A FRAMEWORK FOR THE ECONOMIC EVALUATION OF ENVIRONMENTAL SCIENCE

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Economists, especially agricultural economists, have undertaken extensive analysis of the gains of technological-based scientific research. This is in stark contrast to the efforts undertaken to understand the economic effects of environmental scientific research. Economic evaluation of environmental science is important because knowledge-based government agencies are regularly required to justify their research expenditure and set clear priorities for their research programmes. This paper addresses the gap in the literature by offering a general framework for evaluating environmental scientific research. The paper is structured around two themes central to appraisals of environmental research: (a) the non-market nature of environmental outcomes; and (b) the pathways to achieve these outcomes. Some of the more important and unique issues addressed include the links between the natural systems being researched, the benefits in terms of resulting goods and services, and their subsequent values, as well as the factors influencing the overall contribution research makes to environmental decision-making.

1 INTRODUCTION

Research and development is integral to economic growth and social prosperity. Economists, especially agricultural economists, have invested substantial effort at identifying the gains of scientific research, with major quantitative evaluations from the early the 1950s.

One of the first economists to estimate the contribution of science to social welfare was Schultz (1953), who calculated the value of inputs saved in the United States between 1910 and 1950 from innovations in agricultural production techniques. Griliches (1958) used the economic surplus approach to estimate returns to U.S. farmers from the introduction of hybrid corn. Alston *et al.* (2000) provide a comprehensive review of past attempts at research evaluation in their meta-analysis of returns to agricultural research and development, surveying 292 studies and reporting 1,886 rates of return estimates.

The extensive knowledge and experience gained in research evaluation has resulted in many research institutes now routinely incorporating performance evaluation and reporting into programme design. Effective performance evaluation and benchmarking are seen as vital tools in the allocation of scarce funding, both across programmes and to projects within programmes (Productivity Commission 2007, p. xxv). The emphasis on research evaluation, moreover, spans the entire spectrum of research organisations from international organisations to national research institutes and sub-national government agencies.

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Parallel to empirical evaluations of research, economists have also developed a vast theoretical and conceptual literature for understanding the general value of science, as well as developing and formalising research evaluation guidelines. The techniques developed have been designed so that research evaluations can be performed more systematically and objectively to produce more robust outcomes. Much of this body of work is also focused on agricultural research, and includes contributions from Lindner and Jarrett (1978), Norton and Davis (1981), Mullen and Cox (1994), and Alston, Norton and Pardey's (1998) *Science under Scarcity*. There is also a growing literature in economics on the measurement of the benefits and impacts of social science research, including economics research. Notable studies include Smith and Pardey (1997), Timmer (1997), Schimmelpfennig and Norton (2003) and, most recently, Pardey and Smith's (2004) text *What's Economics Worth*, which features contributions from various specialists in this field.

The advances made by economists towards understanding the benefits of productivity-enhancing science appear in stark contrast, however, to the efforts undertaken to understand the economic effects of environmental science research. This is a significant gap in the literature, for environmental science is the cornerstone of improved management decisions on the environment, capable of generating significant economic benefits.

Environmental research is not directly analogous to productivity enhancing research, which casts doubt upon the applicability and transferability of some of the evaluation techniques previously developed. Agricultural research, for example, alters economic efficiency through improvements in total factor productivity. Conversely, environmental research improves economic efficiency by identifying and reducing environmental externalities. The impact of agricultural research is relatively easy to isolate with its effects mainly confined to markets, whereas the outcomes of environmental research have limited market effects, making them less tangible and identifiable.

The scant attention given to environmental science in the evaluation literature probably reflects the difficulty of the subject, rather than any indication of its importance or value. The Productivity Commission (2007, p. 166), for example, claimed that environmental research evaluation is an unrealistic aspiration, due to an apparent host of insurmountable measurement and methodological issues.

Notwithstanding these difficulties, the evaluation of environmental science is an increasingly important consideration because knowledge-based agencies are under increasing pressure, and often a legislative duty, to justify their investment decisions and set clear priorities for their research programmes. While the challenges of capturing impacts of environmental research may render it difficult to provide other than broad estimates of the overall return to environmental research, it is still important to base these estimates on sound guidelines that pay special attention to the unique characteristics of environmental science. This analysis has yet to occur, with evidence on rates of return to environmental research largely descriptive in nature and usually *ad hoc*. Further, general explorations of the value of environmental science research, such as those by De Groot (1989) and Gysen, Bruyninckx and Bachus (2006), have been too narrow in their focus, exploring only the effectiveness of environmental research at generating policy outcomes or what is known as the science-policy link.

1.1 Objectives

This paper addresses the gap in the literature by providing a conceptual framework for evaluating environmental science research. It develops a set of research evaluation guidelines that highlight some of the more important or unique issues that need to be considered when evaluating environmental research and thus provides a way of organising thinking about environmental science and its contribution to environmental management. The report is structured around two themes which are central to appraisals of environmental research: (a) the non-market nature of its environmental outcomes; and (b) the convoluted pathways of achieving these outcomes.

Section 1 explores the multifaceted nature of environmental science and its implications for evaluation. The section concludes by investigating why environmental science needs to be evaluated and what economics has to offer in this area.

Section 2 outlines the concept of economic value and some of the more common objections to its use. Alternative measures of the value of science are discussed, but largely dismissed, given that they focus on the knowledge content of the information produced by research rather than its applicability. The section also defines and explores the economic consequences of environmental research and the size and distribution of research benefits, and concludes by discussing the dynamic and stochastic nature of research and how this necessitates a move beyond a simplistic framework if the effects of environmental research are to be properly evaluated.

A fundamental challenge of valuing environmental research is to establish the links between the structure and functions of those natural systems being researched, the benefits in terms of goods and services derived by humanity, and their subsequent values. The report addresses these challenges in Section 4 by outlining a process for linking environmental outcomes to its economic effects, the benefits of environmental research, and methods to estimate those benefits.

Finally, in Section 5, the pathways are explored to achieving research benefits. Environmental research is different from technological-based research is that its outcomes are tied primarily to policy changes, either in the form of new policy instruments or changes in existing policies and policy instruments. The proper evaluation of environment research therefore requires an assessment of its overall contribution to environmental decision-making. Issues such as attribution and causality are emphasised and, in particular, their role in biasing estimates of the value of environmental research.

2 NATURE OF ENVIRONMENTAL RESEARCH

2.1 What is environmental research?

Environmental research is the scientific study of the natural world and society's interactions with it. It is an active field of scientific investigation that has gained much momentum in recent decades due to an increasing public awareness of a need to develop responses to major environmental threats, particularly at the global scale. Environmental research issues are diverse, ranging from climate change and biodiversity loss, to groundwater and soil contamination, natural resource depletion, issues of waste management, and air and noise pollution.

With such broad areas of inquiry, environmental research intersects the natural sciences drawing on physics, chemistry, biology, and the geosciences, such as geology, hydrology and soil science.[2] Although sometimes used synonymously with ecology, environmental research is much broader in scope, addressing issues at the sub-organism level of organisation; those involving abiotic environments or non-living systems; as well as the interrelations of living organisms and their physical environment (U.S. EPA 2002, p. 35). As an example consider research on climate change. Physicists create computer models of atmospheric circulation, chemists examine the inventory of atmospheric chemicals and their reactions, specialists in the geosciences, such as oceanographers, add additional breadth in understanding atmospheric dynamics, while ecologists or biologists might analyse the plant and animal contributions to carbon dioxide fluxes.

Irrespective of the area of study, the basic aim of all environmental research is to improve the quality of the natural environment. At its core, it is a process of expanding our knowledge about environmental systems to provide input into environmental management where needed. A subtlety exists here in that the contribution of environmental research is twofold, comprising research outputs and outcomes.

The primary or immediate output of scientific research on the environment is information. Information about the environment is acquired through the scientific method, which seeks to explain the complexities of nature in a replicable way by gathering observable, empirical and measurable evidence on a phenomenon and subjecting it to specific principles of reasoning, namely the formulation and testing of hypotheses through experimentation. The scientific information produced by research usually takes the form of new data, models, methods, or processes.

The information that science generates about the environment is eventually revealed to others through disembodied innovations. These are innovations that do not involve the purchase of a commodity, such as new practices and management techniques, and are distinct from the embodied innovations derived from technological-based research. The disembodied innovations derived from environmental research are more than just knowledge generation, and are perhaps best viewed as intermediate or indirect outputs. That is, to comprise innovation, scientific information is transformed into usable knowledge, which is productively incorporated into an entity's activities and decision making processes (Productivity Commission 2007, p. 7). Some of the main disembodied innovations arising from environmental research include:

- institutional innovations that provide new organisational structures to address environmental problems; and
- managerial and decision-making innovations that improve the environmental choices made by firms, households, consumers and the public sector (Zilberman and Heiman 2004, p. 276).

Ultimately, the objective of environmental research is to produce improved environmental outcomes. These outcomes are achieved only through the adoption or

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[2] In this paper environmental research is limited to research in the natural sciences only. However, in the quest to acquire knowledge about human interactions with the natural environment, environmental research is truly interdisciplinary, and may also encompass research from the social sciences, such as economics, law and geography.

implementation of the disembodied innovations that environmental research helps create. Crucial to evaluating environmental research, therefore, is an understanding of all the interconnections linking outputs—both direct and indirect—to the desired outcomes of research.

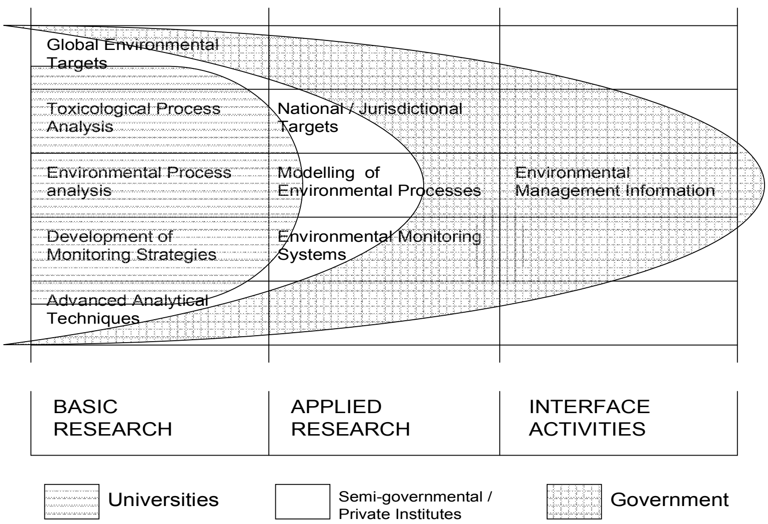
2.1.1 Types of research activities and research organisations

Environmental research activities can be grouped into three categories (Zoeteman and Langeweg 1988, p. 157):

- **Basic research**, also known as pure or fundamental research, advances knowledge of the environment through the development of scientific theories or advanced analytical techniques. It is usually conducted without consideration of its practical applications, although it does form the foundation of applied research. Basic research activities can also clarify environmental phenomena and mechanisms proposed in applied science.
- **Applied research** is the application of knowledge from the natural sciences to practical environmental problems. It informs decision making at every level by exploring environmental problems in empirical contexts with the goal of providing practical solutions.
- **Interface activities** are research activities that aim to disseminate research findings into the broader community to create awareness of environmental problems. Examples of interface activities include public information programmes and environmental management information systems.

Most environmental research is applied in nature and involves the quantification of environmental processes to set environmental goals. This is particularly true of government research, notwithstanding an involvement in all three research activities (see Figure 1). In contrast, basic research is predominantly the domain of universities.

Figure 1 **Research activities by research organisations**



Source: Adapted from Zoeteman and Langeweg (1988, pp. 158–9).

A significant proportion of the applied environmental research undertaken by government provides technical advice and support for day-to-day operational activities in meeting legislative requirements. This research is commonly referred to as ‘environmental impact assessment’ and may include:

- prospective risk assessments to evaluate environmental management options;
- retrospective assessments of environmental impacts to diagnose their causes and to evaluate mitigation options;
- assessments of environmental responses to stressors to support the development of environmental quality criteria; and
- assessments of environment monitoring data to document the condition of specific ecosystems (U.S. EPA 2006, p. A-1).

The scale and complexity of many environmental problems also encourages collaborative research between various research organisations. Depending on the type of research being undertaken, government agencies will often seek strategic alliances and partnerships with other government agencies, scientific organisations, research centres and universities. Generally, government agencies collaborate with other government agencies or specialist scientific organisations to produce environmental impact assessments as defined above, whereas basic research or longer-term research is more likely to be conducted in partnership with universities. The networking of institutes in this manner is a powerful instrument which potentially allows for a more effective use scarce research resources (Zoeteman and Langeweg 1988, p. 158).

2.2 Why evaluate environmental research?

In economics, information is viewed conventionally as a public good. This is because its consumption is often difficult to restrict (non-excludable) and the consumption of information by one individual may not necessarily diminish the amount or quality available for others (non-rival). Although some information is proprietary and conducive to private provision, many markets in information (or disembodied technology) are likely to be non-existent or operating at sub-optimal levels without government support because of these characteristics (Godden 2006, p. 197).

Notwithstanding the problems protecting information, a strong case exists for government involvement in environmental research because of the difficulties in appropriating the environmental benefits that stem from the information that research produces. Environmental research generally has significant spill-over effects and thus innovators are generally unable to sufficiently exclude others from procuring the environmental outcomes generated by their innovations. Private markets in environmental research tend to fail therefore, because of the public good properties of both its outputs and outcomes.[3]

The general case for publicly supported environmental research does not however, provide an indication of a specific project’s value. Gaining an appreciation of the

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[3] Another rationale offered for government support of environmental research is that it allows environmental agencies to discharge their functions more effectively (Productivity Commission 2007, p. 74). Quite simply, government research and innovation, particularly in the form of environmental impact assessments, is deemed pivotal to high-quality environmental management.

value of research is important because research activities involve the investment of scarce resources in the production of knowledge (Alston *et al.* 1998, p. 21). Not all research can be undertaken, and inevitably choices must be made about the total resources devoted to research and the subsequent allocation of those resources among and within research programmes. Therefore, environmental research can be classified as an economic activity, amenable to evaluation that uses an efficiency objective to determine whether the resources employed could earn a higher rate of return in an alternative investment.

