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METHODS FOR ASSESSING THE SOCIOECONOMIC IMPACTS OF GOVERNMENT S&T

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APPENDIX A

LITERATURE REVIEW ON THE TECHNIQUES AVAILABLE TO ASSESS THE SOCIAL AND ECONOMIC BENEFITS OF GOVERNMENT RESEARCH AND DEVELOPMENT

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LITERATURE REVIEW ON THE TECHNIQUES AVAILABLE TO ASSESS THE SOCIAL AND ECONOMIC BENEFITS OF GOVERNMENT RESEARCH AND DEVELOPMENT

Sponsoring Departments and Agencies:

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1.0 Introduction

Throughout much of the post-war era, the primary question of concern when evaluating the feasibility, appropriateness and outcomes of R&D programs and projects was largely one of whether the R&D activities represented "good science". It was generally recognized that R&D represented, among other things, an investment in a nation's physical and human capital and, as a result, R&D had the potential to generate substantial social and economic benefits.¹ However, in an era where government budgetary constraints did not significantly hinder investments in R&D, questions concerning the magnitude of these assumed socioeconomic benefits were not an imperative: in many instances the promise of their eventual realization was a sufficient answer to the questions posed by R&D evaluators and decision makers.

In recent years a number of trends in both public finance and economic development have led decision makers to develop a much greater interest in the identification and measurement of the economic and social benefits associated with R&D activities. Specifically, technological advance has become recognized as an essential component of economic competitiveness, sustained economic and productivity growth, and sustainable economic development. Hence, government and industry alike, in the face of growing foreign competition and mounting environmental and social concerns, have been forced to strategically assess their R&D investments in an effort to develop a clearer understanding of not just the scientific value of R&D, but also the nature and magnitude of the economic and social benefits associated with these activities. In addition, budgetary constraints at all levels of government are forcing decision makers to critically assess expenditure patterns, to try and determine the value received for these expenditures, and to try and compare the value of widely divergent expenditure programs. As a consequence of these developments, public and private decision makers are increasingly in need of practical and accurate evaluation tools to support strategic R&D planning, expenditure and allocation decisions and performance monitoring and assessment.

It is within this context that the ARA Consulting Group was requested to conduct a review of the methods available to assess a specific category of the potential consequences of federal R&D programs and projects; namely, the generation of social and economic benefits. The conduct of this review was divided into two parts. The first part involved a review of the literature addressing the appropriate methodologies for assessing the social and economic benefits of R&D activities and the current techniques employed for benefits assessment in other jurisdictions (i.e., in the private sector and in government organizations in other countries). This appendix summarizes the results of the literature review.

¹ Throughout this appendix the terms "benefit" and "impact" will be used rather interchangeably. However, it is important to note that the two terms mean different things in economics. Specifically, the term impacts generally relates to gross measures of employment and income creation which are usually based on some form of input-output/multiplier analysis. The term benefits (economic or social) reflect changes in the overall welfare of society.

2.0 Background to the Discussion of Methodologies

Before proceeding to a review of the techniques available to assess the social and economic benefits of R&D activities, it is useful to develop an understanding of some of the challenges associated with such assessments.

The first of these relates to the nature of R&D activities and the manner in which their results translate into economic and social benefits. Within economic theory, the benefits of R&D can be readily addressed within the theoretical framework of welfare economics. This framework (which is most typically applied in the form of a benefit-cost analysis) provides a consistent methodology for tracking, identifying, defining, measuring and comparing the costs borne by society, and the benefits received by society as a result of undertaking a given R&D activity. However, what works in theory can be quite difficult to apply in practice.

Most forms of quantitative economic analysis which stem from this theoretical framework and have been developed to capture these benefits, such as benefit-cost analysis, rate of return analysis, scoring models, risk analysis techniques, etc., require a number of technical demands to be met at the outset before they can be rendered operational. As a starting point, most assessment techniques require a statement of the objective of the program or project under analysis. This objective must be formulated in a way that is specific enough to allow it to be used as the basis of analysis; that is, it must be possible to identify a set of project results that are consistent with achieving the objective. In addition, these forms of analyses require an understanding of the probabilities associated with realizing the project results -- at least in a Bayesian sense -- to account for risk and uncertainty. Finally, these techniques require an understanding of the time line over which project results will be realized and project objectives met, as the economic and social returns of a project, which will be received over time, can only be properly considered, aggregated and compared when expressed in present value terms.

Unfortunately, the nature of much of R&D activity is such that it is not always possible to satisfy these technical requirements. By its nature R&D is uncertain and in many cases it is difficult to predict at the outset of a project what the final outcome might be or whether the R&D activity even has the potential to generate measurable benefits. By no means will all R&D lead to measurable benefits (nor should they), but this is very difficult to determine a priori: this is especially true if one is considering basic and strategic R&D. In many instances R&D is concerned with the generation of new knowledge; hence, the possible applications of this knowledge often cannot be foreseen at the outset of the project or, for that matter, until many years after the research is complete. Past reviews of research programs have indicated that many of the technological advances of social and economic import have depended on research results that are decades old, and are often derived from the application of research results in diverse and seemingly unrelated fields. Hence, because of the characteristics of the R&D/innovation process, it is frequently impossible to envisage how the results of a particular activity will interact with other knowledge to produce a particular application, and, even when potential applications can be identified, determining the likelihood of the application occurring

and defining the time frame over which it will be implemented is, in many cases, highly uncertain.

Many of these problems can be overcome as one considers R&D projects which are closer to the applied R&D and/or product/process or system development stages. As R&D becomes more applied and more focused, it is possible to develop a clearer understanding of how the results may have an impact on technology and organizational missions; what applications might result; what the number of potential users for a particular application might be; and the extent of the potential social and economic benefits which may be derived from a certain application. However, even in this instance, the probabilities which need to be associated with these estimates must be considered carefully. The transformation of research into successful innovations is not simply a function of the technical merits of the application. Rather, the innovative capacity of the economy (or society generally) has tremendous bearing on whether R&D results will generate economically and socially useful applications, and this capacity, in turn, is defined by a number of factors. Specifically, the innovative capacity will depend on: the climate for investment; the level of entrepreneurialism in society; attitudes towards risk; the nature of government tax, regulatory and patent policy; the degree of competitiveness and innovative characteristics of industry; the nature of the capital markets; the degree of unionization and the characteristics of the labour force. If these factors are not configured in a manner which renders the economy receptive to innovation, then highly successful R&D activities may never generate social or economic benefits, or may only generate these benefits over a much longer time frame than initially envisaged. Ignorance of the importance of society's innovative capacity has been behind many a failure of "science-push" or "technology-push" applications.

Finally, the relationship between a particular R&D project and the generation of social and economic benefits is rarely direct. Rather, the benefits are derived from a combination of complimentary R&D investments incurred over a substantial period of time. Results of basic research may yield benefits only after they are combined with the results of numerous other basic and applied R&D activities. Similarly, the success of an applied activity may require research contributions from a broad and diverse number of areas. Hence, even if economic and social benefits are realized, it is virtually impossible to attribute them to a specific R&D activity (except under peculiar conditions).

Even if one can overcome many of these difficulties (the possibility of which does exist, at least to a certain extent), there is another general problem associated with the identification and measurement of the social and economic benefits of R&D, and this relates to the economic conceptualization of the R&D/innovation process. The majority of the assessment techniques developed to date have been built on the assumption that the R&D process could be represented as a linear model in which knowledge developed at one level of R&D moves forward in a straight line (and with a reasonably fixed lag length) to more advanced R&D activities (i.e., basic research results flow into applied R&D activities and then on to product/process oriented activities, etc.). However, with the exception of R&D in specific, focused areas, this paradigm has proven to be inadequate as a way of conceptualizing the vast majority of R&D activities and, consequently, of identifying and measuring the related social and economic benefits.

A number of recent studies suggest that R&D (especially, less applied R&D) may incorporate forward knowledge diffusion links, lateral diffusion links (i.e., research in one field may have an impact on research in another), and/or backward diffusion links (i.e., development activities may lead to modifications in basic and strategic research); the knowledge diffusion and innovation process tends to exhibit significantly nonlinear characteristics and is often discontinuous; and the diffusion time lag between activities on the R&D spectrum are not well understood and tend to vary across different R&D disciplines. Existing impact assessment models are severely constrained in their ability to account for the various diffusion links and the number and types of paths along which the benefits associated with R&D may arise. Furthermore, while economic theory has moved away from the linear, vertical impact model, a unified theoretical basis for the R&D/innovation process has yet to emerge, and this has contributed to a lack of advancement in the development of more appropriate and practical assessment models.

