quality;
- the counts may be misleading due to multiple articles dealing with the same work in different journals or conference proceedings;
- in some disciplines, especially new ones, the communication of scientific or technical information may not be done via journals or articles; and
- some employers actively discourage open literature publication for reasons of either commercial or military secrecy.

Frame (1983) points out a number of fundamental questions that must be answered before an evaluator can begin to collect and analyze data:

- What publications are to be included in the evaluation?
- What data sources should be used?
- What time period should be examined? What time lags should be considered to allow for lags between completion of research and publications?
- Should only those publications that are directly

associated with the objectives or field of study of the program be included?

- How should one take account of the wide variations in publication rates between disciplines?

- What control group is most suitable to use for baseline comparisons?

Publications are most valid as an indicator of performance in contexts where one research objective is to contribute to scientific knowledge. In an applied R&D program, the application of science to new products or processes is likely more in line with program objectives (Canada Treasury Board 1984).

Citation analysis. Citation analysis is a more sophisticated version of publication counts. There are also several drawbacks to using citations as a measure of R&D quality. The Treasury Board (1984) identifies some of the distorting influences affecting the use of citation measures:

- the inability to cite the output of secret military and commercial proprietary industrial research;

- the reliance upon personal communication, rather than on formal communications channels (e.g., reports or articles) for the exchange and transfer of technical information;

- the repetition of similar articles by the same author(s) to present the same findings;

- the excessive citations of associate investigators; i.e., the "I'll cite you and you cite me" routine;

- the differences between fields in their citation behavior and publishing practices;

- the habit of self-citation;

- the fact that only the first author of a multi-author paper is used in the citation system;

- the variation in how much emphasis is devoted to disseminating the research; and

- the variation in how extensively an article submitted to a journal is refereed.

Martin and Irvine (1983) note the following as additional problems in using citation analysis:

- authors with identical names;

- clerical errors in preparing the citation index;

- incomplete coverage of journals;

- "Halo effect" citations (citing a well-known author);

- variation of citation rate of a paper due to either initially unrecognized advances, or integration of the major advance into the pool of common knowledge; and

- critical citations, that is, citing authors for their poor research or the unreliability of their findings.

Citation measures cannot be properly used until several years after the publication of research findings because of the substantial time lags involved in publication. Such delays are one of many factors which are leading to the growth of technical reports, the appearance of "shadow" or "gray" literature, and to more reliance on computer communication networks. Because of the time delay, citation measures are best applied to long-term R&D activities. Despite these problems, many studies have shown the results of citation analysis are highly correlated with peer reviews and subjective measures of research quality. Thus, it is a valuable technique in particular evaluation contexts (Canada Treasury Board 1984).

Technical report counts. In contexts where restrictions on publication in the open literature exist, counts of internal technical reports may be a suitable substitute indicator. As with publications in the open literature, the number of technical reports is more a measure of quantity than quality of R&D output. Moreover, emphasis on only the number of reports in a given time period could encourage production of repetitive pieces rather than solid, high-quality reports.

Other methods. In addition to the methods just discussed, Table 10 lists a number of other approaches. Benefit/cost measures were extensively reviewed in Chapters Four and Five; probabilistic methods were mentioned briefly earlier in this chapter and are discussed at length in McDaniels Research and Quantalytics (1986); productivity measures were discussed briefly in Chapter Three; organizational characteristics and patent counts were not discussed because they are likely irrelevant to ENFOR research; further details of these latter two approaches are found in Bennett and Jaswal (1980).

Application to the ENFOR program

What potential do these various methods hold for evaluation of the ENFOR program? To answer that question, we must return to the noneconomic objectives of the program, discussed in Chapter Two:

- creation of information to assist in management of biomass resources; and
- development of national expertise in biomass energy.

The selected evaluation methods are presented below, while implementation is addressed in Chapter Seven.