Economic evaluations of research can occur either prospectively (*ex ante*) or retrospectively (*ex post*). *Ex ante* evaluations attempt to measure the potential benefits of research and provide a basis for allocating resources. These evaluations can help to determine whether a single project should be funded, as well as establish the 'best' allocation of research funds across research programmes (Kilpatrick 1998, p.1). *Ex post* evaluations attempt to measure the actual benefits of research and provide a basis for determining the success of research projects and programmes. Early *ex post* evaluations may be important to help secure additional funding for a project, determine whether additional research should be funded, and help research institutes avoid reincurring start-up costs and losing institutional knowledge (Kilpatrick 1998, p.1).

Drawing on public funds, knowledge-based government agencies have a greater responsibility to justify their environmental research decisions, not only in terms of benefits to the natural environment, but also in terms of fiscal accountability and public support. From Figure 1, it can be seen that government spans all three types of research activities, which requires decisions on the appropriate mix of research activities, as well as the specific research areas to focus on within each group. Clear articulation of the benefits derived from environmental research through either *ex ante* or *ex post* evaluations can help communicate the rationale for taking action and promote consensus by providing more information about the advantages and disadvantages of the various research alternatives on offer (U.S. EPA 2006, p. 3).

Despite the clear need for environmental agencies to make difficult spending decisions that involve tradeoffs in allocating resources—decisions that seem to call for economic analysis—research evaluation has both critics and may be controversial. Economists are often criticised for trying to put a 'price tag' on nature, and have been irreverently labelled as "heathens in the chapel" (Pannell 2003, p. 1). This criticism is especially evident when evaluations are proposed for research involving endangered species or serious public health or safety concerns, where economic considerations are at best secondary items in terms of the research objectives.

As a screening tool, however, economic evaluations of research should be regarded more favourably and as a positive component of science-project planning. Economic assessment can help reduce the occurrence of what could be thought of as 'type I adoption errors' in investment decisions. That is, by identifying, enumerating, quantifying and demonstrating the tangible benefits of research, economic evaluations attempt to minimise incorrect rejections of good science (type I errors), rather than the incorrect adoption of poor science (type II errors). Economic evaluations of research therefore, help to identify 'winners' and encourage and promote science instead of inhibiting, constraining or controlling it, as more commonly thought (see Box 1).

Box 1 **Economic value of invasive species screening programmes**

In a study of Australia's plant quarantine programme, Keller, Lodge and Finnoff (2006) found that the screening of ornamental plants to prevent the introduction of invasive species could save a country billions of dollars in long-term control costs. The study came in the midst of a policy debate over whether countries such as the United States should adopt a screening programme for non-indigenous species.

According to Keller *et al.*'s cost-benefit bio-economic modelling, countries should move to a more cost-effective preventative strategy on importing invasive species. Significant net benefits from applying species pre-screening were found on the basis that once harmful species become widespread they are rarely eradicated and their damages are borne for extremely long periods. Moreover, management options become limited and expensive. The risk assessment technology used by Australia was also found to have an accuracy of nearly 90 per cent. Invasive species screening programmes therefore demonstrate the importance of science leading to new beneficial policy, but, perhaps more importantly, the role of economic evaluations in promoting the value of good scientific research.

Source: Phsyorg.com (2006).

Other research questions also become relevant when managing the environment, given that the broader context of environmental management is to harmonise the goals of natural systems with those of social development. Almost all environmental problems therefore are multifaceted, consisting of more than just physical science facts, but of fact-value dichotomies (De Groot 1989, p. 659). Because environmental research affects individuals, economic evaluations provide a means of justifying and setting priorities for research programmes that protect or restore the environment in a way that leads to efficiency or improvements in social benefits (King and Mazzotta n.d.).

At the core of the question 'why evaluate environmental research?' is clearly a genuine dilemma in the sense that there requires a reconciliation of contrasting philosophical views. As Randall (2000, p. 251) noted, achieving this reconciliation is exactly the right place to start if economic evaluations are to play a significant role in informing public decisions about the environment. That is, for non-economists to be convinced of the benefits from using economics to evaluate environmental research, it is important that they understand—if not accept—the premise of economic value (Smith and Pardey 1997, p. 1534).

3 VALUE OF ENVIRONMENTAL RESEARCH

3.1 Concepts of economic value

Welfare economics provides the theoretical basis for defining the value of an action. The ethical basis of welfare economics is utilitarianism, which is a teleological theory of moral philosophy that places the ultimate criterion of morality in the welfare that results from a particular action (i.e. some non-moral value), where it is the affected people only that decide what is 'good' for them in accordance to their preference-based utilities.

Under a classical utilitarian ethic, social welfare is maximised by treating all groups of people as if they were one. Individual utilities are aggregated to maximise total social welfare, such that at least one individual would be required to sacrifice their utility if, as a result, somebody else is provided with more. A social welfare function is constructed under the assumption that welfare is non-decreasing in individual utilities, and is used to weigh up these tradeoffs in individual utility and thus determine the total welfare implications or value of alternative actions (Perman, Ma, McGilvray, and Common 2003, p. p.62).[4]

There are several problems with applying welfare economics, however, and none more noteworthy than that the social welfare function itself is not readily observable. Even if it were observable, there is the additional problem that it has no generally agreed form. These practical realities have forced economists to rely on, and devise, other utilitarian-based ethical rules to make judgements about welfare changes.

One alternative to the classic utilitarian rule is the Pareto improvement test. It overcomes the need to evaluate tradeoffs in individual utility and the need for a social welfare function, because an action is deemed welfare improving if at least one person gains from it and nobody else loses. Where losers do exist, they must be fully compensated for the change, according to their evaluation of the situation. The Paretian ethic is a form of restricted utilitarianism, where total welfare is maximised subject to a libertarian principle in that everyone has the right to maintain their status quo.

The problem with the Pareto improvement test is that it is unsuited to most economic problems, especially environmental ones, as they tend to involve tradeoffs and thus give rise to both winners and losers (Perman *et al.* 2003, p. 61). Moreover, compulsory compensation is not a realistic feature of policy changes.

To widen the scope for giving advice, economists use a refinement of the Pareto improvement test called the potential Pareto improvement test. This test informs much of the application of modern welfare economics and is based on the Kaldor-Hicks-Scitovsky principle of potential compensation, where an action is desirable (i.e. has value) if:

- the winners could compensate the losers and still be better off; and
- the loser could not compensate the winners for the reallocation not occurring and still be as well off they would have been if it did occur (Perman *et al.* 2003, p. 115).

Although workable, the potential Pareto improvement test offers a more limited basis on which to tender advice, as it is concerned with allocative efficiency and not improvements in welfare *per se*. Allocative efficiency reflects the possibility of reallocating resources so as to achieve an increase in the net value of ‘output’ produced by those resources (Hanley and Spash 2003, p. 47). That is, if compensation can take place, benefits outweigh costs and resources are being allocated to the highest valued user.

While allocative efficiency is necessary for optimality (a situation of maximum welfare), moving from an inefficient allocation of resources towards one that is efficient does not necessarily improve welfare. This is because compensation tests treat winners and losers equally, with no account of the fairness of the distribution of well-being. An action or project that is declared allocatively efficient by passing this

[4] The construction of a social welfare function assumes implicitly that interpersonal utility comparisons are possible or, in a sense, that utility is cardinal.

compensation test will increase welfare only under very strict assumptions.[5] It is important that decision-makers realise this and openly acknowledge it when conducting project appraisals.

3.1.1 General valuation principles and the economic surplus approach

With utility unobservable, compensation tests in applied welfare economics work with monetary measures of utility changes called economic surpluses. The economic value of an action is the total net economic surplus (or net benefit) it generates, which is the sum of the changes in consumer surplus and producer surplus less any additional costs associated with the action.

Consumer surplus is the net benefit individuals receive from the consumption of goods and services, and is measured by the area under the demand curve for a good and above its price.[6] The logic here is that the market demand curve describes consumers' willingness to pay (WTP) for additional units of a good or service, and indicates how much of all other goods and services they are willing to give up to obtain the given item or its gross value (King and Mazzotta n.d.). The market price of the good or service is its cost, and represents the minimum amount that people who buy the good are willing to pay for it.

Producers of goods also receive economic benefits, based on the profits they make when selling the good. The supply function describes the (opportunity) costs of production, and indicates the quantity of a good or service producers are willing to produce and sell at a given price. Profits to producers are measured by producer surplus, which is the area above the supply curve and below the market price.

The standard application of the economic surplus approach to valuation is of course cost-benefit analysis. This procedure measures and compares changes in producer and consumer surpluses in a consistent format to help decision-makers make more informed choices (Arrow *et al.* 1996, p. 221). A positive net present value indicates that a project is delivering a surplus of benefits over costs and thus allocating scarce resources to their highest valued use.[7]

As a potential compensation test, there is no regard for which people are made better or worse off in a cost-benefit analysis, and so issues related to well-being, equity and distribution are outside its scope. It is only intended to select projects that move the economy towards an efficient allocation of its resources (Perman *et al.* 2003, p. 369). According to Timmer (1997, p. 1546), the practical impossibilities of linking research

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[5] Social welfare is improved—in a classical utilitarian sense—under a potential compensation test if the social welfare function is assumed to be an unweighted, additive function in individual utilities, with individual utility functions identical and linear.

[6] The correct monetary measures of utility are the Hicksian compensating and equivalent variations, which net out welfare changes that arise from income effects. Consumer surplus is only a valid monetary measure of utility changes under the assumption that the marginal utility of income is constant. However, consumer surplus is more tractable and, as shown by Willig (1976), has a margin of error for most analyses of 5% or less because income effects are typically small.

[7] Many cost-benefit analyses only approximate economic surpluses as they typically ignore demand and supply elasticities. That is, extra production is usually valued at a single price, which assumes a vertical supply shifting against a horizontal demand curve, or the value of inputs saved is calculated at current production, which implies a horizontal supply curve shifting down against a vertical demand curve (Alston *et al.* 1998, p. 54).

to the actual welfare of society through cost-benefit analysis should not to be interpreted as consent to abandon research evaluations, but rather as an argument for more specificity in the evaluation of research. An evaluation of the efficiency of environmental research can be designed to help the pursuit of equity goals by identifying the groups affected by the research and thus should make an attempt to provide information about the distribution of the resulting benefits and costs.

3.1.2 Objections to economic value

The anthropocentric perspective of welfare economics implies that the economic value of environmental research and the environment more generally, depends on the value humans derive from environmental resources. Moreover, as a consequentialist and subjectivist ethic, research is valuable in economics only if the environmental problem it focuses on passes a preference-based benefit-cost test. If an environmental attribute, such as clean air or the preservation of a wetland, cannot muster sufficient WTP on the part of those who find such actions compelling, then it is said to be socially efficient that the environmental problem remain unresolved. Essentially the environmental problem being researched would be labelled by economists a Pareto irrelevant externality.

For this reason, many environmental scientists object to the basic premise of welfare economics and argue that the concept of economic value must be understood for what it is—a mere definition, or what philosophers of science like Northrop (1967, p. 11) would describe as a concept by postulation. Economists define the social value of something as what people are willing to pay for it and such concepts obtain their meaning from the theoretical structure out of which they emerge and have no independent meaning outside of that contrived structure. The mere fact that many environmental economists happen to believe that WTP is a measure of the ‘value’ of environmental research or any part of nature therefore does not necessarily make it so (Bromley 2007).

For some scientists, social decision-making on the environment (and the value of environmental research informing such decisions) should be based on the inherent rights of natural resources, reflecting more of a naturalist moral philosophy (U.S. EPA 2002, p. 88). This position is often referred to as a ‘deep ecology’ ethic and denies the primacy of rights and responsibilities to human beings, claiming that intrinsic value can be found in the integrity, stability and beauty of all natural systems. Indeed there is much environmental policy that is currently informed by this ethic, most notably the safeguarding of natural environments because of their unusual scarcity, such as national parks, wilderness areas and heritage sites (Perman *et al.* 2003, p. 57).

While it is straightforward to appreciate that the restriction of value to human beings is not a logical necessity, a general adherence to a naturalist ethic, on the other hand, is not advisable because it would prohibit too much human activity. Moreover, a humanist approach to environmental management need not imply that the interests of non-human entities are ignored (Perman *et al.* 2003, p. 59). Non-human interests influence decisions in economics because:

- humans can suffer as a result of the suffering of non-human entities—either directly through consumption or indirectly as a form of altruism;[8] and
- natural resources are used as inputs into production making their future availability a matter of grave concern, particularly in the absence of substitution possibilities.

Ethical differences aside, there are perhaps more mechanistic concerns of greater consequence with the application of anthropocentric utilitarianism, given that it is not always easy to induce market systems of economic organisation to take proper account of the way the natural environment affects human utilities.

First, measuring economic value in terms of WTP does not allow for the possibility that particular goods may be 'incommensurable' for some individuals, because their valuation is constrained by their income level (U.S. EPA 2002, p. 89). Distributional issues therefore become extremely important when valuing environmental research since it would appear that environmental problems have value and exist to only those who can afford to pay to alleviate them. The fact that WTP estimates are based on the existing distribution of income is of further concern when valuing the environment (and environmental research) because it is seems inconsistent with many environmental outcomes being public or free goods.

With WTP subject to income constraints, the value of environmental research is also likely to be increasing in income. This is because higher incomes have typically meant that the demand for natural resource preservation has increased (Alston *et al.* 1998, p. 76). Holding all factors but income constant, identical pieces of research therefore could elicit very different values when evaluated in different spatial or temporal settings.