While the above discussion paints a rather gloomy picture of the potential for comprehensively assessing the social and economic benefits of R&D, a number of practical and credible assessment techniques are available to evaluators. And although the available techniques may not be able to capture all of the impacts associated with a project, for the reasons given above (and especially if they are applied to projects which are far removed from the development end of the research spectrum), they can at least provide guidance in qualitatively identifying potential benefits and, in many cases, can provide for reasonably accurate quantified estimates.

The key point to be taken from the above discussion is that, given the problems associated with determining the economic and social benefits of R&D activities, an evaluator must be careful to select an assessment technique (or group of techniques) which is capable of addressing the purpose and specific objectives of the project under consideration and has the potential to capture the widest array of potential benefits associated with that project. It is not appropriate to select an assessment technique simply because it fits the available data, nor is it wise to reject a technique because of the technical demands it imposes: the application of more demanding techniques can still provide qualitative benefit information, and/or a partial set of quantified benefits information, and it can help identify data gaps which can be addressed through modifications in the project monitoring process.

However, having said that care should be taken in selecting assessment techniques, it is not often obvious which techniques are the best to apply to certain R&D activities. As indicated earlier, R&D activities are not readily compartmentalized into discrete and easily definable activities and there is no single assessment method which applies to a single category of activities in all instances. Although R&D can be defined in terms of a spectrum running from basic research through to product/process development, even this categorization may not provide sufficient guidance concerning the selection of appropriate assessment techniques, as the boundaries between the R&D activities on the spectrum are often blurred (e.g., the boundaries between basic and strategic research, between strategic and applied research, etc.). Given the nuances involved in the R&D process, it is virtually impossible to specify the most appropriate technique for every R&D activity. Rather, the methods available for evaluating the impacts of R&D frequently must be adapted and combined to meet the specifics of a particular R&D activity, as

well as to address the peculiar problems which vary with the activity's position on the R&D spectrum. However, this brings us back to the question as to which set of techniques does one initially select, and then subsequently adapt and combine, to meet specific project characteristics?

As a result of the literature review, the following were identified as being the main factors that determine which methods are most appropriate:

- (1) The time frame for the assessment—specifically, whether the social and economic impacts of an R&D activity are being assessed prior to or after the R&D has been completed.
- (2) The type of R&D—basic and strategic research, applied research, or product/process development.
- (3) The purpose of the R&D—in particular, which of the following categories best describes the R&D activity:

Category 1-R&D Infrastructure: R&D undertaken to contribute to society's R&D infrastructure (through the development of research equipment, the maintenance of research capability, and so on).

Category 2-Policy Development: R&D undertaken to provide information needed to develop government policies, standards, or regulations.

Category 3-Policy Attainment: R&D undertaken to provide information, products, processes, and systems that will contribute to the attainment of government policies (such as environmental protection, economic development, and so on).

Category 4-Industrial Development: R&D undertaken in support of industrial innovation.

A description of each of the major methods or techniques discussed in the literature and their applicability, strengths and weaknesses in assessing social and economic benefits is provided in the next section. While we have compartmentalized these techniques, many are related. Furthermore, a number of these techniques, on their own, may be inappropriate for benefit assessment; however, when modified and combined with other methods they can prove quite useful. Thus, it should be kept in mind that in assessing a particular R&D activity, adjustments to these techniques are generally necessary to fit the characteristics of particular projects and that the best approach to follow is often to use a combination of techniques when assessing the benefits of R&D.

3.0 Impact Assessment Methods

3.1 Peer Review

Peer reviews of research activities represent evaluation by experts in a particular research field or closely related area.² This technique is the most widely used form of R&D assessment, and is generally used to evaluate the quality of the science associated with basic and strategic R&D activities (and Category 1 and Category 2 projects). In addition, peer review is regularly applied as a method of screening articles for publication in scientific journals and for evaluating academic appointments. This particular assessment method is based on the view that scientists agree to some extent on the definition of "good science" and, therefore, can make objective judgements concerning the merits of individual R&D proposals.

While a generally accepted method of conducting evaluations with reference to scientific criteria, there are a number of problems associated with its practical application. First, there may be partiality among the peers which can lead to decisions being made for other than technical ("good science") reasons. Secondly, in certain areas an "old boy" network may exist which may protect established fields and provide resistance to new directions. Third, a number of peer reviews can fall victim to a "Halo" effect which increases the possibility that funding will be directed towards more visible scientists, department and institutions. Finally, the peer review process assumes agreement about what good science is, and what are promising opportunities; however, reviewers often differ in their opinions as to the appropriate criteria to assess and interpret the meaning of good science.³

While the literature indicates that peer reviews are the most widely used evaluation technique, and provide a useful approach for assessing the scientific quality of R&D projects (in fact it is the only useful approach for this task), it is not a useful technique for assessing issues concerning the economic or social benefits of research. In most instances, the expertise of peers is based on the internal criteria of science which provides insufficient grounds for judging economic and social effects. However, it is not uncommon, in situations where social and economic impacts are part of the criteria of evaluation, to employ modified peer reviews, which are discussed below.

² This technique, its variants, and associated problems are thoroughly discussed in *Research Impact Assessment*, Office of Naval Research, 1992.

³ In practice, however, studies on evaluation have revealed that researchers disagree greatly on what is good science, regardless of the discipline.

3.2 Modified Peer Review

Modified peer review is used predominantly for assessing strategic and applied areas of science (although it can also be used to assess some basic research activities, if the objectives are fairly clear).⁴ This form of review is common when the evaluation criteria go beyond the quality of science and include issues concerning the social and economic impacts of research, and/or the potential for the utilization of the research results. Normally, scientific expertise alone is not sufficient to make judgements of this kind. Hence, the standard practice is to modify the normal peer review process by including non-peer members in the expert group, such as economist, other social scientists and civil servants. Sometimes these non-peers will include clients or potential users of the research.

In general, this approach involves asking the socioeconomic experts to assess the past (if the review is ex post), or potential future usefulness (if the review is ex ante or on-going) of the R&D activity, and to assess the potential for associated economic and/or social benefits. This approach is particularly useful in assessing the social and economic benefits of R&D, especially for more applied research, because it provides the main proxy for the market.

Modified peer reviews generally do not go beyond a basic question and answer format, often facilitated by interview techniques. However, in the case of ex ante reviews, it can involve more extensive analysis through the use of Delphi techniques (which attempts to project probabilities and occurrence times for events through an iterative discussion process), or morphological analysis (which tries to define different possible solutions to a set of problems and consequently different combinations of possible occurrences). However, the applications of these techniques within a modified peer (or peer) review are rare (a noted exception is the Dutch Organisation for the Advancement of Pure Research which uses a two-stage version of peer review using the Delphi technique for assessing funding decisions).

While useful, for at least qualitative benefit assessment, modified peer reviews have a major weaknesses—namely, given the relatively small number of individuals that are usually involved, it may not be possible to gather a sufficiently broad base of knowledge to credibly comment on the economic and social benefit potential of an R&D activity. This problem can be effectively overcome by broadening the modified peer review through the application of an extended set of interviews and questionnaires, discussed below.

3.3 Interview/Questionnaire Methods

The most common method for assessing the economic and social benefits of R&D involves the use of interviews and questionnaires, and is akin to a large modified peer or client relevance review. These methods have the advantage of providing a more systematic review by using standardized interviews and questionnaires, thereby gathering the views of a wide number of experts, clients and potential users, and overcoming the restrictions involved in using a modified

⁴ This technique is also thoroughly discussed in *Research Impact Assessment*, Office of Naval Research, 1992.

peer review procedure with a limited number of participants. This technique also provides the advantage that quantitative indices can be formed if the questions are amenable to scoring, thereby providing a convenient method for making comparisons among R&D projects. The technique is useful for assessing the benefits associated with R&D activities nearer the applied and development end of the R&D spectrum. For basic and strategic research activities, information concerning their objectives and potential outcomes may be too vague and too limited to serve as a basis for fruitful discussions under this methodology.

These methods overcome the main problem of modified peer reviews, insufficient breadth of information, by virtue of the fact that a wide number of individuals can be questioned in a systematic manner.