Creation of management information

The chief example of program activities falling under this objective is the National Biomass Inventory program; others include environmental research and similar topics. Chapter Five indicated that a value-of-information approach could theoretically be used to analyze the economic contribution of new information to biomass resources management decisions. However, we demonstrated that this approach would be impossible in practice. Once the objective has been established, and once the economic criteria are deemed inappropriate, the next step is to determine the appropriate noneconomic criteria. It seems that both the *quality* and *usefulness* of information produced by ENFOR would be appropriate evaluation criteria. The task remaining is to select the appropriate indicators and methods for judging these criteria.

Research under the National Biomass Inventory program, as well as other information-related ENFOR work such as environmental research, might be classed as either basic research or research falling between basic and applied research. Table 10 indicates that the most relevant evaluation approaches for these stages of research include:

- peer reviews;
- publication counts; and
- citation analysis.

In a similar vein, the Treasury Board (1984) recommends these same methods as appropriate for evaluating the quality of R&D; it also recommends client surveys as appropriate for judging the usefulness for R&D.

Given the nature of ENFOR both citation analysis and publication counts can be ruled out as evaluation methods. The dominance of the private sector among the contractors, and the relative lack of emphasis on contributions to the open scientific literature, suggest that these methods would be inappropriate here. Instead, the following methods are recommended:

1) To evaluate the *quality* of ENFOR research designed to generate biomass management information, peer review is the appropriate method.

2) To evaluate the *usefulness* of ENFOR research designed to generate biomass management information, client surveys are the appropriate method.

Development of national expertise

This objective essentially refers to fostering a national capability in biomass research, including expertise in forestry, environmental science, engineering, and economics. None of the evaluation methods discussed earlier seem directly applicable to this objective. Instead, creativity is needed to establish an appropriate criterion and method.

Perhaps the most straightforward approach would be to document the number of professionals active in biomass research before 1978 in terms of their experience, research areas, and qualifications. Then a similar exercise could determine the pool of professionals presently active, again documenting experience, research areas, and qualifications. Care would have to be taken to determine the incremental effects of ENFOR on this increase in national expertise. That is, the increase due to ENFOR and that due to conventional market forces or pure scientific interests would have to be established. To document these changes, a nation-wide survey of researchers would be required.

Chapter seven

Implementation

Implementing the methods presented in the previous chapters is the topic of concern here. Discussed below are key issues and recommendations for using both economic and noneconomic evaluation criteria within the context of a prospective ENFOR program evaluation.

Economic methods

1) Because the fundamental objective of ENFOR is economic it is clear that economic methods (e.g., benefit/cost analysis) should be a key aspect of any ENFOR program evaluation. Yet, previous chapters have at many points stressed that *ex post* economic evaluation of R&D is at best a difficult process, rarely applied in renewable energy contexts. In Chapters Four and Five, effort was devoted to establishing workable approaches to the theoretical and empirical complexities. Before embarking on a full-scale economic program evaluation, we recommend that the methods outlined in these chapters be applied to one or two case studies, as a test of the practicality of the approach.

2) The case studies should deal with specific ENFOR research projects that are close to the product development end of the R&D spectrum. That is, technology applications that involve developing machinery for recovery of forest residues, or producing some similar marketable product, would be the best candidates. The specific case studies to be investigated should be selected by ENFOR program managers.

3) When completing either case studies or a full-scale economic evaluation of ENFOR research, two key issues that deserve thought are the timing of the analysis, and the price forecasts. Timing is important because the innovation and diffusion processes are lengthy and uncertain. If an evaluation were conducted too early, the potential benefits may be underestimated because the innovation would not have fully penetrated the market. Price forecasts are important because they are highly uncertain, and have a major effect on potential benefits.

4) The approach recommended in Chapter Five avoids direct consideration of timing and price issues by assuming demand curves are perfectly elastic at a fixed level, say $75 or $100 per ODt. This approach focuses only on the shifts in supply curves created by an innovation, and thus provides estimates of potential benefits that would be realized once demand attains the assumed level. These points suggest that before proceeding to a case study, ENFOR program managers and this study's scientific authority should confirm that the recommended approach is acceptable. The clarification is needed because the implicit assumptions would likely have major effects on the results of a case study.