Another problem with the concept of economic value is the scope for bias in eliciting WTP estimates. For evaluations of environmental research, bias is derived predominantly from the description of an environmental problem, which according to Löwgren and Segrell (1991) can be classified in three distinct ways: as a substance (e.g. nitrogen), a process or mechanism (e.g. eutrophication), or located to some medium (e.g., water pollution). Given that each description will supply important information about the perception of an environmental problem, different values can emerge for what is in essence the same problem.

A final criticism of preference-based utilitarianism is that individuals are not always the best judge of what is good for them. A 'consumer sovereignty' approach to welfare begs the question as to whether people generally have enough knowledge about the environment to properly assess its value, let alone value complex scientific research on the environment. On this basis, Sagoff (1998) recommended that WTP elicitations on the environment should be based on the principle of a deliberative citizen instead of consumer sovereignty and left to the opinions of experts only.

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[8] Sen (1987) distinguishes between 'sympathy' and 'commitment' in altruism on the basis of individuals having a fundamental dualism, being both consumers and citizens. As consumers, individuals can only display sympathy for others in such a way that this form of altruism becomes reflected in the arguments of a utility function. As citizens however, individuals can express a commitment to others where such altruistic concern comes at a cost to personal utility and is based therefore on other ethical principles.

However, even experts grapple to properly appreciate and understand the role of ecosystem services in supporting human life. This casts some doubt over the capacity of economics to fully appreciate and thus evaluate environmental research, especially the more obscure outcomes generated by basic research. Perhaps the most acute criticism of economic evaluations though is Norgaard (1989) who believes that the reductionist methodology of economics is forever ill-suited to the study environmental problems, because it is altogether incompatible with the holistic approach of ecologists that the whole is greater than the sum of its parts.

3.1.3 Alternative measures of research value

A variety of alternative methods exist with which to value environmental research. These evaluation methods are largely didactic, extending beyond the debate over the philosophical motivations underpinning environmental research to focus on the scientific significance and excellence of a piece of research.

A premise still central to scientific inquiry is the axiom knowledge for knowledge's sake. If this is to be construed as an evaluative criterion, then research ought to be justified on its own terms and considered valuable if it achieves its intended objectives. This type of goal-orientated measure of the value of research implies that knowledge acquisition should never be driven by its instrumental value but rather intrinsic value, and that benefits need not be known before accepting potential risk (Andrew 2004). Indeed many big scientific breakthroughs throughout history have invariably been achieved by observing this kind of ambitious, open-ended inquiry.

More common among scientists is to appraise research according to its scientific rigour or quality. Here, environmental research is not judged on what it sets out to achieve *per se*, but on its academic merit and thus standing within the scientific community. Scientific rigour is an indicator of quality because it provides credibility, inspires confidence, and increases the likelihood with which management actions achieve the intended outcomes. There is a host of peer review measures with which to evaluate the academic quality of scientific research, including replication, bibliometrics, and esteem-based indicators. A brief description of each follows:

- **Replication** is an important part of scientific inquiry, used to validate research results. If a piece of research is replicable, it is generally regarded by scientists as being reliable. Replication as an evaluative method, therefore, is an important screening tool before science is used to develop policy and perhaps subjected to further evaluation (Kilpatrick 1998, p. 4).
- **Bibliometrics** is the measurement of published materials stemming from research, such as citations and publication counts. It is an indicator of the quality of research insofar that it can demonstrate the popularity a piece of research gains in the scientific community. Bibliometrics however is not without flaws. It is an imperfect quality indicator because citations and publications may only signal the familiarity of a piece of research rather than its true relevance or impact (Kilpatrick 1998, p. 5). Basic research, for example, may not fare well under this evaluative method because of its elitist nature.
- **Esteem-based indicators** of quality are similar to bibliometrics in that they signal the standing of a piece of research within the scientific community. Esteem-based indicators include research grants, academic prizes and awards. Research that attracts such praise is deemed to be of higher repute and thus more valuable.

Outside peer review measures, the quality of science can also be gauged by the number of research linkages present. Research that is a product of a strategic alliance or partnership of several scientific organisations, including universities, is often regarded as superior in quality because it better demonstrates relevance, particularly to policymakers. Collaborative science is also alleged to suffer from less bias.

The problem with all quality-based evaluations of research however, is that by focusing on outputs they provide at best an imperfect proxy for the value of research outcomes. This is because, according to Lindner (2004, p. 166), quality indicators focus on the knowledge content of the information produced by research rather than its applicability. In contrast, economic evaluations of research are outcome focussed in that they attempt to measure the benefits to society at large from the research undertaken. For this reason, it is perhaps more apt to interpret economic evaluations as a supplementary, dispassionate performance measure of environmental research, instead of a decisive evaluation tool or perfect substitute for other measures of the value of research.

3.2 Economic consequences of environmental research

The question of what precisely constitutes the benefits of research is not straightforward and depends on the type of research under evaluation (Smith and Pardey 1997, p. 1531). For research geared towards disembodied innovations, such as social science research, Ruttan (1984) argued that its importance stems from the institutional changes it fosters. According to Smith and Freebairn (2004, p.118), most institutional changes have joint effects on households, the private sector and government and thus the consequences of this type of research are likely to be widespread.

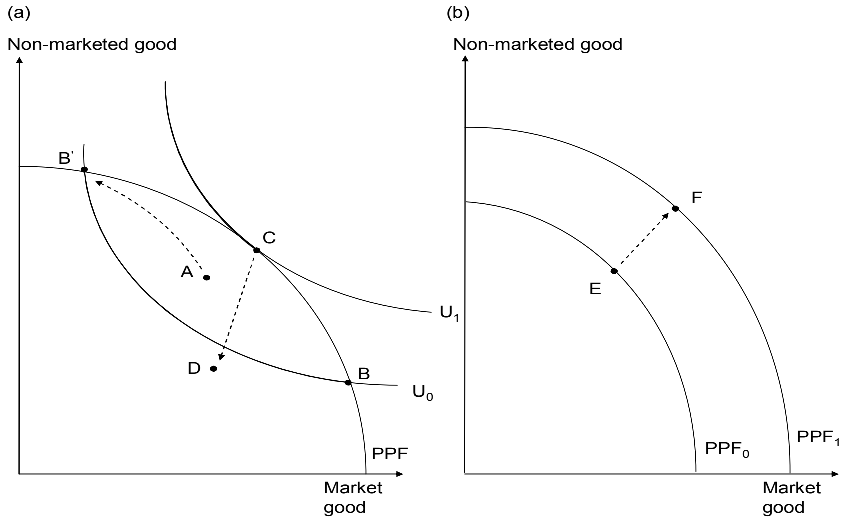
Applying this argument to environmental research, its economic consequences can be described as the efficiency gains it generates by facilitating improved management decisions on the environment, and thus reducing uncertainty about the optimal way to allocate society's scarce resources towards solving environmental problems (Schimmelpfennig and Norton 2003, p. 82). Generally speaking, environmental research will lead to greater efficiency by either:

a) informing new environmental policies and improving the design of existing environmental policies;
b) providing timely advice on the environment that prevents decision-makers from making poor policy decisions; or
c) creating new management processes that help moderate the perceived conflict between economic development and environmental management (see Box 2).

Box 2 **Impact of environmental research**

Environmental research primarily contributes to economic efficiency by stimulating society to reallocate its use of limited resources towards the production of non-marketed goods (or environmental management). In Figure 2(a), this is illustrated by an economy moving from an inefficient product mix like point A to an efficient product mix on the production possibility frontier (PPF) like point B', upon receiving improved knowledge about the environment. Improvements in efficiency however need not improve society's welfare (see Section 3.1). With the social indifference curves U_0 and U_1 representing lower and higher levels of economic welfare respectively, the distinction between efficiency and welfare is clearly demonstrated in this hypothetical example as the move from point A to B' actually lowers social welfare.

Figure 2 **Efficiency gains from environmental research**



Source: Adapted from Pardey and Smith (2004, p. 6).

Environmental research can also generate more subtle efficiency gains by providing timely advice that prevents decision-makers from making poor (policy) decisions. The benefit of environmental research in this instance is represented as the avoided efficiency loss (and even perhaps welfare) from preventing a move from point C to D or, more likely, A to D in Figure 2(a).

Finally, environmental research may lead to the creation of new management processes that expand an economy's productive capabilities. This is illustrated in Figure 2(b) as a shift in the production possibility frontier from PPF_0 to PPF_1 and the economy moving from point E to F. Research innovations of this type improve society's technical efficiency or its capacity to produce both market and non-marketed goods, somewhat moderating the conflict between development and environmental management. This impact of environmental research is akin to the traditional view of research altering welfare through improvements in total factor productivity, broadly defined to include the effects on the productivity of households, government and the private sector (Smith and Freebairn 2004, 112).

Different research activities will produce different types of knowledge and thus contribute to economic efficiency in different ways. Basic research, for example, plays less of a direct role in policy formulation, but remains crucial to environmental management because it helps identify the sources of major environmental threats. Applied research, on the other hand, is more targeted in focus and thus better at helping frame environmental agendas. An underrated contributor to economic efficiency is the interface activities developed and administered by scientists. They help to create public awareness of important environmental problems and thus rally the support necessary to secure the resources needed to respond to these problems. For example, systems of environmental information developed by the United Nations Environmental Programme, such as the Global Information Resource Database and the International Registry of Potentially Toxic Chemicals, have been instrumental in the development of many national environmental regulations, particularly in developing countries (Speth and Haas 2006, p. 64).

Perhaps the most important scientific function for policymakers, however, is environmental monitoring. This is because it provides a way of putting environmental performance in context and allows decision-making to be based on firmer analytic foundations. Environmental monitoring, therefore, serves to improve the enforcement of environmental standards and contributes to economic efficiency in the sense that it enables government to set targets that better reflect optimal pollution levels.

3.2.1 Economic value of environmental research and environmental externalities

Whatever its form, by identifying and characterising environmental problems, environmental research allows public decision-makers to properly 'cost' the environment and factor these costs into private production and consumption decisions. Environmental research has economic value, therefore, because it informs policy that predominantly aims to internalise negative externalities that cause social costs to diverge from private costs (Norton and Alwang 2004, p. 225). A negative externality arises when there is a spill-over effect of production or consumption on the environment that is not fully compensated through market transactions (Alston *et al.* 1998, p. 294). One example would be the pollution to ground and surface water from the use of agricultural chemicals. In this case, the social cost of agriculture is greater than the private cost perceived by farmers.

The potential benefits derived from environmental research are illustrated more clearly in Figure 3. Without knowledge of an environmental spill-over (e.g. some type of production-based emission), production decisions would be made according to private costs only, leading to a production level of Q_0, where marginal private costs (MPC) intersect marginal benefits (MB) from consumption. At Q_0 however, there is too much production from society's perspective, because attached to each unit of output is an environmental externality equivalent to the vertical distance between MSC and MPC.[9] Consequently, society incurs an environmental cost from producing Q_0 that is unaccounted for, equal to the area of the polygon $I_S bcI_P$.

The role of environmental research is to reveal the relationship in Figure 3 that exists between production and environmental damage and so the true marginal social cost (MSC) of production. Knowledge of this externality would then lead to it being internalised through an appropriate management action, resulting in a reduction of output to Q* where MSC intersects MB. The value of environmental research is given by the shaded area, which corresponds to the area under the MSC curve less the area under MB curve, over the reduced level of output Q_0 to Q*.[10] The distribution of benefits between producers and consumers from environmental research could also be obtained in Figure 3 by estimating the changes in consumer and producer surplus that result from the reduction in output and increase in price.

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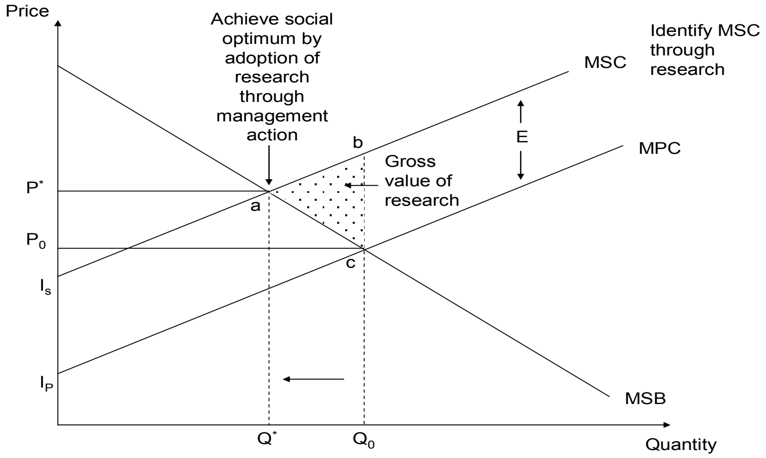
[9] The MSC curve is parallel to MPC because environmental damages per unit of output are assumed constant (equal to E). If emissions per unit of output are also assumed constant, this translates to a constant marginal damage function mapped in emissions space. Alternatively, MSC and MPC could be divergent, such that the externality increases in output. This would imply an increasing marginal damage function, assuming a constant relationship between output and emissions is maintained.

[10] The value of research would be greater if MSC and MPC curves were divergent—see Footnote 7 for details.

Figure 3 **Environmental research benefits from the internalisation of negative production externalities**



Under the economic surplus approach, therefore, the value of research is estimated as the sum total of each affected individual's demand for the environmental outcome it helps generate less the opportunity costs of achieving this outcome (or undertaking the research). The demand for the environmental outcome is represented by what people are willing to pay to increase their access to the specific environmental goods and services in question or, alternatively, by what people would be willing to accept in compensation for reductions in them.[11] Conversely, the social cost of the environmental research is the sum of the opportunity costs incurred by society from securing the research-prescribed environmental outcome, which could be, for example, the value of the goods and services lost by society resulting from the use of resources to comply with and implement an environmental regulation, as well as from the reductions in output.

3.2.2 The size and distribution of environmental research benefits

The key elements of the economic surplus approach that influence estimates of the value of environmental research are the:

- nature of research disclosed externalities;
- functional forms of supply and demand; and
- elasticities of supply and demand.