One problem historically associated with client and user surveys is the problem of "grateful testimony"—the possibility that clients and users may be more positive about the relevance and usefulness of the R&D than is warranted.⁵ There are a number of ways of dealing with this. One practical and effective way around this problem is simply to pose a large number of questions, of different types, all dealing with different aspects of client relevance and usefulness. These questions could relate to the interest of the client in the research area; indicators of the value of the R&D to the organization; and indicators of the importance of the R&D to the client's organization. In addition to asking a large number of different types of questions, a second method for circumventing grateful testimony, and a way of gathering more specific information on associated benefits, is to ask the (potential) client or user to describe, in very specific terms, the details of the use (or potential use) of the R&D and its related social and economic benefits (this approach is quite useful if personal interviews or case studies are combined with questionnaire methods). A third method that can be used, and which has proven to be very effective, is to conduct follow-up interviews with a subset of the (potential) clients/users surveyed to test the veracity of their answers by probing for additional details, which generally reveals how honest they have been. Finally, the validity of the interview/questionnaire results can be assessed, in ex post and on-going reviews, by comparing them with other primary and secondary data relating to the relevance and usefulness of the R&D activity: the primary and secondary data should support the results obtained through the client/user surveys.

A second potential difficulty with this method is that it can sometimes be difficult to interpret the results. For example, if 50% of the clients for a particular group of R&D projects rate the usefulness of the projects as "high", 30% rate the usefulness "medium", and 20% rate the usefulness "low", what does this mean? Is this a good result or a bad result? The main solution to this problem is to ask a fairly large number of detailed questions about relevance and usefulness. In addition, client surveys have now been carried out for a sufficiently long period that one can begin to compare the result from different studies.

⁵ Bennett, D. and I. Jaswal, *Relevance and Limitations of Various Methods and Approaches to R&D Evaluation*, Paper presented to the NRC Seminar on the Evaluation of R&D Programs, December 14, 1989.

While the use of interview/questionnaire methods have proven valuable for gathering information on the views of clients, users and suppliers as to the value of R&D activities and their potential for generating social and economic benefits, this approach has its pitfalls. The two main problems to keep in mind are, first, that in developing questionnaires and interview guides, one has to be careful to standardize the question in a manner which facilitates analysis but does not place undue constraints on the amount of information that can be obtained and, therefore, lead to the collection of trivial information. Secondly, the individuals involved in developing the interview guides/questionnaires must have a clear understanding of the nature of the R&D activity under analysis. If not, the potential exists that the wrong questions may be developed and, again, trivial results could emerge.

Structured focus groups are a variant of these methods which can sometimes provide more in-depth information regarding relevance and usefulness.

3.4 Semi-Quantitative Methods

Semi-quantitative methods attempt to measure the quality of science, or the economic and social benefits of R&D activities, indirectly by correlating these issues with certain identifiable project output or inputs. Two general methods fall into the category of semi-quantitative methods: (i) bibliometrics; and (ii) science and technology indicators.

Bibliometrics

Bibliometric indicators (and its variants) are essentially tools for assessing the quality of science associated with R&D activities, and are not of much use for assessing the associated economic and social benefits.⁶ The use of bibliometric indicators is based on the assumption that progress in science comes from the exchange of research findings, and that the published scientific literature produced by a scientist or from a particular R&D project is a good indicator of the project's or scientist's progress. The simplest bibliometric indicator involves a count of publications. However, over the last decade a number of additional indicators have developed, including citation indexing analysis, co-citation analysis, co-word analysis and co-classification analysis.

While most bibliometric techniques are of little use for assessing social and economic benefits, one particular variant has attempted to gauge the economic consequences of R&D (and particularly industrial R&D): patent analysis. The principal behind patent analysis is that the technological performance of an R&D activity can be assessed by counting the number of patented products, processes or system which come out of the activity. The problems with this technique are numerous. First, it is dangerous to assume that patents are the sole output of

⁶ An extensive discussion of this technique is provided in: *Literature-Based Data in Research Evaluation: A Managers Guide to Bibliometrics*, Susan E. Cozzens, Department of Science and Technology Studies, Rensselaer Polytechnic Institute, Troy, New York, 1990; and, *Research Funding As An Investment: Can We Measure the Returns?* Office of Technology Assessment, Washington, 1986.

research. Patents do not arise uniquely from a particular R&D project, nor is it an indication of failure if the project does not lead to patentable result. Also firms have variable propensities to patent and these may change over time. Furthermore, while patents may protect intellectual property, secrecy is often selected as a method of protecting this property. Second, from the point of view of assessing the social and economic impacts of R&D, patent analysis provides no indication of whether the patented item is in use, who the users are, or how large the user group may be. Hence, on its own, patent analysis (and bibliometrics generally) provides little guidance for the assessment of the social and economic benefits associated with R&D. For certain activities (such as Category 3 and Category 4 R&D projects), patent analysis can be useful as an initial, albeit partial, indicator of R&D outputs; however, this technique is only useful when combined with more sophisticated assessment methods.

Science and Technology Indicators

Technology indicators are meant to assess the on-going vitality of research by assessing the degree of investment made by society in research and development. A wide number of indicators are available which relate to the economic impact of R&D and are based, at least implicitly, on the assumption that an innovation chain leads from basic to applied research, to further experimental development, to innovations, and finally to increases in productivity and economic growth. Given this linear model, the idea is that as long as R&D inputs are going in one end, economic benefits should come out the other. The more common indicators of this type include statistics relating to R&D expenditures in specific fields and industrial sectors; the number of R&D scientists and engineers per 1,000 labour force, and all scientists and engineers per 1,000 labour force; the utilization of advanced manufacturing technologies by industry sector; the number of graduate students and degree recipients by field, sector and institution; and the support for graduate education and training.

In addition to the indicators relating to economics effects, which are essentially *input* indicators, a set of *output* indicators which relate to the social returns brought by technology are also calculated. These indicators are built, at least implicitly, on the assumption that most social improvements are the result of advances in technology; hence, measures of changes in social conditions will reflect the benefits of technology. The most common of these indicators include life expectancy, infant mortality, access to clean water, and so on.

A number of problems are associated with the use of science and technology indicators as measures of the social and economic value of R&D. First, for both economic and social indicators, these measures are compiled at a very aggregate level and it is not possible, using these indicators, to associate benefits with particular R&D activities. Secondly, with respect to the economic indicators, their formation is based on the linear innovation, or "science-push", model of technological development which, as indicated in Section 2.0, is no longer generally accepted as an adequate reflection of the R&D process. With respect to the indicators of social benefit, there is no way of separating out the advances in the social condition that are associated with R&D, educational changes and behavioural changes. Finally, irrespective of the indicators used, there does not exist a generally agreed upon way to analyze and interpret these indicators. In summary, science and technology indicators are not useful measures of social and economic

benefits. At best, they can only provide an indirect indication that some level of benefits are emerging from a process that is assumed to be related to R&D.

3.5 Quantitative Methods

A wide array of assessment techniques fall under the rubric of quantitative methods; however, their common feature is that they are primarily designed to focus on the assessment of the economic and social impacts and benefits associated with R&D activities, and this is generally done through a mathematical formulation. The methods that are available differ in terms of the level of quantification they provide and the time frame for which they apply. In addition, while a number of individual techniques can be identified from the literature, in essence they are simply variations on one of three quantitative methods: (i) benefit-cost analysis (its variants include rates of return calculations, and net present value calculations); (ii) econometric analysis; and (iii) economic surplus or economic impact analysis. The merits of each of these methods of analysis are discussed in turn below.

Benefit-Cost Analysis

As a method for assessing the economic and social benefits of R&D activities, benefit-cost analysis possesses the strongest theoretical foundations for the task. This form of analysis seeks to assess private and public investments in R&D (or in any other investment category for that matter) in terms of both the economic and social benefits generated for society by the investment, as well as the economic and social costs incurred by society to execute the project. The utility of the investment from society's point of view is then expressed in terms of the net benefits (i.e., gross economic and social benefits less economic and social costs) generated by the activity. In defining these costs and benefits, very specific definitions and methods of valuation are used.

In terms of the costs of the R&D activity, they are calculated as "opportunity" costs, which represents the value of the goods or services that society forgoes when resources are transferred from one occupation to another. It is assumed, under this methodology, that society's land, labour and capital resources are approximately fully employed; hence, they can only be utilized on a new R&D project if they are withdrawn from their alternative areas of employment. The value of the goods or services lost as a result of this reallocation is the cost society would have to incur to pursue the new R&D project. There are three main types of costs associated with conducting an R&D activity that must be assessed in this way: the costs of generating the research results; the costs of introducing and supplying the results to end users; and the costs incurred by the end users to implement the results. Each of these cost categories needs to be identified and included in the analysis.