5) The case studies are appropriate topics for investigation in the Phase III of this study, to be undertaken in the fiscal year 1987-88. Chapter One stated that Phase III was originally planned to be a case study of the evaluation methodology developed in Phase II (this report). Once the case studies are completed, the final report for Phase III should provide recommendations on the viability of a large-scale economic evaluation of selected ENFOR projects.

Noneconomic methods

1) The application of noneconomic methods (discussed in Chapter Six) in an ENFOR evaluation is at the same time more straightforward and more complex than reliance on economic approaches. Noneconomic methods are more straightforward because the recommended approaches are well established and they require no testing. The issues are more complex because it is unclear whether ENFOR managers want to or should pursue such an evaluation strategy at this time, given that the program is being sharply curtailed in coming years. The following points merit consideration if ENFOR managers are considering an evaluation of ENFOR's effects based on noneconomic objectives.

2) To evaluate the quality of research intended to

provide information for the management of biomass resources, Chapter Six recommended a peer review approach. Such a peer review should be initially focused on the National Biomass Inventory program, since it represents such a major share of ENFOR's overall budget. We recommended that a paid team of peer reviewers be drawn from universities or the private sector, perhaps with a coordinating consultant who is a specialist in evaluation. The team would evaluate the quality of research as well as various related (and equally important) issues regarding the National Biomass Inventory program. Some key evaluation questions for this peer review team to consider are:

- the overall quality of research, based on the analysis of methods employed, assumptions adopted, data sources, the degree of which uncertainties are indicated, and similar concerns;

- the originality of research;

- the research efficiency, in terms of subjective comparisons of budgets to results;

- the relevance of the research to the ENFOR program's mission;

- whether the program should have been redesigned in any way, or budgets reallocated, to better achieve the objective;

- how the resulting information has affected (or could eventually affect) resource management.

Depending on the level of detail devoted to this peer review, the costs would range from $60 000 to $90 000. This is a reasonable expenditure for evaluation of a major research program.

3) To evaluate the usefulness of new information for biomass management, Chapter Six recommended a client survey. Again, attention should initially be focused on the National Biomass Inventory program. Here, only a limited client survey, employing a telephone interview format, is needed. Senior analysts dealing with biomass resources in Energy, Mines and Resources Canada, the Canadian Forestry Service, and similar ministries in Ontario, Quebec and British Columbia should be interviewed to answer the following questions:

- is the person familiar with the National Biomass Energy program, and why;

- how has (or could) the program contribute to biomass resource management and biomass resource allocation decisions in future years;

- how has (or could) that agency's activities been affected by the program;

- how has (or could) that agency make better use of information from the National Biomass Energy program;

- are there any potential "spin-off" or indirect uses of the program's data base that may be of interest to the agency, such as in forest fire management, ecological modelling, acid rain impact assessment, or similar uses?

Such a survey and the resulting report would be a small undertaking, requiring a budget of perhaps $5000 to $10 000. The survey could perhaps be integrated with the peer review panel discussed above, if an evaluation consultant is retained to coordinate the peer review.

4) To evaluate the effects of ENFOR on the creation of national expertise in biomass energy, a mail survey is recommended. The potential participants of the survey could be identified through a search of ENFOR files, engineering and environmental consulting associations, and the Department of Supply and Services science procurement information network, as well as other sources. The survey should investigate the following topics:

- whether the organization was involved in biomass research before 1978, the year ENFOR was created;

- the number, areas of expertise and qualifications of professionals active in biomass research before 1978;

- the total amount (in dollars) of biomass related research conducted annually from 1978 to 1986, and the percentage accounted for by ENFOR;

- the maximum total number of biomass-related professionals employed between 1978-86, and the current number employed, their areas of expertise, and their qualifications;

- a subjective assessment of the incremental effects of ENFOR on the organization's expertise in biomass-related research.

Depending on the number of organizations surveyed, such a survey could be conducted and a report prepared for $10 000 to $20 000. The consultants recommend placing a lower priority on this evaluation task, because of the imprecision of the objective of creating national expertise in a given field.

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