The nature of the ‘supply shift’ or type of environmental externality that research discloses has important implications for the size and distribution of research benefits. Most obvious is that the more relevant or significant the externality uncovered by science, the greater the benefits to society from internalising these externalities and thus the value of research. This is easy to see in Figure 3, with the shaded area larger in size the greater the parallel distance between MSC and MPC.

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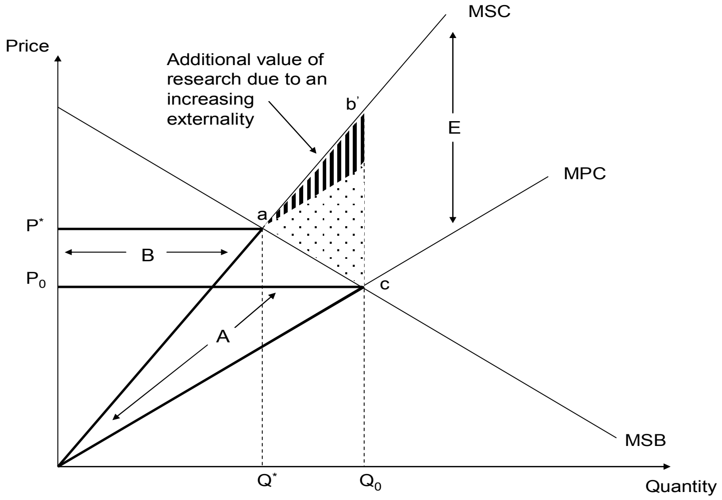
[11] The appropriateness of WTP and willingness to accept (WTA) to value changes in environmental quality depends on assumptions regarding the initial allocation of property rights of individuals experiencing the change (U.S. EPA 2002, p. 89).

The benefits from environmental research are also larger if the externality it discloses increases per unit of output. This is represented in Figure 4 by divergent MSC and MPC curves. The overall value of research is larger in this case because there are greater benefits to be gained from internalising the externality since environmental damage is increasing at the margin.

Figure 4 **Environmental research benefits with an increasing production externality**



Unlike the case of a constant externality, producers need not necessarily lose as a result of environmental research when they face an increasing externality. This counterintuitive result stems from the fact that elasticities also play an important role in determining the size and distribution of research benefits. As can be seen in Figure 4, producers will only lose from cutting back production with an increasing externality if area A is larger than area B. This depends on the slope of the MB function relative to both the social and private marginal cost curves.

More specifically, when demand is inelastic for a product, the loss in output from complying with environmental management will be more than offset by the accompanying rise in price, raising total revenue and leading to an increase in producer surplus. Area B will outweigh area A in Figure 4 therefore, and producers will benefit from environmental research. This result occurs because producers sell fewer goods as a result of internalising environmental externalities, but do so at a higher price. Because of this price-quantity trade-off, the more inelastic the demand of the affected product (i.e. MB curve), the more the distribution of benefits from environmental research will favour producers.

The distributional implications of environmental research seem to be exactly opposite to those of agricultural research. This is because environmental research serves to reduce output, whereas agricultural research is productivity enhancing and expands output. Environmental research that identifies parallel MSC and MPC curves (i.e. constant marginal externality costs) will never benefit producers.[12] For agricultural research, a parallel shift in supply will always benefit producers. When MSC and

[12] This finding assumes linear supply and demand functions and ignores extreme cases where the functions are either perfectly elastic or inelastic.

MPC curves are divergent, internalising environmental externalities only benefits producers if demand is inelastic. Contrastingly, pivotal shifts in supply resulting from agricultural research benefit producers only when demand is elastic (Norton and Davis 1981, p. 689).

The more inelastic the demand of the affected product, however, the smaller is the benefit from environmental research (in both the case of a constant and increasing externality). This is because consumers place a greater value on the commodity being produced and so are less inclined to substitute the environmental outcome for consumption. Therefore, although society benefits from internalising the externality, the reduction in output comes at a greater cost to consumers, which leads to a lower reduction in output and a lower net return to environmental research.

The friction that exists between the overall size of research benefits and the distributive effects to producers, especially under an increasing externality, poses somewhat of paradox for government. The most valuable research in terms of efficiency gains may prove to be the hardest to endorse because of its adverse affects on producers.

Finally, as noted by Alston *et al.* (1998, p. 64), economic theory is not informative about the functional form of research-induced supply shifts. Therefore, the specification of all the different factors influencing estimates of the value and distributive effects of research, such as whether demand is elastic or inelastic, is left largely to the discretion of the researcher.

3.2.3 Other economic impacts from environmental research

The economic consequence of environmental research as described in Figure 3 is quite unique and differs somewhat from other types of research—in particular agricultural science research—in that it generates net benefits to society primarily through reductions in output. That is, instead of revealing the MSC of production, research of a more commercial orientation would have the effect of lowering the MPC curve and generating benefits to society by raising production levels above Q_0. This is because most non-environmental research tends to develop innovations in the form of new decision making strategies or technologies which lower private costs of production or raise firm productivity levels (Lindner 2004, p.154).

However, environmental research may be yield-enhancing or cost-reducing and generate benefits similar to other types of research. Instead of merely alerting society to the existence of an environmental problem, a piece of research may be more proactive than given credit for in Figure 3 and actually provide a partial solution to an environmental problem. For example, research could develop an innovation that helps reduce emissions per unit of output, thereby reducing the severity of the damage caused by an externality. This would have the effect of shifting the MSC curve downward, leading to an increase in both the optimal level production (somewhere between Q^* and Q_0) and the ensuing net economic surplus attributable to the research.[13]

[13] This example assumes that the 'solution' to the environmental problem does not impact upon private production methods in any way and therefore only affects MSC. Moreover, a parallel shift of the MSC curve assumes that there is a proportional reduction in emissions per unit from research so that emissions per unit of output remain constant.

Another profound result of research on the environment may be the capacity it has to enhance industry productivity through the positive spill-over effects on private production that arise from the mitigation of particular environmental problems. For example, it is quite plausible that increased private conservation could lead to improved soil fertility and consequently better agricultural yields. Similarly, climate change research can facilitate investment timings and technological decisions by business and government owned utilities (Productivity Commission 2007, p. 155). Environmental research in such instances would lower MPC (and MSC by an equivalent amount, given the damage per unit of output remains unaffected), again leading to an increase in the optimal production level and ensuing net economic benefits. However, these ancillary productivity gains from environmental research are extremely difficult to measure in real life because the processes of environmental improvement are difficult to isolate and often gradual in nature.

Although difficult to relate to Figure 3, environmental research can also contribute economic value by developing innovations that lower firms' abatement costs. The idea here is that the adoption of a new, reasonably priced 'end-of-pipe' innovation would allow firms to essentially reach the environmental outcome associated with production level Q^* at a lower cost (i.e. tantamount to facing a lower MPC curve). With the gains from lower abatement costs mostly in the form of higher profits, environmental research of this kind has presumably commercial appeal and thus is more likely to be privately provided.

Finally, beyond the gains associated with revealing environmental externalities, environmental research can generate benefits by improving the cost-effectiveness of managing known externalities. A gain from research not recognised in the literature is the contribution it makes to economic efficiency by broadening the scope, and improving the integrity, of the economic instruments available to government to respond to environmental problems. Through a better understanding of stressor-response curves, for example, a regulator might be placed in a better position to adopt more innovative regulatory instruments such as a Pigouvian tax to address a particular environmental problem, or be able to refine an existing instrument to target the specific source of an environmental problem instead of its symptoms. Research may also improve the efficiency of environmental management in a more obvious manner by reducing the enforcement costs of existing environmental regulations. The development of less costly and more precise monitoring techniques is a good example of such research.

3.3 Issues affecting the value of environmental research

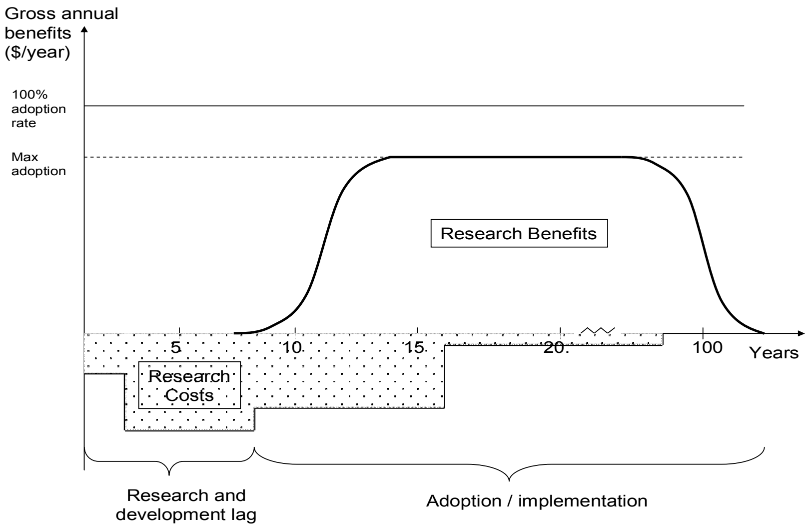
Although instructive, the exposition of the economic consequences of environmental research has so far assumed a static and risk-free framework. However, because environmental outcomes are laden with uncertainties and span long time horizons, there is a clear need to move beyond this simplistic framework if the effects of environmental research are to be properly evaluated. This is noted by Alston *et al.* (1998, p. 22) in their work on agricultural research, with the following questions considered important to address:

a) What is the probability of the scientific outcomes of a particular line of inquiry?
b) How soon will the results be ready for adoption, how applicable are the results, and how quickly will they be adopted?
c) How long will the research contribute to changes in welfare?
d) What are the costs of the research and how are they distributed over time?

3.3.1 Lags in research and adoption

No aspect of environmental research is instantaneous. It is a dynamic process that unfolds over many years, generating asymmetric streams of costs and benefits over time. A typical flow of gross annual research benefits is illustrated in Figure 5.

Figure 5 **Distribution of research benefits and costs over time**



Source: Adapted from Alston *et al*. (1998, p. 30).

The benefits derived from environmental research are usually delayed and gradual in nature due to lags in both research outputs and outcomes. There are frequently long intervals between commencing research and the generation of robust results. Lags also arise at the development stage, when scientific information is transformed into management actions, and then upon seeing management actions adopted. Finally, management actions may take some time before they materialise into environmental outcomes and economic benefits, which themselves can last well into the future. The economic benefits of a stock of knowledge will eventually erode however, due to depreciation and obsolescence (Alston *et al.* 1998, p. 30).

In contrast, the costs of research are frontloaded and occur well in advance of any benefits. Research costs increase during the development and adoption of research, and continue to accrue throughout its implementation, albeit at lower rate.

While the lag structure in Figure 5 is largely illustrative, basic research will generally have longer lag distributions than applied research. It will exhibit longer research and development lags, with lower upfront costs, and generate smaller benefits, but over longer time horizons. The results from basic research are also less sensitive to depreciation than applied research.

The asymmetry between the stream of costs and benefits demonstrates the importance of selecting appropriate time horizons when evaluating environmental research. Truncating the various lags in the research cycle inappropriately, or selecting an incorrect time horizon, is analogous to omitted variable bias in econometric modelling. In particular, much research would not pass a benefit-cost test if the time horizon selected for evaluation were too short. The dominance in short-term commercial objectives in setting research agendas therefore, poses a real problem for environmental science. For example, any evaluation conducted below the 15 year mark for the research project depicted in Figure 5 would not fare well, whereas an evaluation approaching the 100 year mark might.

Discounting

Related to the time horizon of a project is the issue of discounting and the notion of time-preferences for consumption. With benefits and costs spread over time, an evaluation of environmental research needs to be standardised to reflect the different values placed on consumption and production occurring in different years. Without going into detail about the process of discounting and the choice of discount rates, the most appropriate discount rate for evaluating environmental research appears to be either the social opportunity cost of capital for short-term projects or the social time preference rate for longer-term projects. A social discount rate is recommended because environmental research deals primarily with externalities of social significance.[14]

Discounting can radically alter the economic assessment of the net present value of a research project. The higher the discount rate the less favourable a research project becomes. Moreover, longer time frames will produce even more dramatic effects on a project's net present value. This would appear to place basic research at a disadvantage. Projects with large initial outlays will also be prejudiced, such as the more capital intensive applied research. And finally, projects with long delays before benefits are realised will also be penalised as a result of discounting. Research on landfill facilities, reductions in contamination of environmental systems from hazardous waste, and the protection of the atmosphere provide good examples of such projects.

3.3.2 Treating uncertainty

The impact of new scientific knowledge on the environment and society at large is plagued with uncertainty. This is due to the inherent variation of natural processes and the limited knowledge about the many relationships between stressors, exposure and effects (U.S. EPA 2002, p. 158).[15] These uncertainties make it difficult to say with precision what reduced environmental damage will result from environmental research, let alone the amount of reduction achieved. For example, the impact of climate change research on the environment will depend on many unknowns, including uncertain relationships between greenhouse gases (GHG) emissions, GHG concentrations and a host of climatic effects (Pindyck 2007, p. 49).

In general, the predictability of research-induced environmental outcomes is determined by the novelty and complexity of the research undertaken, as well as the availability of pre-existing scientific knowledge. The probabilities of different environmental outcomes will vary therefore, by scientific activity (applied cf. basic research), scientific field (hydrology cf. climatology), and research topic (climate change cf. groundwater quality).

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[14] The U.S. EPA (2000, Ch.6) in their *Guidelines for Preparing Economic Analyses* give a comprehensive review of the different approaches to social discounting in appraisals of environmental projects and policies.
[15] Uncertainties in the research process itself, such as whether a line of inquiry will produce usable results, are treated as issues of attribution and covered in Section 5.2.