Against these costs are weighed the benefits of the R&D project, which result from the new, or improved, products, process or systems which result from the activity, and they are valued at the price society is willing to pay for them. In addition, benefits associated with increased educational and training opportunities, reduced environmental damage, improvements in health and safety, etc., are also included in the calculation; however, in many instances it may not be

possible to associate a value with each of these benefits. Nevertheless, in the absence of appropriate valuation techniques, these benefits still need to be identified in the analysis. It should be noted that the array of potential economic benefits associated with R&D may accrue at various levels and to different groups within society—the researcher, the manufacturer or promoter of the research technique or product, and the end user or consumer. The benefit-cost framework takes into consideration the benefits at each of these levels.

In addition to the definition and valuation of the costs and benefits associated with an R&D activity, the probabilities associated with the realization of these costs and benefits must be determined (this generally applies to ex ante and on-going analyses), and the time sequence of the relevant costs and benefits must also be determined. These values are necessary as the expected value stream of annual costs and benefits must be discounted to their present values in order to allow for comparison.

Many of the difficulties associated with assessing the economic and social benefits of R&D mentioned in Section 2.0 apply to benefit-cost analysis. Specifically, the requirements of identifying the objectives and outcomes of R&D, their probabilities of occurrence, and the time sequence of their realization can be exceedingly difficult to establish, especially for projects nearer to basic and strategic research. In addition, many of the economic and social benefits arising from R&D may not simply surface in exploitable products and processes. Rather, the benefits may be realized as increased educational opportunities, reduced health and safety risks, etc., and it may be quite difficult to assign values to these benefits. Furthermore, many of the economic and social benefits of an R&D project are realized indirectly through the impact of the research results on activities in similar research fields or in unrelated areas. Tracking and gathering the information necessary to estimate these benefits can be difficult as well. Finally, even if each of these problems is overcome, it is often not possible to attribute specific costs and benefits to individual R&D projects or programs—for example, costs associated with the use of research equipment. The calculations necessary for attribution must be based on incremental benefits and costs—i.e., only those which would not have occurred in the absence of the project or program. Many social and economic benefits result from a combination of complimentary R&D investments, incurred over substantial periods of time, and it is generally not possible to ferret out the influence of the various R&D activities. One must also take in to account whether the same research results might have been generated independently of the particular project or program—for example, by parallel research being carried out elsewhere.

In theory, then, benefit-cost analysis is appropriate for assessing social and economic benefits, but it is often difficult to identify, in a sufficiently robust way, the range of associated costs and benefits and acquire the necessary data to value these costs and benefits. Furthermore, many of the benefits of research are intangible and existing valuation techniques do not readily apply. Finally, given the inherent uncertainty of R&D, many evaluators find that benefit-cost analysis is completely impractical, and far too technically demanding, for most R&D projects except possibly those near the applied, product/process end of the R&D spectrum and/or for Category 3 and Category 4 R&D projects. These criticisms are valid in many instances; however, benefit-cost analysis can still be of value in that it offers a systematic framework for identifying the objectives, costs, benefits and wider implications of R&D and its exploitation. It provides a

methodology which can at least allow for a qualitative description of how the various tangible and intangible benefits (and costs) of an R&D activity are generated and captured by society.

Econometric Methods

Econometric methods are based on the specification of functional relationships between gains in industry output or productivity and research and non-research inputs. They have been applied at both the national or macroeconomic level (with reference to Category 1 R&D projects/programs) and with reference to more restricted R&D endeavours (predominantly Category 4 activities such as agricultural and aviation R&D). On the basis of the functional relationships specified, statistical measures of social rates of return to expenditures on research can be estimated (examples of the approach can be found in Link, 1981; Griliches, 1958; Mansfield, 1981, 1989, 1991; and Doyle and Ridout, 1984, among others).

A major drawback of the econometric approach is that it is subject to very demanding design and data requirements and is not a very a practical option for most federal program managers. In the first place, the specification of behavioral relationships, and the specific functional form, is problematic as it is driven by the data. Also, it is difficult to aggregate research expenditures through time as a homogeneous input (the mix of activities changes through time). Furthermore, the R&D input data is related to production mix and level statistics which also may not be homogeneous through time. Secondly, while the nature of the functional form is driven by the data, there is no clear way of knowing if the functional form is correct; however, the resulting estimates of the social rate of return are quite sensitive to the specification. This is further complicated by the fact that, quite often data or other constraints necessitate the use of highly aggregated or simplified variable definitions, which may be remote from the real research product. At best, the selection of variables is somewhat subjective. Thirdly, obtaining a sufficient number of usable data points or observations is generally a problem, and would most certainly be so with respect to any single research endeavour. In other words, most of the academic studies that have been undertaken have as their independent variable some generalized and aggregated R&D figure, one that is rarely reducible to identifiable research streams. Finally, it is assumed that the gains in productivity are entirely attributable to research and would not have materialized in the absence of that research.

Due to the shortcomings associated with this technique, especially the data problems, it does not provide a viable and accurate approach to assessing social and economic benefits, especially for specific R&D projects and programs. In terms of evaluating the historical performance of Category 1 R&D, this technique may be of some benefit; however, the results must be interpreted with extreme caution and should only be used to support arguments that R&D is socially and economically useful.

Economic Surplus/Economic Impact Methodologies

Much of government R&D (and in particular basic and strategic R&D) is designed to support the missions of particular agencies, as opposed to being specifically directed towards the generation of economic activity and/or the development of commercially or industrially viable

products, processes or systems. However, much of this R&D may contribute directly to the economy through the economic impacts associated with expenditures on researcher's salaries and material/equipment purchases. In addition, the R&D activity may indirectly contribute to the development of commercial/industrial products and processes through what are termed "spillover", "spin-off" or "fall-out" effects. The economic surplus methodology⁷ attempts to determine the rate of return to society's investments in R&D activities by comparing the value of the public tax revenues that are invested in an R&D activity to the value of the economic impacts associated with both the direct research expenditures (on salaries, etc.) and any consequent spillover/spin-off effects (examples of applications of this methodology can be found in Schmied, 1977, 1982, 1987). The technique begins by defining these direct and indirect impacts in terms of the primary and secondary economic effects of R&D activities.

In terms of the primary economic effects of R&D, these may arise along two paths. First, even for R&D whose primary aim is to generate knowledge, the application of at least part of the increment in knowledge stemming from the R&D may lead to the generation of innovations and/or improvements in products and processes of economic use. These innovations/improvements may be directly developed and sold by the research institute itself, in which case the value of the resulting sales comprise part of the primary economic effect of the R&D activity. The second pathway along which primary economic effects can be generated stems from the fact that the execution of a research program, or the operation of a research institute, requires the purchase of materials, equipment, and the hiring of researchers. Thus, the expenditures required to conduct the R&D activity gives rise to additional investment and employment, as well as tax revenues for the government (income tax, sales taxes, GST/VAT taxes). These tax revenues, the investment and employment impacts, and any direct institute/program sales, comprise the value of the primary economic effects associated with the R&D activity.

The secondary economic effects associated with R&D institutes/programs (i.e., the value of the spin-off/spillover effects) stem from the fact that a major part of the scientific equipment necessary to carry out a particular R&D activity may be purchased from industry. In many cases, the delivery of this equipment may represent a technical challenge to industry, and the development of the know-how required to address this challenge may generate additional economic opportunities for industry which go beyond its direct sales to the research institute/program. These additional economic opportunities may arise from: increased sales associated with the incorporation of the knowledge gained into new or existing products or processes; the sale of the specific product/process developed for the research institute/program to other users; and/or increases in sales associated with the fact that a firm references in its marketing material that it has provided technical equipment to the R&D institute/program which, in turn, improves its prestige and market position.

⁷ The use of the term "surplus" in this instance is not to be confused with the more common use of the term in the economic literature (i.e., consumer/producers surplus, net economic surplus, etc.). Rather, in this instance surplus is taken as a measure of the increment in economic activity associated with R&D expenditures.

The increment in sales enjoyed by industry as a consequence of their association with the R&D activity gives rise to economic impacts in that either: (i) additional investment and employment are required to generate the incremental sales volume (i.e., additional employment and investment is created in the economy as a result of the R&D activity); (ii) existing, but underemployed, labour and equipment in the firm's employ are used more intensively and effectively to generate the incremental sales volume (i.e., the profits accruing to the firm, as a consequence of its association with the R&D activity, improve); or (iii) some combination of new and existing labour and investment resources are employed to produce the incremental sales volume (i.e., both additional employment, investment and profit impacts arise due to the firm's association with the R&D activity). In addition to these impacts, the payments made by firms to garner the resources they require gives rise to additional income taxes, sales taxes, and GST/VAT taxes with flow through to the government. The culmination of these employment, investment, profit and taxes consequences, which are a by-product of the R&D activity, are termed the secondary economic effects.