Even when research-induced environmental outcomes are known (i.e. in *ex post* evaluations), measures of research outcomes would still be uncertain due to uncertainty about market parameters, most notably elasticities and functional forms of supply and demand (Alston *et al.* 1998, p. 35). That is, compounding the uncertainty of environmental processes is uncertainty over their economic impacts and the technical changes that might serve to smooth or ameliorate these economic impacts (Pindyck 2007, p. 49). Continuing with the example of climate change research, its impact would also depend on predictions of complex market behaviour including, perhaps, the demand and supply responses to carbon taxes, technological advances in energy conservation, the emergence of alternative energy sources and the development other 'abatement' technologies, such as carbon sequestration.

The various uncertainties characterising environmental problems are crucial to research evaluation and need to be taken into account to avoid biased estimates of its value. According Pindyck (2007, p. 48), making allowances for uncertainty is more important for environmental problems than other public policy problems given the non-linear nature of environmental benefit and cost functions, the irreversibilities often present, and longer time horizons. Where benefits and costs are uncertain, the way of incorporating them into any evaluation is to weight them by probabilities and then maximise the project's expected net present value.

Treating uncertainty by considering expected net benefits is based on a risk neutrality assumption. Arrow and Lind (1970) argued that this risk preference is entirely appropriate for appraisals of public investments because government effectively pools risk into unimportance through the sheer size of its investment portfolio. However, accepting the Arrow-Lind risk-bearing role of government does not imply that risk has no social consequence nor that mean-variance tradeoffs are irrelevant for decision making.

Knowledge of central moments of higher-order—notably, variance and skewness—are important to research evaluation when the distribution of research benefits is not symmetric (Alston *et al.* 1998, p. 37). In these instances the expected mean will be a biased estimate of the most likely research outcome. Attractive research projects with large expected returns therefore may prove to be 'fools gold' in the sense that they have little chance of ever coming to fruition. Individual agencies or research institutions need to be aware of this because they might not have the luxury of sufficiently large investment portfolios that render the cost of bearing such risk trivial.

Diversification strategies to reduce the riskiness of research investments also become relevant and legitimate non-efficiency objectives when research programmes have statistically dependent projects. Similarly, risk considerations are relevant for projects where endogeneity problems exist, such that the quality of the environment as a whole becomes correlated with research benefits (e.g. research on pervasive environmental problems like climate change). Minimising variance may also be used as a research evaluation priority when many projects have roughly the same expected value. And, finally, expected benefits are unlikely to be an accurate reflection of value for 'risk-reducing' research—that is, research focused on lowering the probability of uncertain outcomes, with no regard for returns.

The trouble with treating uncertainty formally, however, is that often entire probability distributions are themselves unknown. Sensitivity analysis is recommended therefore, where only a select range of the likely values of uncertain research parameters are estimated (Productivity Commission 2007, p. 659). Moreover, the analysis should be further limited to those that are considered to be particularly important because a full sensitivity analysis that includes every research parameter is unlikely to be feasible. Identifying 'switch point' values for key research parameters in the benefit-cost analysis is also advisable as it can shed light on the robustness of value estimates (U.S. EPA 2000, p. 28). Switch points are those conditions at which recommendations regarding the value of a research project change.

Uncertainty and the discount rate

The discount rate should not be used as a device to incorporate information on the uncertainty of future research benefits and costs in the evaluation. This is because a risk-adjusted discounted rate only serves to entangle the very separate issues of risk and time preference.

Uncertainty over future discount rates, however, is another issue altogether, and will influence the rate used for research evaluation (Pindyck 2007, p. 46). There are two alternative discount rates for research evaluations affected by discount rate uncertainty: the expected discount rate and the effective discount rate. The expected discounted rate is the weighted average of the range of plausible discount rates to select from. The effective discount rate is derived from the expected discount factor, given discount rate uncertainty. It will be lower in magnitude than the expected discount rate, because the expected discount factor is greater than the discount factor calculated using the expected value of the discount rate.

The gap between the two alternative discount rates will increase the greater the uncertainty over future discount rates. According to Newell and Pizer (2003), uncertainty in the discount rate begins to have noticeable depreciative effects on the effective discount rate the longer the time horizon (usually greater than 100 years). With many environmental problems spanning such long time horizons, understanding the nature and extent of discount rate uncertainty could prove crucial to research evaluation.

3.3.3 Costing research

Figure 3 accounts for only the (opportunity) costs of achieving research-induced environmental outcomes. A 'true' net value of research however, requires that all real resources devoted to the entire research process be costed and included in the analysis. This includes, among others, the resources employed to undertake the research itself, in-kind contributions, and any displaced resources from strategic management decisions or the realisation of environmental outcomes.

The actual costs of undertaking research are measured as the direct and indirect expenditures on project inputs. As shown in Figure 5, most of these costs are immediate and should be relatively easy to estimate. To minimise any oversights though, best practice would dictate that they be recorded at a disaggregated level and in a systematic fashion—preferably itemised under different cost categories and recorded on a yearly basis.

Direct research costs include:

- **Labour costs**, which includes all labour directly involved in the project, such as section managers, principal scientists, research assistants and post-graduate students. Labour costs should be calculated using full time equivalent salaries, include all salary related expenses (e.g., superannuation, leave loading, etc), and be apportioned according to the percentage time each staff member devotes to the project. Any volunteers used in the project, such as field workers, should also be included in the analysis and costed in a similar way.

- **Capital costs**, which includes all new and existing capital assets directly related to the project, such as laboratory equipment, machinery, specialised computers, and intellectual property. Capital costs should also reflect the percentage of time each capital asset is devoted to the project.
- **Operating expenses**, which includes all other variable costs directly related to the project, such as lesser equipment and consumables, specialist software, travel expenses, consultancies, conferences, maintenance on capital assets, and capital rentals, such as vehicle or aircraft hire.

When recording direct costs it is important not to overlook the value of resources devoted to the research activity by other participants or collaborators. This is includes contributions from both public research agencies and private partners.

Due consideration must also be given to indirect research costs. These costs relate to all the in-kind contributions a research project receives, such as non-funded staff (e.g. administrative assistants), property maintenance, utilities, general computer usage, and general infrastructure use. Given that there is no easy way to enumerate these types of ancillary inputs, it is conventional to use a project multiplier to capture in-kind costs.

Beyond costing the research itself, there is a host of other research related activities to cost which are tied to the development, adoption and implementation of research findings. The adoption and implementation of environmental research can be quite involved and, to cost properly, may require estimating administrative and enforcement costs linked to environmental management actions. In general, the particulars of research related costs depend on the pathways to environmental outcomes or research benefits, which are discussed in some detail in Section 5.

Additional research costs may need to be taken into consideration at the research programme level, in particular the adjustment costs that result from priority setting exercises (Alston *et al.* 1998, p. 39). That is, significant changes to research programmes can lead to expensive re-training of personnel and employment of other 'organisational' capital. Often neglected, these adjustment costs are a common source of upward bias in the estimated net benefits from programme evaluations. Another important cost often ignored when estimating the cost of research programmes is the possible value foregone of uncompleted research projects (Alston *et al.* 1998, p. 39).

Adjustment costs (as well as transactions costs) might also follow from research-induced environmental outcomes. When they occur, these costs are additional to the cost of foregone output as depicted in Figure 3. For example, an environmental outcome may actually displace resources such as agricultural labour. To fully cost the environmental outcome the relocation and retraining of this labour would need to be costed additional to any lost agricultural output.

Finally, because publicly funded environmental research is sourced from consolidated revenue, it may be appropriate to adjust research costs to include a deadweight cost of taxation. This cost accounts for the inefficiencies arising from the burden of taxes used to finance a project (i.e., called the marginal excess burden).

Empirical studies suggest the social cost of government spending to be in the range of 1.2–1.5 times the amount spent (Alston *et al.* 1998, p. 77).[16]

4 ESTIMATING THE NET BENEFITS OF ENVIRONMENTAL RESEARCH

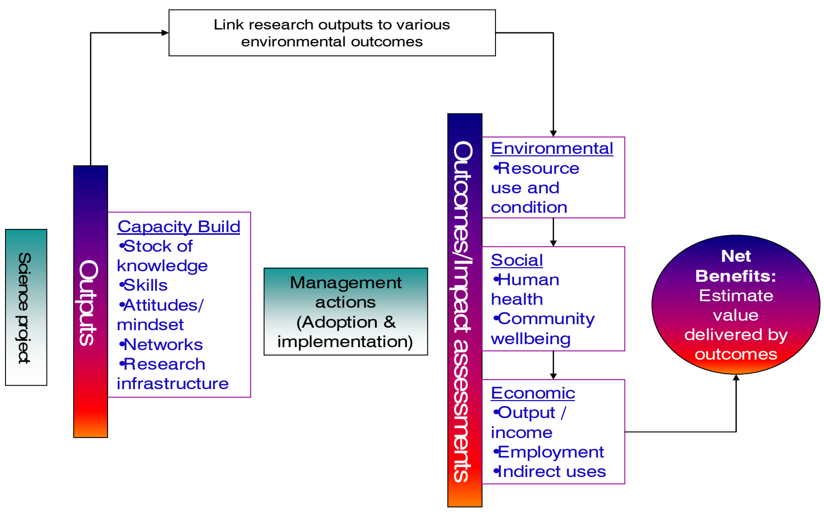
4.1 Evaluation process

It is seldom possible to obtain a single, comprehensive value estimate for the entirety of an action in a cost-benefit analysis. Analysts have little alternative but to follow a general 'effect-by-effect' approach for benefit valuation, where the collection of effects that result from an action are addressed individually and their values aggregated to arrive at an overall verdict. The three steps in an effect-by-effect approach include:

- identifying potentially affected benefit categories;
- quantifying physical effects of change; and
- estimating the values of these effects (U.S. EPA 2000, p. 62).

Evaluating environmental research—whether retrospective or prospective—requires therefore the quantification of relevant environmental outcomes in physical terms and the estimation of the social value of those outcomes. This calls for two separate, but related, assessments of a piece of research to be conducted: an assessment of its environmental impact, followed by an assessment of its economic impact.

Figure 6 **Evaluation process for environmental research**



Source: Adapted from ACIAR (2006, p.15).

[16] The social cost of government spending will be much lower when financed from taxes in demand-inelastic markets, because deadweight loss is derived from changes in quantity and not price. For example, land taxes, carbon taxes and consumption taxes where demand elasticity is close to zero will cause relatively small changes to occur in quantities consumed and thus a much lower deadweight loss.

An environmental impact assessment is a comprehensive review of the environmental outcomes generated by research. Economic impact assessments link environmental outcomes to economic effects and then estimate the values of the economic effects. Combined, these impact assessments establish the links between the structure and functions of those natural systems being researched, the benefits in terms of goods and services derived by humanity, and their subsequent values.

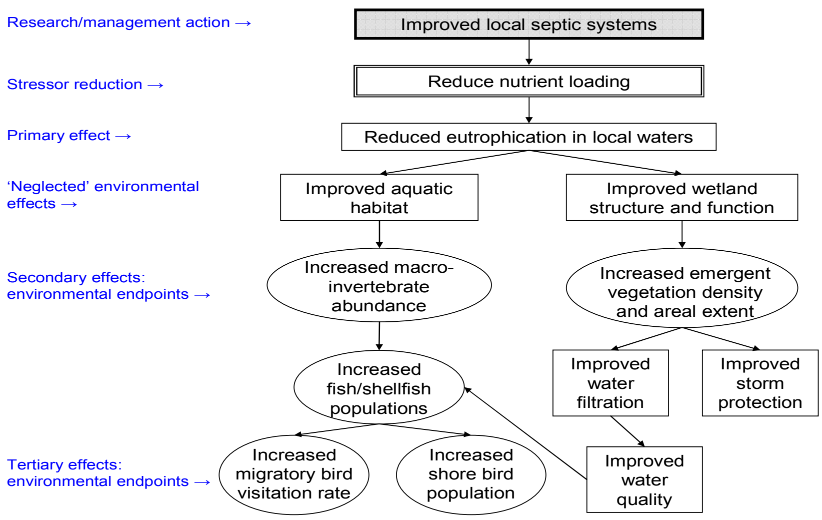
A schema of the evaluation process for environmental research is provided in Figure 6. Clearly, an evaluation process that is iterative and emphasises interdisciplinary teamwork is crucial to the appraisal of the net benefits of environmental research. Increased and continual collaboration among natural and social scientists will improve assessments of environmental research in several ways, including helping to identify appropriate environmental outcomes, identifying and collecting necessary data, and developing and applying the appropriate methods to quantify and value changes in those outcomes.

4.2 Environmental impact assessment

Environmental impact assessments map out all present and future effects the research findings are thought to have on the environment—that is, identifying and quantifying research outcomes (U.S. EPA 2002, p. 55).

An environmental impact assessment should begin with a qualitative description of research outcomes, where scientists identify the full range of likely environmental endpoints. Environmental endpoints are explicit descriptions of all the environmental attributes that are expected to change in response to actions that may result from the research. The consequences of the proposed actions should be traced from the sources through the initial changes produced in the physical and chemical characteristics of the environment, direct effects on environmental entities, and then the cascade of secondary and tertiary environmental effects that might follow (U.S. EPA 2002, p. 14). Environmental endpoints should also include human health risk assessments. Figure 7 illustrates a simple conceptual model depicting possible environmental endpoints of research aimed at improving local septic systems.

Figure 7 **Linking research to cascade of environmental effects**



Source: Adapted from U.S. EPA (2002, p. 67).

When identifying environmental endpoints, geographical and temporal changes should be clearly identified, as well as the interconnections within the environment. It is also important not to omit often-neglected environmental effects, in particular the entity ‘ecosystem services’. Ecosystem services include biotic resources, such as species habitat, biotic productivity, food chain support and pollination, and natural processes, such as microclimate control, energy and nutrient exchanges, and purification of resources.

The remainder of the environmental impact assessment involves quantifying the research outcomes by conducting exposure and response assessments of the environmental endpoints and characterising any uncertainty associated with these estimates.

Exposure assessments map out the complete pathway by which a pollutant or activity (i.e. stressor) acts on endpoints. They begin by identifying the source of a stressor and then indicating the level, intensity, duration and frequency of the stressor, and the co-occurrence in time and space of the stressor with environmental endpoints (U.S. EPA 2002, p. 74).