In order to determine the rate of return on society's investment in an R&D activity, the primary and secondary economic effects described above must be identified and valued. Under the economic surplus methodology, the primary economic effects are quantified on the basis of data collected through interviews with the research activity's principals and through a review of the expenditure data pertaining to the R&D activity (e.g., salary data, data on purchased materials, etc.). This data allows for the quantification of the primary investment, employment and tax effects associated with the execution of the R&D activity (and any direct sales by the R&D program/institute of products or processes). In addition to the data on primary economic effects, the research principals are also asked to identify the various firms which delivered products or services necessary to the execution of the R&D activity: this data provides the jumping-off point for the estimation of the secondary economic effects.

The quantification of the secondary economic effects is somewhat more complex and is accomplished by way of a counterfactual experiment which compares the following alternative states:

- the actual performance of the firm (or firms), identified by the research principals, over a given period after it has been subjected to a well defined external influence -- namely the demands placed on in by the R&D activity; and
- an assessment of the hypothetical performance of the same firm (or firms), over the same time period, under the assumption that the commercial/industrial participants had no contact with the R&D activity.

The collection of the data necessary for this comparison is gathered through questionnaires and personal interviews with representatives of the firms that have been influenced by the R&D activity. Specifically, representatives of the relevant firms are first asked to determine what part

of their annual sales can be directly attributed to their contact with the research activity.⁸ Once the annual increment in sales attributable to the firm's interaction with the R&D activity has been quantified (and the direct sales to the R&D program/institute have been netted out), the next step is to evaluate the impact of this increment in sales on employment, investment and profits. Then, with estimates of the employment, investment and profit impacts in hand, multipliers for income taxes, sales/VAT taxes and corporate taxes can be calculated, from firm specific tax data, and applied to determine the total secondary tax impact associated with the R&D activity.

The various impact calculations described above are performed for each firm associated with the R&D activity. The firm-specific estimates are then aggregated to provide an estimate of the total secondary economic effect of the R&D activity. The value of the quantified primary economic effects can then be added to the value of the secondary effects to provide an overall estimate of the investment, employment, profit and tax revenue impacts associated with the R&D activity. On the basis of this data, the tax revenue impacts associated with the R&D activity can be compared to the public expenditure on the activity to derive an estimate of the rate of return to the government. In addition, the tax revenue and profit impacts can be combined and compared to the government's expenditure on the R&D activity to derive an estimate of the rate of return to society (as taxpayers) of the investment.

The economic surplus approach provides an interesting technique for estimating the potential direct primary and secondary economic impacts (in terms of employment and income generated) that can be associated with R&D activities (predominantly Category 4 and 5 R&D). As a method for determining direct impacts, the approach offers the advantage of a well structured framework for data collection and assessment. This technique can also be used to gauge the overall economic impacts (both direct and indirect income and employment impacts) associated with R&D. Specifically, the direct impact data gathered through the application of this approach can be entered into a standard economic impact model (such as the Statistics Canada national and interprovincial input-output models) and the multipliers imbedded in the model will project the firm specific impact data into economy-wide economic impact values (i.e., total employment and income). While precedents for this application of the economic surplus methodology exist, the resulting economic impact data must be interpreted with great care. A number of assumptions underlie national economic impact estimation models and they have significant bearing on the interpretation and validity of the impact results.

While a potentially useful tool for estimating potential direct economic impacts, the economic surplus approach does not provide a measure of the social and economic *benefits* of R&D. The principles which underlie benefit calculations are much different than those that underlie economic impact analysis, and the results of these analyses are not comparable. For example, within benefit-cost analysis, taxes are not generally taken as a measures of social return;

⁸ The interaction with a particular research program/institute is rarely the only cause for a change in the level of industrial/commercial production. However, a variety of techniques and models are available which can be used to quantify the increment in sales attributable to the influence of a particular R&D activity (for examples of the approaches that can be used, see Schmied, 1987).

whereas, under the economic surplus approach, taxes are considered as a valid return. In addition, the economic surplus/economic impact approach assumes that there are no resource constraints in the economy (in terms of investment and employment); thus, the opportunity costs of certain activities are not adequately taken into account -- as they must be if a measure of economic benefits is desired.

In short, economic surplus/economic impact techniques do not provide valid measures of the economic and social benefits of research, but then again the technique is not designed to measure benefits. However, the general principle of the technique can prove useful if benefit-cost principles are explicitly taken into account.⁹

3.6 Case Studies and Histories

Case studies represent one of the most useful techniques for examining the relationship between research and its associated economic or social benefits. Case studies involve a detailed and thorough analysis of particular R&D projects or programs and seek to track the evolution of social and economic benefits throughout the life of the activity. They are generally conducted in conjunction with other methods (such as benefit-cost assessments of case study projects, and as a method of validating interview/survey results), and are usually applied in ex post assessments of Category 3 and 4 projects. The advantage of case studies is that, when they are carried out in sufficient number and in sufficient detail they represent probably the best chance of fully identifying the relationships between the R&D activity and the generation of benefits. The problem from the point of view of the evaluation of research is that, since case studies relate to specific R&D projects or a specific sample of projects, it is difficult to generalize the result to other forms of research in a defensible way.

A variant of the case study approach, which can also be useful as a method of identifying the relationships between R&D activities and the generation of benefits, are the Hindsight and the Technology in Retrospect and Critical Events in Science (TRACES) approaches.¹⁰ These approaches were originally developed in the 1960s and have recently been invoked by the Office of Naval Research in the United States and the Science and Engineering Research Council in the United Kingdom. The object of these techniques is to trace out historically the development from research to application and vice versa and to try and identify the major events which link the former with the latter. However, a number of problems are associated with these techniques. First, they suffer from the difficulties of using a linear model as the heuristic in selecting and structuring the data. Secondly, these approaches are often criticized, on the basis of the original applications in the 1960s, for falsely assuming causal connection between events; for incorrectly assigning equal weights to events; and for ignoring historical dead ends. Third, the results of these analyses tend to be sensitive to the selected timeframe.

⁹ For an example of the use of elements of this approach to estimate the potential secondary benefits of the KAON project see *KAON Economic Assessment*, the DPA Group (now the ARA Group), February, 1990.

¹⁰ See *Research Impact Assessment*, Office of Naval Research, 1992, for a discussion of these techniques.

While these historiographic approaches are partially useful for assessing economic and social impacts, they tend to be more concerned with process. However, as a result, the approaches are useful in that they highlight the complexity of the problems faced in linking R&D to economic and social benefits, and the results of these techniques serve to direct attention to the assumptions on which many of the existing economic and other quantitative models are based. As a result, these techniques may provide useful information for developing an appropriate theory (and hopefully model) of the relationship between R&D and economic and social benefits.

In summary, both standard case study techniques and applications of TRACES and Hindsight techniques use a historiographic approach that seek to identify significant research or development events in the metamorphosis of research programs in an effort to understand and explain the evolution of R&D into economic and social benefits. However, while these approaches do provide interesting information and insight into the transition process from research to development to products to processes or systems, the selectivity and anecdotal nature of many of the results may, in many cases, render conclusions as to magnitude of benefits or their generalizability suspect.

3.7 Partial Indicators of Impacts

This method involves the collection of information (generally relatively readily available) for a number of items each of which provides some insight into the extent of the socioeconomic impacts resulting from the R&D. For example, for an R&D program the information that is collected can be information on inputs (program funding, number of people involved in running the program, and so on), program activities, program outputs, or program impacts themselves. In effect, one sets up an information collection system for the program, and, once the information has been collected, it is organized and presented in a way that enables people who are reviewing the information to draw conclusions regarding the impacts of the program (and especially changes in the impacts over time).

For example, the Swedish Plastics and Rubber Institute has set up a system of partial indicators which includes the following indicators for assessing the impacts of past R&D:

- The percentage of projects completed during the past year for which the technical goals were met (or exceeded).
- The number and percentage of available project reports sold to industry during the past year.
- The number of projects that have had a documented impact on industry during the past year.
- The percentage of projects completed within the past year for which it is highly likely that the results will ultimately be used by industry (this one requires an external assessment).

- The number of patent applications during the past year.
- The number of licence contracts signed during the past year.
- The amount of revenue obtained during the past year from licences.
- The number of products developed during the past five years that are being further developed or marketed by industry.