Subsequent to the exposure assessment is description of stressor–response relationships. These are the links between stressor characteristics and the magnitude of the resulting environmental effects. The changes to environmental endpoints considered may be biological (e.g. introduction of a non-native species), chemical (e.g. presence of a toxic substance), or physical (e.g. loss of habitat) (U.S. EPA 2002, p. 51). Because environmental impact assessments aim to describe net research outcomes, they should not overlook the possibility of adverse effects. Therefore, all negative as well as positive changes in environmental services that might result from the research should be evaluated.

To support economic analyses the magnitude and extent of responses in the endpoints must be assessed down the entire cascade of environmental effects identified. Where possible, the analysis of environmental effects also requires the development of full stressor-response profiles that describe all the likely responses of those endpoints to such exposures (U.S. EPA 2002, p. 80). This is particularly important given that most stressor-response relationships are nonlinear. Many environmental scientists may be unaccustomed to undertaking such detailed analysis, as it is common practice for them to identify only thresholds for adverse environmental effects, usually based on the most sensitive receptors (U.S. EPA 2002, p. 53).

The analysis of environmental effects will be based primarily on data from laboratory and field experiments conducted as part of the research, but may also require scientists to conduct further modelling and some educated guesswork. In the case of endpoints that are not directly connected to the research, scientists may have to rely on past observational studies of the same or similar stressors on similar ecosystem components (U.S. EPA 2006, p. A-2). When treating uncertainty, environmental scientists will also have to provide estimates of the likelihood of a number of linkages and determine the sensitivity of those relationships.

Finally, environmental impact assessments of research outcomes should aim to evaluate changes to endpoints at the highest possible level of biological organisation (U.S. EPA 2002, p. 53). This is because research outcomes are often distributed widely across the environment, and connect geographically remote regions and temporally separated events. For example, research on watersheds or climate change would require landscape-level assessments of endpoints because this type of research is likely to affect ecosystems and habitats over large geographic areas. Much research, however, is based on metrics that cannot be translated directly into changes in population or higher level effects, such as laboratory experiments that determine lethal concentrations. Although difficult, it is important that attempts are made to expand the use of both laboratory- and field-derived data in higher level models to be able to predict a wider range of potential effects.

4.3 Economic impact assessment

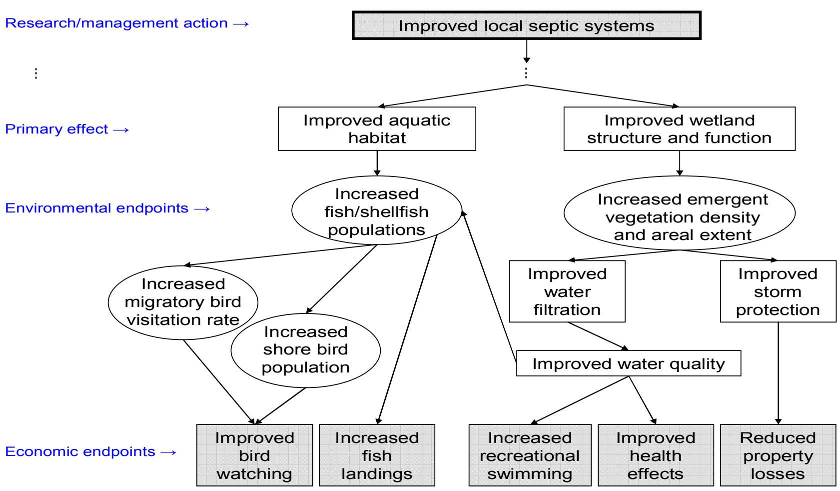
The economist's role is to identify the potential economic endpoints stemming from the environmental changes expected to occur from the management actions that might arise out of the information generated from scientific research. Changes in the economic endpoints are then used to assess the economic value of the action under study. Again, uncertainty needs to be accounted for, however for economic analysis uncertainty focuses on the link between environmental and economic endpoints.

4.3.1 Identifying and quantifying economic endpoints

Economic benefit endpoints are the goods or services provided or supported by environmental resources, directly or indirectly, that have economic value to society. The thoroughness of the economic impact assessment depends on identifying and defining as many of the linkages between changes to environmental resources and changes to the economic endpoints as possible. Identifying and defining these linkages begins with a qualitative understanding of the relationships and interactions that occur within the natural system, as outlined in the environmental impact assessment (EPA 2002, p. 18).

Figure 8 provides an example of economic endpoints that might arise from a policy that changes the quality and quantity of water resources given research on septic systems, and follows from Figure 7. The economist looking at changes to these water resources might list increased availability of drinking water, increased opportunities for river recreation, and improved quality of recreational and commercial fishing as some of the potential economic endpoints.

Figure 8 **Linking environmental endpoints to economic endpoints**



Source: Adapted from U.S. EPA (2002, p. 67).

To link environmental endpoints to economic endpoints, and develop a comprehensive list of goods and service flows, it is good practice to think through the different benefit categories associated with environmental resources and the type of economic value they provide—that is, either direct market uses, direct non-market uses, indirect non-market uses, or non-use values. This categorization of economic endpoints reflects how each service is experienced by individuals or groups and the extent to which they can be restricted from enjoying the service. Characterising the economic benefit endpoints in this way also helps economists identify appropriate valuation techniques for each endpoint (U.S. EPA 2002, p. 16). Table 1 illustrates this categorisation scheme and suggests commonly-used techniques for estimating their values.[17]

Table 1 **Taxonomy of good and services provided by environmental resources**

Benefit category	*Service flows*		*Commonly-used valuation methods*
Human health			
Mortality risks	*Reduced risk of:* -cancer fatality -acute fatality		-averting behaviours -hedonics -stated preference
Morbidity	*Reduced risk of:* -cancer -asthma -nausea		-averting behaviours -cost of illness -hedonics -stated preference
Amenities	-taste -odour -visibility		-averting behaviours -hedonics -stated preference
Environmental			
Direct market uses (products)	*Provision of:* -food -fuel -fibre	-building material -medicine -water (potable)	-market
Direct non-market uses	*Provision of:* -recreational opportunities (fishing, hunting, camping, swimming) -aesthetics (sightseeing, scenic vistas)		-production function -averting behaviours -hedonics -recreation demand -stated preference
Indirect non-market uses	*Ecosystem services:* -climate moderation -flood control -groundwater recharge -sediment trapping -soil retention	-pollination -biodiversity -water filtration -soil fertilisation -pest control -nutrient cycling	-production function -averting behaviours -stated preference
Non-use values	-scarcity value -option value -existence value	-bequest value -altruistic value -cultural/heritage value	-stated preference
Materials damage			-market -averting behaviours

Source: U.S. EPA (2000, p. 67).

[17] The U.S. EPA (2000, Ch.7) give a comprehensive review of each of the different benefit categories listed in Table 1, as well as noting issues associated with quantification.

The potential value of a research project will largely depend by and large on the magnitude of the environmental changes linked to the economic endpoints. In some cases however, an environmental change that is relatively small in magnitude may provide large economic benefits. Therefore, it is important to describe the cause-and-effect relationship between seemingly unimportant environmental changes and changes with obvious implications for humans (EPA 2002, p. 18). By working closely with the scientists, economists can be sure that those environmental changes are included in the environmental impact assessment and thus the evaluation process.

Similarly, improvements considered important by scientists might be overlooked by economists because they are not necessarily appreciated by the public. Scientists should ensure that economists do not overlook changes that might appear to be relatively minor, but in fact have widespread or long-term consequences. As a general rule, environmental and economic benefit endpoints should be roughly ranked according to both their environmental and economic importance (U.S. EPA 2002, p. 21).

Of course, the process of linking economic benefit endpoints to environmental endpoints is rife with uncertainty. Changes to endpoints that are better understood and more certain, therefore, should be given higher ranking than changes to endpoints that are less well understood or more variable (U.S. EPA 2002, p. 22). This is because economists should aim to provide a more certain estimate of the benefits of an action to better support policy decisions. However, where changes are potentially very large, they need to be considered even though they might be highly variable or not well understood (see Section 3.3.2 on treating uncertainty).

Ultimately, what can be measured in the environmental impact assessment will dictate, in part, what economic effects are captured by the economic analysis. The number of endpoints that can be evaluated in detail in the economic benefits analysis also depends on the time and resources available for the economic assessment (U.S. EPA 2002, p. 22). Generally, economic endpoints should be prioritised with the following factors in mind:

- environmental relevance of the endpoint;
- likely economic impact of the endpoint;
- susceptibility of the endpoint to the proposed action;
- importance of the endpoint to decision-makers;
- uncertainty associated with predicted changes to the endpoints; and
- practicability of appropriate valuation technique.

4.3.2 Methods for benefits valuation

Once the economic endpoints have been identified and quantified, they need to be valued. The following is a description of the methodologies available for benefits valuation:

- **Market methods** are used when direct markets for environmental goods and services exist. Benefits are estimated using price and quantity data on these market transactions. When employing market methods, it is important to include any changes in market behaviour (e.g., prices) attributable to the changes in the environmental resources examined.

- **Revealed preference methods (for missing markets)** are indirect approaches to infer the value placed on environmental goods and services using data on actual choices made by individuals in related markets.
- **Stated preference methods** are direct approaches to estimate the value placed on environmental goods and services using data on hypothetical choices made by individuals. Stated preference methods are the only methods capable of estimating non-use values (U.S. EPA 2000, p. 71).

The specific valuation techniques that fall under each of these methodologies are presented in Table 2.[18] They are grouped into two categories according to the process by which preferences for the environmental good or service in question are translated into monetary values.

Table 2 **Valuation techniques**

	Direct estimation of value	*Indirect estimation of value*
Market methods	-estimated supply/demand -market simulation models	
Revealed preference methods	-user fees -replacement costs -restoration costs -production function approach	-travel cost models -discrete choice models -hedonic price studies -avoidance expenditures -referendum voting -cost-of-illness
Stated preference methods	-contingent valuation -choice modelling	-contingent ranking -conjoint analysis

Source: adapted from U.S. EPA (2002, p. 111).

The almost inherent contradiction between how the market and society values environmental outcomes (i.e. many are externalities) usually implies a need for employing non-market valuation techniques to establish the value of environmental research—either revealed or stated preference techniques (Timmer 1997, p. 1546). However, non-market valuation techniques should be considered as a last resort only, either when the market value of the research cannot be determined or when the market value of components of the research is insufficiently large to justify the research costs (Norton and Alwang 2004, p. 226). This is because many of non-market valuation techniques are protracted, costly, and incur problems in theory and practice, especially stated preference methods.

When non-market valuation techniques are employed, it is preferable to lean towards those that do not involve sophisticated econometric analysis. Of the revealed preference methods, priority should be given to averting expenditures, user fees (and tourism expenditure) and cost-of-illness estimates to proxy environmental benefits, as this type of market data is relatively easy to acquire. However, these valuation

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[18] For the purpose of this framework it is sufficient to only list the valuation techniques available for environmental benefit assessments. For an overview of each method and description of their application to such assessments consult either U.S. EPA (2000, Ch.7), Hanley and Spash (2003), or Perman *et al.* (2003, Ch.12).

techniques are likely to underestimate the benefits of research outcomes, providing at best a lower bound.

Opportunity cost methods should also be given consideration, including direct opportunity costs, replacement costs, and restoration costs. Direct opportunity costs are the costs of attaining an environmental outcome, such as foregone industry output, and thus represent the cost of undertaking, adopting and implementing research. Although direct opportunity costs do not provide an actual measure of research benefits, they do provide analysts with a clear threshold above which benefits must exceed, and therefore a firm basis for evaluating research.

Replacement costs can also be used to value research outcomes. These are the costs of replacing the functions provided by an environmental resource, and can be useful proxies for the value of the ‘neglected’ ecosystem services that research generates. Specific examples include:

- the cost of building a retaining wall, which could be used to estimate the value of wave buffering services that stem from research on a wetland or coastal marsh area; and
- the cost of fish breeding and stocking programmes, which could be used to estimate the value of fish nursery services arising from research on estuary or river health (U.S. EPA 2002, p. 118).

In contrast to direct opportunity costs are restoration costs, which are the costs of restoring a degraded environmental resource to its original state, such as the costs of rehabilitating endangered species, rehabilitating mine sites, or regenerating ecosystems. Interpreted as the avoided costs of early intervention in environmental protection, restoration costs could provide a measure of the foregone benefits of not implementing research findings. Many restoration costs involve nonlinearities that should not be overlooked. For example, a piece of land that is 70% degraded may cost four times as much to restore than one with half the level of degradation. Generally speaking, restoration costs will be a function of the irreversibility of the environmental damage under consideration.

Where environmental outcomes cannot be monetised, it is important to list their impact, either qualitatively or quantitatively. Physical changes in the condition of natural systems may be taken as measures of benefits when the relationship between environmental conditions and social benefits is conceptually clear (U.S. EPA 2006, p. 5). They can also be used in cost-effective analyses, where even if it is impossible or impractical to measure benefits in dollars, economists can provide evidence that environmental research investments are being managed to maximise environmental benefits per dollar spent.

Another possibility is to use regression analysis estimate the role of research capabilities in contributing to some measure of environmental quality and management (Productivity Commission 2007, p. 160). Environmental indicators, such as the Environmental Sustainability Index, can provide biophysical data concerning the state of the environment to gauge the environmental impact of research. To measure research performance by way of environmental indicators, however, there must be a strong theoretical link between the research and the particular indicator selected.

Failing all else, the impact of environmental research may be measured through option values. These are the values associated with preparedness from the knowledge and skills science provides. Generally, option values will be higher (a) the lower the stock of current environmental resources; (b) the more complex the future potential environmental problem; (c) the higher the quality of present environmental scientific resources; and (d) the greater the potential of future scientific capabilities (Productivity Commission 2007, p. 164).

Benefit transfer

Budget constraints often prevent analysts from conducting original benefit estimates of non-market goods and services. Given the likely need for such estimates in the evaluation of research, a feasible alternative is benefit transfer. Boyle and Bergstrom (1992, p. 657) define benefit transfer as the transfer of existing estimates of non-market values (from the 'study site') to a new study (called the 'policy site') which is different from the study for which the values were originally estimated. By relying on information from existing studies, benefit transfer avoids the need to collect primary data, therefore providing a cost-effective means of obtaining quantitative estimates for research evaluation.

There are two main benefits transfer techniques: (a) point estimates; and (b) benefit function transfer. The point estimate approach involves taking the mean value (or adjusted mean value) from the study site and applying it directly to the research outcome requiring valuation. The benefit function transfer approach, on the other hand, involves transferring the entire benefit-defining function from the original study and substituting into it applicable values of key explanatory research variables. Kirchhoff *et al.* (1997) found the benefit function transfer to be more robust than transfer of average site benefits, particularly when demand functions cater for a large number of site characteristics.

Irrespective of which benefit transfer approach is employed to value research outcomes, the scientific debate about the validity of benefit transfer is ongoing (Kirchhoff, Colby, LaFrance 1997, p. 75). Generally speaking, the reliability of benefit transfer will depend on the similarities between the research project and the study site. In particular, the basic commodities should be equivalent, the baseline and extent of the changes should be similar, and so too the affected populations. Benefit transfer also operates on the principle that the study site estimates are 'true' measures of benefits. Benefit estimates should therefore come from a credible source, taking into consideration whether the original study was carefully conducted and used sound valuation techniques.

There are significant search costs in locating suitable estimates when conducting a benefit transfer. To find comparable measures of the environmental changes as used in the original valuation study, the analyst will need to identify and review a range of relevant studies, which can be a time consuming exercise (U.S. EPA 2002, p. 23). To facilitate this process and minimise search costs, analysts should consider using specialist environmental valuation databases as an information resource. The most comprehensive is perhaps the Environmental Valuation Reference Inventory (EVRI). EVRI contains over 1,900 international studies providing values, techniques and theories on environmental valuation and the benefit transfer approach.[19]

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[19] EVRI is free to all residents of EVRI membership holding countries including Canada, France, UK, USA and most recently Australia. It is managed by Environment Canada and can be accessed at http://www.evri.ca/.

4.4 Establishing the counterfactual

One of the most important aspects of research evaluation is defining an appropriate base case or establishing the counterfactual. This is because the concept of economic value is incremental in the sense that the economic surplus approach measures research benefits from shifts in 'benefit' curves due to changes in states of knowledge.

In many economic analyses, the counterfactual reflects the existing situation, which is called the 'without' case. For research evaluation, the baseline definition therefore will be delivery of environmental services in the absence of the research (U.S. EPA 2000, p. 21). Given that the role of science is to support environmental management, there are two types of base case from which to select:

- if science identifies a new problem (for example, through basic research), the base case should represent a situation in which there is no management action; or
- if science improves knowledge about an existing problem (for example, an environmental impact statement that identifies new endpoints, or improved monitoring), the base case should be the continuation of the existing management action to which amendments will be made.

The counterfactual must identify a particular point in time from which point forward the effects of the action are assessed. This is a tricky question in research evaluation, as the appropriate starting point may not be obvious. When research outcomes are tied to management actions, earlier starting points may be supported if divergence from the baseline occurs due to anticipation of promulgation. Options to consider include the date that the authorising legislation is signed into law, the date the rule is first published, or other regulatory development process milestones. In some instances, parties anticipating the outcome of a regulatory initiative may change their economic behaviour, including spending resources to meet expected emission or hazard reductions, prior to the compliance deadline set by enforceable requirements. In these cases, it may be appropriate to include these costs and benefits into the analysis, and not subsume them into the baseline scenario (EPA 2000, p. 22).

According to Zilberman and Heiman (2004, p. 249), the assessment of possible counterfactual outcomes is perhaps the most difficult aspect of an evaluation, especially *ex post*. The base case should not be interpreted as simply a 'before-and-after' comparison, as there may be trends in economic activity or key technological developments that occur for reasons independently of the research. The base case will frequently require detailed forecasting of key variables. All aspects of the counterfactual should be clearly defined from the start to facilitate such analysis, with all assumptions and uncertainties made explicit. The counterfactual should also account for the depreciation of knowledge and obsolescence, since the impact of research is neither uniform, nor indefinite. Knowledge is replaced over time and, in some instances, research is only ever intended to 'gap fill'.

It is also crucial that the use of baselines is consistent throughout all components of the research evaluation. In particular, estimates of changes in environmental and economic endpoints should be derived using the same baseline, so that estimation of net economic benefits yields meaningful economic measures (U.S. EPA 2000, p. 22). Likewise, if comparing and ranking alternative research projects, the same baseline should be used for all projects under consideration. To ensure that a consistent base case is specified, scientists should be consulted and engaged in the process from the outset.

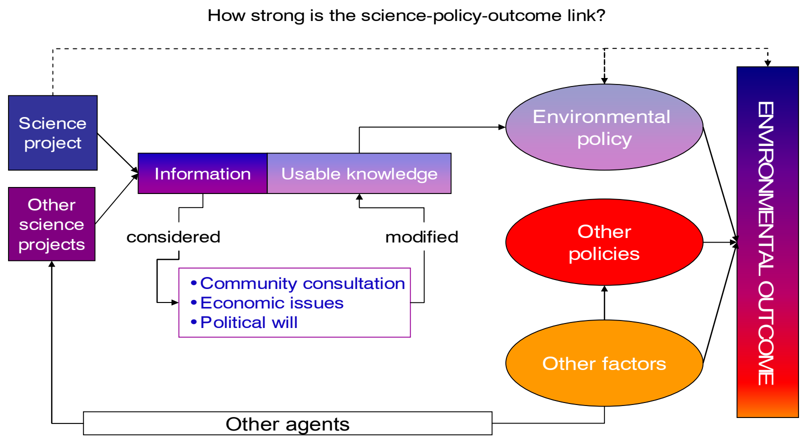
5 PATHWAYS TO RESEARCH BENEFITS

5.1 Environmental decision making

What distinguishes environmental research from other technological-based scientific research, such as agricultural research, is the principal vehicle through which that research affects changes in allocative efficiency. The initial incidence of environmental research, particularly publicly funded research, occurs within government agencies through information that leads to policy changes, either in the form of new policy instruments or changes in existing policies and policy instruments (Smith and Pardey 1997, p. 1532).

Notwithstanding a deep connection with the policy process, environmental science is nevertheless only one of many inputs into environmental decision making. Figure 9 highlights the many factors that potentially influence environmental policies and their outcomes. For example, a particular science project will produce information about the environment in conjunction with numerous other projects. All science information is then considered and modified by policymakers, to eventually become usable knowledge. This knowledge informs environmental policy to produce environmental outcomes, which are also affected by other policies and factors.

Figure 9 **Connecting environmental research to environmental outcomes: the science-policy-outcome link**



Given the convoluted pathways to research benefits, evaluation of environmental research requires understanding of the strength of the science-policy-outcome link. Science is a definite driver of environmental policy and its outcomes, but the question is the strength of this linkage?

Identifying the pathways to environmental research benefits is akin to assessing the rate of adoption of research and development. It is a critical aspect of research evaluation as it serves to limit upward bias in benefit estimates by correctly apportioning credit to science research. Unfortunately, untying science and policy is also what makes research evaluation a difficult task. In measuring the contribution of science to changes in environmental outcomes, several issues are crucial. These include:

a) how to apportion credit among the many factors affecting a policy change;
b) how to assess the causality between research and the implementation of policy; and
c) how to establish the effects of a policy change (Norton and Alwang 2004, p. 225).

5.2 Issues of attribution

5.2.1 Additionality and displacement

To avoid overestimating the benefits of environmental research it is important to assess the proportional impact of the research on policy decisions. In particular, economists must discern whose policy-orientated environmental research, past or present, accounts for which part of a policy package. This is known as the attribution problem according to Pardey and Smith (2004, p. 304), and comprises the key issues of additionality and technological displacement.

Additionality measures the extent to which a research project is genuinely new or has duplicated another project or crowded out a project that would have taken place under the counterfactual (Productivity Commission 2007, p. 659). Several pieces of research will often contribute to policy change and it is important to separate out their individual effects. A comprehensive evaluation would be concerned with only a project's marginal contribution therefore, and make an attempt to account for the impact of other research, either originating from within an organisation's own research programmes or from other research organisations.

Apportioning credit among different research projects is difficult as there are no quantitative theories or tools to draw on. Cost-benefit analysis tends to provide information about total costs and benefits and thus ignores the impacts of marginal projects (Productivity Commission 2007, p. 654). The difficulty of attributing environmental outcomes to different research projects is also compounded by research lags, most notably the fact that implementation lags behind the publication of research results. Generally, *ad hoc* rules will be needed to determine the shares among different studies. Zilberman and Heiman (2004, p. 292) suggest interviewing policymakers and scientists and asking them to rate on a scale of one to ten how the particular piece of research under evaluation contributed to various policy outcomes. These rankings can then be used to develop weights to use in the cost-benefit analysis.

Much applied research also benefits from other research. Projects may draw upon basic research on theory and methods, or ideas generated in related research projects undertaken concurrently, especially by outside groups. Norton and Alwang (2004, p. 225) stress that, where possible, these links have to be recognised in the evaluation process, with supporting research represented as a fixed cost to the project under evaluation. However, decisions have to be made on how narrow or broad the boundaries are drawn, as it would be infeasible to represent all theoretical and empirical influences in an evaluation (Productivity Commission 2007, p. 655). For example, when evaluating a piece of applied research that is based on basic research, the knowledge produced across entire scientific fields that the basic research itself draws upon may have to be ignored (i.e. treated as a sunk cost).

When assessing a project's marginal contribution it is also important to consider whether it has displaced research, both spatially and temporally. Where complete crowding out occurs, a project may elicit no benefits (nor involves direct costs) because it merely displaces those associated with a crowded-out project (Productivity Commission 2007, p. 659). The crowding out of research is more likely to occur when the private returns to a project are sufficiently high to create strong private incentives for private funding.

Crowding out may extend to research in other disciplines. Similar to the market-sector productivity gains that environmental research may generate, research expenditure directed into economic development can generate environmental benefits. It is important that environmental research does not crowd out these spill-over effects or duplicate them. For example, research in agribusiness could reduce methane production by cows, which may lessen urgency for particular types of climate change research (Productivity Commission 2007, p. 156).

An evaluation of environmental research should also consider the implication of technical change. That is, the incremental benefits of research will usually be displaced after a number of years. This means that counterfactuals should extend to not just to the likelihood of other research producing similar technical outcomes, but a range of approaches that may eventually lead to better ways of achieving particular outcomes (Productivity Commission 2007, p. 659). An evaluation of research on carbon sequestration, for instance, should factor in the emergence of renewable energy sources as they represent substitute technologies capable of overtaking traditional energy sources and rendering them and the need for carbon sequestration obsolete.

The type of research under evaluation will dictate the extent to which issues of attribution need to be considered. Applied research—particularly that specific to environmental problems within a geographical region, such as research on a threatened species—is largely unique and less likely to be additive than say general research. On the other hand, basic research is less likely to be displaced, but could suffer from additionality because it potentially benefits many countries. This can be seen in Figure 1 with basic research an activity undertaken by all types of research organisations. Finally, collaborative research, whether basic or applied, potentially minimises duplication of effort, which may render the issue of additionality and displacement less relevant.

Cherry picking and the problem of dimensionality

One issue related to attribution is how to select particular projects for assessment when they are recognised as forming part of a larger research programme. This is an important consideration because the impact of a research project can have one of three efficiency effects: it can have few or if any effects on efficiency ('shallow well'), large positive effects ('gusher'), or produce negative benefits ('poisoned well') (Smith and Pardey 1997, p. 1533). Consequently, to obtain credible estimates of the benefits of research on a particular environmental problem it is important that those projects selected for evaluation are truly representative.

Fortunately, studies on the distribution of research benefits and the effects of research programmes suggest that these distributions are skewed (Zilberman and Heiman 2004, p. 288). Contrary to Smith and Pardey's (1997) view therefore, a 'cherry-picking' approach to research evaluation appears unlikely to be misleading in most cases, especially when research programmes are devoid of poisoned wells. In these instances, selecting the best projects for evaluation will produce a lower bound on the benefits and avoid the need of having to contend with a prohibitively expensive review of possibly hundreds of research projects.

Good practice is to list and document all projects in the programme so that others can form opinions of whether the projects selected for evaluation are representative and whether the programme contains any significant poisoned wells that were overlooked in the evaluation. When a programme contains suspect projects, Smith and Freebairn (2004, p. 124) suggest choosing first the number of projects to be evaluated, according to the resources available, and then using a random sampling procedure to select those specific projects to be evaluated. If the distribution of research projects within the programme is highly skewed, then a stratified random-sampling procedure could be used instead. In either case, this approach to the dimensionality problem would ensure that benefit estimates are unbiased in a statistical sense.

5.2.2 Uncertainty of science

Further to the uncertainties surrounding the impact of new scientific knowledge on the environment (i.e. research outcomes), there are sources of uncertainty in the research process itself that require consideration (i.e. research outputs). According to Alston *et al.* (1998, p. 35) these include uncertainty about achieving the objectives of the research, the time taken to complete research, and the applicability, relevance and reliability of the information generated. Given these uncertainties, *ex ante* evaluations should reflect on the possibility of science failing—or generating outputs different from those intended.

The probability of the technical success of science will vary by scientist, research capacity and facilities, scope for cross-fertilisation of ideas, and the type of research being undertaken (Alston *et al.* 1998, p. 35). The success of basic research generally relies on the excellence and credentials of individual scientists. This is in somewhat contrast to applied research, which benefits more from teamwork because collaboration and networking among different scientists and institutes creates a more innovative and creative environment better suited to arriving at practical results (Zoeteman and Langeweg 1988, p. 160). Applied research is also highly dependent on access to suitable and good quality research facilities.