The advantage of partial indicators is that the information required to specify the indicators is relatively easy to collect. Their disadvantage is that they only provide a very partial picture, and while this can be useful for program monitoring purposes, it is generally not sufficient for demonstrating the impacts of the R&D—or even understanding what they have been. Systems of partial indicators are implicitly used by many research managers in selecting projects and project areas (i.e., indicators such as: Is there an identified need? Is there an identified client?), and they are heavily used in the monitoring of on-going R&D projects and programs.

This method is applicable to all types and all purposes of R&D, and it is probably the best method for more fundamental R&D and for R&D oriented toward the development and maintenance of research infrastructure. It can easily be combined with other methods—for example, if a modified peer review is carried out, the opinions of the reviewers regarding the likely usefulness of the research can be incorporated in the indicator system.

3.8 Priority-Setting/Ex Ante Assessment Techniques¹¹

There are about eight generally accepted methodologies, of varying degrees of sophistication and usefulness, that can be employed for ex ante assessment of R&D projects and to establish research priorities. The purpose of these methods is not to replace scientific judgement in the selection of projects. Rather, they are meant to provide a set of tools that will help to increase and organize the information available for updating prior knowledge; to increase the objectivity of judgement; and to inject continuity in the priority-setting/assessment process. The specific techniques identified in the literature, and discussed below, include:

¹¹ Applicable source documents include: Bureau of Industry Economics (1992), *Economic Evaluation of CSIRO Industrial Research: Overview of Case Studies*, Commonwealth of Australia, Research report #39; Commonwealth Scientific and Industrial Research Organization (CSIRO), and the Australian Bureau of Agricultural and Resource Economics (1992), *Rural Research -- The Pay Off. The Returns from Research Undertaken by the CSIRO Institute of Plant Production and Processing*. Occasional Paper #7, May; International Service for National Agricultural Research (1987), *Priority-Setting Mechanisms for National Agricultural Research Systems: Present Experience and Future Needs*, ISNAR Working Paper, The Hague, Netherlands; International Service for National Agricultural Research (1988), *Priority-Setting in Agricultural Research*, ISNAR Working Paper, The Hague, Netherlands; and Smith, Keith (1991), *Economic Returns to R&D: Methods, Results and Challenges*, Science Policy Support Group, London.

- Congruence
- Checklists (Partial Indicators)
- Integrated Partial Indicators
- Mathematical Programming
- Prospective Benefit-cost Analysis
- Cost-Effectiveness Analysis
- Simulations/Econometric Analysis
- Peer Review/Modified Peer Review

The first seven of these are described below. The use of the peer review techniques in ex ante assessment is the same as described in Sections 3.1 and 3.2, except that the information upon which the judgements are based is more speculative.

Congruence

Congruence is a rather simplistic technique that should really only be used as a starting point in a priority-setting exercise. This technique is most commonly applied in specific sectors, such as agriculture. Using this sector as an example, the congruence principle is based on the idea that, other things being equal, total available research funds should be allocated among agricultural commodities in the same proportion as their existing contribution to agricultural domestic product. Given the manner in which funding is allocated under this approach, congruence can only be directly applied to programs based on commodities/products.

This approach is not useful as a method of estimating benefits (under this techniques, benefit estimation relies on the extrapolation of the past benefits of commodity specific R&D), and it tends to discriminate against new products. As a method of R&D funding allocation, it is also not particularly useful. However, as noted above, it can be used as a starting point for the allocations of funding among R&D projects, and then other techniques can be used to make necessary allocation adjustment.

Checklists (Partial Indicators)

Though the least sophisticated of all priority-setting techniques, checklists can greatly improve the quality of the priority-setting exercise at little extra cost. The idea is that one comes up with a list of the criteria, and associated questions, which should be considered and addressed when deciding on priorities (most of the questions will tend to revolve around the impact of the research, its cost and its feasibility). Each research project is then reviewed against this checklist, which provides a screen for weeding out projects that do not adequately meet the specified criteria. For large R&D activities, and for basic and strategic R&D, where funding tends to be based on historical allocations and personal judgement, a checklist provides a useful starting point for a formal priority-setting exercise. In addition, to the extent that the generation of benefits is taken as a criterion for R&D projects, this approach forces decision makers to at least think about the issue and whether the candidate R&D projects have the potential to generate benefits.

This technique is simple to apply; however, it does require a great deal of understanding of the various research areas that are putting forth candidate R&D projects for funding consideration. This factor will have bearing on the types and appropriateness of the criteria/questions developed and their relevance to the projects under review. The checklist method does not include any quantification of the relative importance of various criteria/questions; however, the checklist concept can be readily expanded into a system of integrated partial indicators by attaching numerical weights or scores to the various criteria.¹²

Integrated Partial Indicators

This approach (often called "weighted multiple criteria analysis" or the "scoring approach") provides a way of incorporating and ranking a wide variety of quantitative and qualitative factors that influence, and are deemed relevant to, the selection of R&D project options. Conceptually, the method differs little from a checklist. The difference between the two approaches lies in the fact that each R&D project is evaluated with reference to a specific set of criteria/questions; the projects are assigned a numerical weight in line with their ability to address the various criteria/questions; and then the array of R&D projects up for consideration are ranked in order of priority according to the sum of the numerical values assigned to the various criteria.

The integrated partial indicators approach offers a number of advantages in terms of providing a method of setting priorities and for assessing whether a project has the potential to generate benefits. Specifically, it forces R&D decision makers to determine the criteria for assessing what makes for a good R&D investment (such as will it generate benefits); it forces the decision makers to consider, for each project, all the significant factors which have bearing on priorities and to make conscious trade-offs among multiple goals; and it compels decision makers to rank R&D projects in terms of their relative importance. In addition, this approach offers the advantage that it provides a quantitative decision rule for evaluating R&D proposals.

The difficulty with this approach involves the potential arbitrariness and subjectivity in assigning weights to various criteria. The elicitation of these weights must be carefully structured to avoid bias. This problem is especially evident in instances where decision-makers may conclude that the score given to a particular project may not appear to be in accord with "common-sense". In this event, the decision-maker may choose to manipulate the weights assigned until a result emerges which appears to be more reasonable. This manipulation of weights is not necessarily inappropriate and may be done by a single decision-maker, or by a group consensus (which is preferred). However, it is important to guard against manipulating the results until they merely reflect a priori assumptions and historical preferences. An additional difficulty with this approach stems from the practical problems connected with attempting to rank R&D projects in significantly diverse research areas. A certain set of criteria may be more relevant to one

¹² In fact, the checklist approach at least implicitly forms the basis of several of the methods discussed below. However, when used as a basis for these alternative methods, greater care must be exercised in the selection of both the criteria and the weights.

research area than to another; thus, one must be careful to ensure that the trade-offs being made do not reflect a bias for one particular research area over another.

Mathematical Programming

The mathematical programming approach is similar to the integrated partial indicators approach in that weights are placed on a set of goals or criteria. However, mathematical programming provides a more powerful and sophisticated priority-setting technique in that it relies on the mathematical optimization of a multiple-goal objective function, subject to a resource constraint (namely available funding, human resources, etc.), to select a portfolio of research projects. As a consequence, this procedure has an advantage over the integrated partial indicators approach in that it provides for the selection of an "optimal" portfolio, taking into account the various evaluation criteria and constraints imposed in the programming problem rather than simply ranking research areas.

Mathematical programming provides a useful alternative for selecting research projects; however, it is not particularly useful for evaluating too diverse a set of R&D projects (where the various project attributes are not easily assessed). If either the criteria for project assessment, or the constraints faced in executing R&D projects (especially over time) are not well defined, there is a risk that an "optimal" but nonsensical solution can result.

With respect to using the mathematical programming approach to assess the benefits/impacts of R&D, again this approach may not be especially useful. Unless the connection between a set of projects and a certain magnitude of benefits is clear, it is not readily apparent how one would set up the objective function to be optimized. However, if the connection between a project and its potential for benefits is clear and can be ranked, then this approach can be used to select a suite of projects that will at least maximize the potential for R&D investments to generate benefits, but it will likely not indicate the magnitude. In sectors such as agriculture, however, where the relationship between R&D and economic effects (changes in productivity, etc.) is clearer and more direct, then it may be possible to incorporate a specific economic impact in the objective function (such as a certain percentage change in input productivity, yield rates, etc.) and then use the mathematical programming approach to select the "optimal" suite of R&D projects.¹³

Prospective Benefit-Cost Analysis

Most of the previous discussion (in Section 3.5) involved the application of the benefit-cost methodology in an ex post analysis; however, prospective benefit-cost, which is applicable for ex ante analysis and priority-setting, is not methodologically different from ex post applications—it is just that the data is much more difficult to come by.

¹³ It should be noted that, in an example such as this, the distinction between mathematical programming and simulation models becomes somewhat blurred.

In prospective benefit-cost, as in ex post analysis, the costs and benefits of an R&D project are evaluated with reference to a well defined set of principles. However, in an ex ante analysis the benefit-cost practitioner must rely on a wider range of assumptions with respect to R&D project benefits, costs, R&D adoption rates, the probabilities of research success, etc. The development of these assumptions generally incorporates expert opinion which can be gathered from a wide variety of sources (as a general rule, the more diverse the sources the more robust the assumptions). If the prospective analysis is conducted with respect to projects nearer the applied end of the R&D spectrum and/or with respect to individual projects, the assumptions that are necessary to conduct a quantitative prospective benefit-cost analysis may prove to be reasonable. If the prospective analysis is conducted with respect to projects nearer the basic/strategic end of the R&D spectrum, and/or with respect to large blocks of projects, or an entire R&D program, the assumptions may prove hopelessly unrealistic and it is unlikely that this approach will provide any useful quantitative information.

Despite the difficulties in setting out the assumptions necessary for specifying the future cost and benefit streams of R&D projects, the advantage that the benefit-cost framework provides remains. Specifically, it provides a structured approach for considering the implications of particular R&D choices; for identifying some of the criteria to be used in judging projects; and in ensuring that all the necessary evaluation questions are being addressed.

The Australian Bureau of Industry Economics recently carried out a fairly detailed comparison of the pros and cons of prospective benefit-cost analysis versus the integrated partial indicators approach used by the Commonwealth Scientific and Industrial Research Organization (CSIRO).¹⁴ Their study indicated that:

"Benefit-cost analysis is not well suited to R&D direction setting ... [but] benefit-cost analysis can contribute to the CSIRO framework by providing, first, economic principles to guide the decision makers in their priority-assessing deliberations, and, second, a support, verification, and back-up capability."

Cost-Effectiveness Analysis

Cost-effectiveness analysis is a variant of benefit-cost analysis which is applicable in cases where it is not feasible or practical to assess the potential benefits of a project (in either an ex ante or ex post sense). A common example of the types of projects that fall into this category include R&D related to standards development,¹⁵ health and safety, etc. It is a comparatively simple task to postulate that R&D in these areas may be of benefit to society; however, in the general case, it is not a simple task to quantify these benefits, especially in ex ante terms. However,

¹⁴ Bureau of Industry Economics (1992), *Economic Evaluation of CSIRO Industrial Research: Overview of Case Studies*, Commonwealth of Australia, Research report #39.

¹⁵ The cost-effectiveness approach is recommended for determining resource allocations within the Australian National Standards Laboratory (pg. 43, BIE, 1992).

if we accept these benefits as the objective of R&D, then the R&D project choices that have to be made involve decisions on alternative ways of reaching the objective. In essence, in cost-effectiveness analysis one employs benefit-cost principles to evaluate the costs of alternative projects which, at least conceptually, are capable of meeting the stated objective. The decision rule then becomes one of selecting the project that can attain the objective at the least cost to society. The difficulty with this approach, however, is that of ensuring that the suite of alternative projects under consideration have the potential to generate the same kinds of societal benefits (i.e., that they are equally capable of reaching the stated objective).

Simulation/Econometric Models

The use of simulation/econometric models to gauge the impacts of R&D can be traced back to the 1950s and the pioneering work of Abramowitz (1956), Solow (1956) and Griliches (1958).¹⁶ Simulation models provide a framework within which the impact of an R&D project on a specified objective function(s) can be gauged. These models can vary in complexity from simple, spreadsheet based functions to elaborate econometric models. While the simulation/econometric models that have been used to assess R&D vary in their construction, a number have been based on a production function approach where the impact of R&D can be gauged by changes in factor productivity. Most of the problems with this approach (especially the more formal econometric ones) have been discussed in Section 3.5 and will not be reiterated here.

More recent simulation models that are more applicable to priority setting and project evaluation have been developed, although predominantly within the agricultural R&D sector where the connection between R&D and sectoral economic impacts are clearer and more direct.¹⁷ Within these models various agricultural demand, supply, price and production relationships, financial constraints and technological relationships (incorporating assumptions on the probability of research success and adoption) are specified. With the sectoral simulation models in hand, it is then possible to evaluate and rank the costs of alternative R&D projects and their contributions to certain sector specific goals (such as increased crop productivity, reduced input costs, etc.).

The advantage of simulation models is their flexibility. They can be constructed as relatively simple or extremely complex models; they can incorporate ranking or optimizing algorithms; and they can readily include probabilistic functions. Their major disadvantage is that, to be at

¹⁶ Abramowitz, M. (1956), "Resource and Output Trends in the United States", *American Economic Review Papers and Proceedings*; Solow, R. (1957), "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*; Griliches, Z. (1958), "Research Costs and Social Returns: Hybrid Corn and Related Innovations", *Journal of Political Economy*.

¹⁷ An interesting example, noted in the literature, of an agricultural sector simulation model is the Pinstrup-Anderson/Franklin model (Pinstrup-Anderson, P. and Franklin, D. (1977), "A Systems Approach to Agricultural Research Resource Allocation in Developing Countries", *Resource Allocation and Productivity in National and International Research*, ed. T.M. Arndt, D.G. Dalrymple, and V.W. Ruttan, University of Minnesota Press, Minneapolis).

all useful, they must accurately reflect the relationships between technological advancement and economic development. This generally requires the construction of a relatively complex model which typically requires extensive amounts of time to construct and data to operate. As noted above, in sectors such as agriculture where the relationship between R&D and the resulting economic consequences is fairly clear and direct, the development of a roughly accurate model may not be as problematic. However, for less specific sectors and less applied types of R&D, the relationships between economic benefits and R&D are often indirect, non-linear and exhibit markedly different lag distribution patterns. In these instances, the development of simulation/econometric models becomes quite burdensome in terms of the development effort and data required, and the utility of the resulting model may be suspect.

4.0 Benefit Assessment Practices in Other Jurisdictions

Having established, and reviewed, the accepted techniques for assessing the social and economic benefits associated with R&D activities, we conducted a review of the literature concerning the benefit assessment techniques applied to R&D activities in the public sector in other jurisdictions, and in the private sector.

4.1 The Public Sector

The review of the evaluation literature pertaining to R&D assessment practices in other jurisdictions covered a number of countries; namely, the United States, Australia, the Netherlands, Germany, France, Italy, Greece, the United Kingdom, Sweden, Norway, Finland, and Japan. In conducting this review, two particularly interesting points came to light which should be mentioned. First, it would appear that the evaluation practices in different countries are considerably influenced by the national and/or organizational context within which the R&D activity occurs. Economic, cultural and political features as well as administrative systems have a strong impact on the role of evaluation in the R&D policy process, and in the selection of the methodological tools considered as appropriate for assessing different aspects of R&D programs.

The second point that is worth noting is that there appears to be a dichotomy in the manner in which the R&D evaluation literature pertaining to practices in other jurisdictions is presented. Specifically, the literature published prior to the middle of the 1980s focuses almost exclusively on techniques for assessing the quality of research and describes in detail the peer review processes (and its variants) adopted in various countries. There are some exceptions, as will be noted below, that dealt with attempts to measure the economic and social benefits of investments in basic research, and R&D infrastructure generally, as well as attempts at identifying the economic impacts associated with applied R&D. However, articles addressing these subjects are in the minority.

The bulk of the literature published since the mid to late 1980s exhibits an entirely different characteristic in that it focuses on the evaluation process and its connection to decision making. This body of literature recognizes that R&D activities are operating within a new economic reality and stresses the need for a movement away from an ad hoc assessment process to a more systematic evaluation procedure for R&D management. Hence, for a number of countries, detailed discussions concerning the structure, objectives and purpose of R&D evaluations, the need to assess the economic and social consequences of R&D, and how the results of R&D assessments fit into the political, cultural and decision-making process are presented. The importance of this new focus on evaluation has been demonstrated by the appearance of a number of assessment manual and guidelines, such as: *R&D Assessment: A Guide for Customers and Managers of Research and Development*, published by the Cabinet Office of the United Kingdom; *ROAME Guidance for Collaborative Research and Development*, published by the Department of Trade and Industry in the United Kingdom; *Projektitoimintaopas*, published by the Technical Research Centre of Finland; *Voraussetzungen für die Tätigkeit von*

Großforschungseinrichtungen und Kriterien für eine Erfolgskontrolle, published by the German Federal Ministry of Research and Technology; etc. Nevertheless, while these manuals suggest possible techniques for assessment, very little information is presented in the manuals, or the literature generally, concerning the techniques which are, in fact, being applied for assessing the social and economic benefits of R&D. However, a careful reading of the literature does demonstrate that the methods used in practice to evaluate R&D generally, and economic and social benefits specifically, are very few in number and have changed little over time. A brief discussion of the techniques that are used in the various jurisdictions is provided below.

As expected, the dominant conclusion drawn from the literature is that peer review remains the foremost research program evaluation techniques. This technique has been combined, especially in Europe and to a lesser extent in the United States, with bibliometrics and science and technology indicators. However, as noted in Section 3.0, these approaches are of very little use for assessing economic and social benefits. In order to assess these aspects of R&D, especially for less applied R&D and for ex ante assessments, other qualitative techniques, such as modified peer reviews and client relevance reviews, appear to have gained the broadest support.

The manner in which the modified peer reviews are conducted in the various jurisdictions differ very little, and essentially reflect the description of the process presented in Section 3.0. However, some notable exceptions exist. In particular, the Dutch Organisation for the Advancement of Pure Research, in assessing its funding decisions, uses a two-stage version of the modified peer review which employs the Delphi technique to determine the probability of obtaining benefits, among other results, from its research activities (Luukkonen-Gronow, 1987). Similarly, the Swedish Natural Science Research Council uses a two-stage modified peer review panel, composed of foreign and domestic experts, to assess both scientific and technical outcomes and commercial applicability (Georghiou and Gibbons, 1987). This same method is used to a lesser extent in Finland, Norway and Denmark for the evaluation of some basic research fields (Luukkonen-Gronow, 1987). The Japanese have probably extended the modified peer review to its most interesting incarnation in that decisions concerning R&D investment are determined through continual consensus-seeking discussions held between industry groups, R&D organizations, the government and its advisory body. The purpose of what is in essence a large scale, continuous modified peer review, is to provide not only continual on-going assessment, but also a framework within which new opportunities can be identified and acted upon (Tanaka, 1989; Office of Technology Assessment, 1986).

For more applied R&D, and for on-going and ex post assessment, the majority of the countries reviewed combined a variety of data gathering and analysis techniques with the modified peer/client relevance review process. The most common combinations involve survey and interview techniques and case study methods to gather information on the consequences of particular R&D activities. However, some other combinations are noted. Specifically, the United Kingdom has used modified peer reviews in combination with patent analyses (Department of Trade and Industry, 1988); and Germany, France, the Netherlands and Sweden employ science and technology indicators as an information input (Meyer-Krahmer and Montigny, 1989). The results of the analyses based on these techniques are often published in what are known as "accomplishments books". These documents are an effort by research

organizations to display the impacts of funded research on advancements in science; actual or potential impacts on advancements of allied science or technology; actual or potential economic consequences; and potential impacts on the organizations mission. However, they rarely provide detailed examinations of the social and economic benefits of R&D activities.

In terms of the use of more quantitative techniques for the assessment of the social and economic consequences of R&D, the dominant practice is to use data collected through interview, questionnaire and case study exercises, and then evaluate that data within a benefit-cost methodological framework, an economic surplus framework, or an econometric exercise. Assessments of these kinds are generally done for large research centres, which contract to industry, and for applied and industrial development R&D projects. The practice of assessing survey and case study data on the basis of benefit-cost principles is exemplified by the National Institute of Standards and Technology, which has used these techniques to assess the economic and social benefits of its industry research support programs and its standards development activities (see Link, 1991, 1992a, 1992b).

The practice of assessing survey and case study data within an economic-surplus framework is most popular in Europe, and is exemplified by the work conducted to quantify the value of research "spin-offs" associated with R&D conducted by the National Aeronautics and Space Administration (NASA); the European Nuclear Research Centre (CERN); and the European Space Agency (ESA), (Schmied, 1987, 1982, 1977). However, as indicated in Section 3.0, while it is possible to estimate benefits with this methodology, its applications have focused on the estimation of economic impacts only.

Assessments of the economic benefits of R&D, conducted on the basis of survey, case study and published data, and evaluated within an econometric framework, have been done in the United States and the United Kingdom. In the United State, econometric/production function techniques have been applied in the evaluation of some basic research efforts (see Mansfield, 1991, 1989, 1981), in the assessment of federal, commercially directed R&D (General Accounting Office, 1979), and for research done in support of the agricultural and aviation sectors. In addition, the National Bureau of Standards has used surveys and case studies in order to gather information and has evaluated the data through a production function/econometric approach in order to measure the social rate of return and the productivity impacts of the Semiconductor Technology Program (Logsdon and Rubin, 1985). Econometric analyses in the United Kingdom also have concentrated on specific sectors such as agriculture (Doyle and Ridout, 1984). However, as noted in Section 3.0, econometric evaluation is data intensive, subject to numerous specification errors and, with the exception of research in specific sectors (such as agriculture), it is very difficult to conduct at the project or program level.

In terms of the methodologically most appropriate technique for assessing the economic and social benefits of R&D—a formal benefit-cost analysis—the literature would seem to indicate that it is rarely used. The countries which are cited for employing this technique are Canada and Australia; however, the evidence suggests that formal benefit-cost analyses are only conducted on an ad hoc basis and are primarily used for evaluating the short-term, development-oriented aspects of R&D activities (Krull and Sensi, 1991). We stress the term formal because, as

indicated above, a number of assessment techniques can (and do) incorporate benefit-cost principles in the analysis of data. For example, while the data collected by Albert Link, in many of the studies conducted on behalf of the National Institute of Standards and Technology, came from a variety of sources and were evaluated in an economic-surplus framework, the data was initially adjusted to reflect true economic and social benefits, in accordance with the principles of benefit-cost analysis.

Summary

The review of the public sector assessment practices in other jurisdictions indicates that, in general, there is agreement as to which techniques are most applicable for assessing the economic and social significance of R&D activities. Specifically, for R&D activities near the basic research end of the spectrum, the standard technique is to employ modified peer reviews and client relevance reviews. As the projects under evaluation move closer to the applied end of the spectrum, additional techniques, such as surveys, interviews, and case studies, are used to gather the additional information necessary for assessment, and the results are generally quantified. For industry-oriented research and applied research, surveys, interview and case study techniques are used for data collection and the information is generally assessed within an economic-surplus or benefit-cost methodology or, more rarely, in an econometric framework. The application of formal benefit-cost analysis is rare.

Regardless of the technique used, however, formal quantitative assessments of economic and social benefits are not common. In many instances the views expressed by potential users concerning the usefulness of an R&D activity, or the identification of technology links between a project and industry provide sufficient justification that the R&D is economically and socially relevant. Furthermore, when quantitative assessments are conducted, the resulting estimates tend to relate more to the potential economic impacts of R&D (i.e., employment and sales generation), and not the associated economic or social benefits.

4.2 The Private Sector

As anticipated, the literature concerning the R&D assessment practices employed in the private sector is sparse. However, the literature that does exist presented some surprising conclusions. Specially, in the private sector, where one might expect quantitative assessment techniques to dominate, given the general existence of a well defined economic objective for private sector participants, the opposite was found. R&D managers and decision makers in the private sector have indicated that, for the selection and ex ante evaluation of basic and applied research projects, existing quantitative techniques tend to be too simplistic, inaccurate, misleading, and are subject to serious misinterpretation. Rather, for ex ante reviews and on-going evaluations of R&D projects, as in the public sector, peer review dominates.

As the projects move closer to the development end of the spectrum, the application of quantitative techniques increases. Specifically, economic rate of return models, scoring models and risk analyses are often applied in on-going evaluations and when making decisions as to whether to continue with a certain project. This tendency is to be expected given the fact that,

as a project nears the development end of the cycle, the costs and benefits associated with a project become better known, and the risks associated with the project can be assessed on the basis of marketing information and past experience.

In summary, private sector decision makers, like their public sector counterparts, appear to use a combination of qualitative and quantitative techniques. Qualitative techniques are used almost exclusively for R&D projects of a more basic nature. At the level of applied research a mixture of quantitative and qualitative measures are used; however, decision makers still rely more on the qualitative measures. As the project moves into the development stage, decisions concerning the activity are guided increasingly by strictly quantitative measures such as rate of return techniques and risk analyses.

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Methods for assessing the
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