Peer reviews of past research can be used to judge *ex ante* the reliability of a particular line of scientific inquiry. Using a bibliometric measure, environmental research in Australia appears not to suffer from credibility issues, with one in every 20 articles in global publications on ecology and the environment being Australian—a figure significantly higher than its average scientific contribution (Productivity Commission 2007, p. 165).

The importance of creativity as a determinant of scientific productivity should also not be underrated (Lindner 2004, p. 171). Creativity is an especially important trait for scientists undertaking research in novel areas. Research within new scientific paradigms however, tends to produce more uncertain science than mature paradigms. This may be counteracted by the fact that successful research within a new paradigm is more likely to generate greater returns due to its novelty.

Despite these general guidelines, it remains very difficult to predict the success of scientific research. Moreover, a project that fails to deliver its expected outputs due to technical difficulties involved with the science need not necessarily be unsuccessful as it could contribute to building knowledge and skills, as well as research technology. The value of this research is very difficult to estimate as its impact depends on subsequent investments in research, perhaps even unrelated to the original research area.

5.3 Issues of causality

5.3.1 Science-policy link (policy development)

Perhaps nowhere is the scientific content of public policy more prominent than in the area of the environment (Speth and Haas 2006, p. 90). However, this does not imply that the role of science and scientists in the policy process is straightforward. Policies are implemented for many reasons, and an evaluation of science needs to assess how instrumental the research is in causing the policy change and the attendant stream of benefits and costs (Smith and Pardey 1997, p. 1534). The issue of causality in relation to the science-policy link therefore, refers to the degree to which scientific knowledge will actually influence environmental management.[20]

Science research is generally considered to be restricted and integral to the first phase in the environmental policy cycle, which is the phase of problem identification and agenda setting (Zoeteman and Langeweg 1988, p. 155; and Speth and Haas 2006, p. 89). According to Mickwitz (2003), there are no environmental problems over which decisions need to be made unless they are perceived as problems, and perceptions are affected mainly by knowledge. To this end, science plays an important role in policy development by formulating environmental problems and their responses—that is, it guides the point at which a threat is spotted to the point where there is tacit agreement among governments and stakeholders to address the problem.

Without environmental research, for instance, the world would not yet recognise the depletion of the ozone layer, climate change or biodiversity loss as major environmental problems (Mickwitz 2003, p. 418). Throughout the 1970s a stream of scientific publications from prominent scientific organisations such as the International Union for the Conservation of Nature, the U.S. National Academy of Sciences, and the United Nations Environment Programme identified these environmental threats and brought them to the attention of the global community. The research efforts of these organisations, which included the 1974 study by Rowland and Molina linking chlorofluorocarbons (CFCs) to the depletion of stratospheric ozone and the 1979 Charney report on the risks of climate change, have meant that these environmental issues have since dominated the global environmental agenda becoming subjects of many treaties, plans of action, regulations, and voluntary agreements (Speth and Haas 2006, p. 62).

Some scientists will engage further in the policy process than just identifying a problem by taking sides overtly in politically contested debates. Pielke (2007) acknowledges this and identifies four potential roles that scientists can play when engaging in the policy process:

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[20] Separate from research-led policy and the issue of causality is research-dependent policy. Research-dependent policy is environmental policy that depends on science, but is not necessarily ‘caused’ by science. Establishing links between science and policy in this instance would appear to be more straightforward.

- **Pure scientist** plays a passive role in the policy process, largely indifferent to how their scientific information is used by policymakers.
- **Science arbiter** is an input only in the policy process, providing facts to policymakers and not specific recommendations.
- **Honest broker** expands or clarifies the choices available to policymakers with balanced information, while leaving the decision to policymakers based on their own agendas.
- **Issue advocate** attempts to promote an issue or option by making specific recommendations.

In terms of evaluating science, it is useful to get a feel for which of these specific roles scientists play, or might play, in the policy process. This is because ideologically driven decision making can lead to the promotion of poorer science, while a passive approach may lessen the impact of important science. With a growing number of environmental scientists making impassioned pleas in the media, Pannell (2007) observed that it is not uncommon in environmental science for scientists to use their status to promote one side of an argument and adopt the role of issue advocate. He argued that this "role runs the risk of damaging the special status of science as a source of independent expertise…, especially in complex debates where different scientific experts may adopt opposing advocacy positions".

When there are strong links between science research, policy analysis, advising, design, implementation and evaluation, strong connections can be established between environmental research and environmental outcomes (Timmer 1997, p. 1546). However, knowledge transfer is not an unproblematic process (Evans 2006, p. 517), and the formation of these policy links and actual adoption of environmental research can be very slow, occurring many years after the scientific information is first produced, if at all. In general, the influence of science in policymaking, and therefore its productivity and value, will depend on:

- political will and the demand for institutional change;
- science literacy of policymakers and the broader community; and
- the amount of extension services supporting scientific research.

The political will to confront and resolve environmental problems is most important for the uptake of science. Science can draw attention to particular situations, but ultimately it is pressure from within society that compels government to act on them. Following Ruttan (1984), a precondition for environmental research to contribute to greater economic efficiency through changes in the organisation of political institutions and government policies therefore, is demand for institutional change from voters and lobbyists.

Environmental research will be most valuable when it is practically relevant to management decisions or has strong links with policy decisions that need to be made. This is particularly true if non-market valuation techniques are used to elicit the value of research outcomes. Marsh, Burton, and Pannell (2006), for example, found that the benefits of salinity monitoring programs increased significantly when they were in demand and linked to specific on-farm strategies. Conversely, technology for harnessing solar energy, such as photovoltaics, is a good example of science research that has had little political support, because of a lack of demand for institutional change in energy markets. As a result, this type of research has yet to reach its potential value, despite it being well developed.

The key determinants of the demand for policy change and thus the likelihood of government adopting environmental research include changes to the natural environment; changes or disequilibria in product and factor markets; growth in population or income; constraints on institutional changes imposed by ideology, religion and tradition; budgetary pressures, political costs and self-interest; and the projected benefits of research/policy outcomes (Norton and Alwang 2004, p. 226). The latter determinant raises an interesting issue in that it suggests that beneficial research is to some extent self-selecting in the policy process. This may make it easier to establish causality between science and policy in *ex post* evaluations.

The relationship between political will and the impact of science need not necessarily be unidirectional. An issue might receive little attention either because it is not well understood and recognised or, perversely, because it is very well known and a conceptualisation is generally accepted (Löwgren 1991, p. 614). In these instances, science itself can attempt to influence the demand for institutional change by better educating policymakers and the public.

The effectiveness of science in inciting concern over the environment will depend on the science literacy of policymakers and the broader community, which in turn depends on the amount of extension services supporting research. Here, interface activities play an important role in linking science to policy, as do advisory committees that promote the acquisition and dissemination of knowledge in matters involving science to improve public policy, such as the U.S. National Academy of Sciences and Australian Academy of Science.

As crucial actors in the policy process, environmental campaigners and non-governmental organisations can also significantly influence the authority of science on environmental policy. The importance of an advocacy coalition therefore—a loose confederation of scientists, NGOs, journalists, and other opinion leaders—in bringing an issue onto the public agenda should neither be underestimated nor ignored when evaluating science, particularly *ex ante* (Speth and Haas 2006, p. 92).

Given the heterogeneity in science literacy of the general population and policymakers, Zilberman and Heiman (2004, p. 282) stressed the importance of selecting appropriate mechanisms and vehicles to transmit research results. They suggested that new scientific paradigms should be communicated through formal science education, particularly to policymakers, whereas well established science should appear in print and electronic media at varying levels of sophistication so that it is made accessible to laypeople.

The improved science literacy of policymakers and the general public can increase the net benefits from research by both increasing the transmission of research and by reducing the cost of future extension (Zilberman Heiman 2004, p. 282). The interdependency between the impact of research, science literacy and extension, however, will require decisions to be made about the optimal allocation of resources between environmental research and extension. Ideally, this should occur where the marginal benefit of research is equal to the marginal benefit of extension (Zilberman Heiman 2004, p. 282). Any extension used to support research should also be fully costed in an evaluation.

Even with extension services in place, scientific disagreements and uncertainty can lead to contentious debates in the policy process, stifling policy action (e.g. climate change research and ratification of the Kyoto Protocol). Such disagreements need not devalue science, as these obstacles can be overcome by precautionary decision rules in the policy process. Precautionary measures, such as the Precautionary Principle or legislative objectives relating to sustainability, are provisions that allow policymakers to address potential threats and thus generate environmental outcomes when issues are poorly understood and inconclusive. If precautionary measures are used to defend the policy relevance of a piece of research in an evaluation, proof of political engagement in an issue and therefore a strong public demand for institutional change ought to be demonstrated.

Measuring the science-policy link

The relevant question to ask when assessing the causality between science and policy is whether the policy change would have occurred without the research. This question is important because many sources influence the policy process and upward bias would be introduced into an evaluation by not recognising the contributions of other inputs.

A good starting point for evaluation is to establish the content of the scientific information so as to better understand who will be using the research and number of decisions that potentially might utilise the research (Linder 2004, p. 155). The timeliness of research is another important consideration in determining the strength of science-policy links as it will have a significant influence on the likelihood of recommended changes being adopted (Norton and Alwang 2004, p. 226).

According to Zilberman and Heiman (2004, p. 292), estimating the probability that policy recommendations will be adopted and their subsequent influence on policy is perhaps the most important yet equally the most difficult aspect of *ex ante* evaluations. They suggested viewing the connection between research and policy in the same way as technological innovations, with research being given 25% credit for the development of policy, other actors in the policy process getting 50% for marketing and production, and unobserved factors taking the remaining 25%. Environmental research though, may warrant consideration of higher weights assigned to it than 25%, given its profound relationship with environmental management. Monitoring, for example, is a key function in the control phase of the policy cycle and thus has an unmistakable link with policy (i.e. it is needed to implement many policies). The specific weights assigned to environmental research in an evaluation is probably best determined in consultation with policymakers and scientists.

As alternative to relying on crude assessments about the influence of science on policy, sensitivity analysis can be conducted to determine the contribution science would need to make to generate positive expected net benefits. Lindner (2004) developed an expected net present value criterion for investment in social science research that allows for switch point conditions to be estimated for the proportionate level of adoption of research output, as well as other factors affecting attribution and causality including implementation delays and probabilities relating to the uncertainty of science. Similarly, Zilberman and Heiman (2004) developed an expression for net research benefits that permits its exploration to changes in the number of users, education of users, extension, the influence of other players in the political systems, and the additionality of research. Alston *et al.* (1998) related research, knowledge formation and policy outcomes by interlinking knowledge and agricultural production functions, although they did note that this representation provides more of a conceptual apparatus for handling attribution and causality than an empirical tool.

Establishing links between science and policy is also recognised in the literature as being closely related to Bayesian decision theory (for example, Lindner 2004; Norton and Alwang 2004; and Schimmelpfennig and Norton 2003). This connection is made because Bayesian decision theory provides a method for placing value on the information available to decision makers under conditions of uncertainty.

In Bayesian decision theory, the probability distributions with which decision makers start are modified or revised through a learning process. An assessment is then made as to whether the new information changes posterior probabilities enough to influence an outcome (Norton and Alwang 2004, p. 225). For research evaluations therefore, the relevant issue is how science changes decision makers' prior probabilities/distributions assigned to key policy parameters. The value of science becomes the difference between maximum utility with and without the new research or outlook information (Norton and Alwang 2004, 229).

Bayesian decision theory however, still relies on subjective probability estimates on the value of new information, especially in *ex ante* evaluations. The challenge of employing this approach is estimating the prior probabilities and defining the states of nature for which prior expectations exist. Norton and Alwang (2004, p. 230) proposed that prior probabilities would have to be elicited from interviews with individual policymakers.

Finally, whatever the degree of causation established between research and policy or required for net benefits to be positive, evaluations of research will be biased upward if policy costs are excluded from the analysis. Policy costs have been largely ignored in the literature on research evaluation, which is a significant omission or oversight given their potential size. The logic of including such costs in evaluations of policy-based research is quite simple: if policy is the vehicle through which research outcomes are accomplished, then policy development must become a research-related cost to balance out the cost-benefit analysis. Policy costs will comprise all activities associated with developing and implementing policy, including the engagement of policy officers, legal staff, and government regulatory costs such as administration and enforcement. Any policy cost included in an evaluation however, should only be proportionate to the influence the research has on the various policy outcomes.

5.3.2 Policy-outcomes link (policy implementation)

According to Zilberman and Heiman (2004, p. 280), the results of research may be wasted because there is a difference between recommending a policy and implementing it. Environmental research can identify an environmental problem, but the environmental outcome it produces is inextricably linked to the design, effectiveness and efficiency of the technologies, institutions and regulations devised to solve these problems. The final step in research evaluation therefore is to link the measured environmental outcomes with the specific policies that science informs.

Given the social dimension of most environmental problems, 'non-ecological' disciplines are often needed to solve them (De Groot 1989, p. 660). Policy instruments employed to achieve environmental outcomes can range from traditional command-and-control regulation, such as technology-based standards, to more flexible market-based instruments and voluntary programmes. In general, incentive-based mechanisms will achieve environmental objectives at a lower cost than command-and-control regulations, improving therefore the potential efficiency gains derived from, and value of, environmental research. In a review of *ex ante* empirical studies on incentive-based policies for air pollution control, Tietenberg (1990), for example, found that traditional command-and-control approaches cost, on average, six times the least-cost policy option.

The use of market-based instruments to achieve an environmental outcome at the lowest cost, however, is a theoretical proposition which needs to be recognised for what it is—an 'ideal' situation. Hahn (2000, p. 382) stated that political obstacles generally lead to markets with high transaction costs and institutional barriers that reduce the potential for cost savings from market-based instruments. Based on actual trades, he found almost all *ex ante* simulations of policy outcomes to suffer from upward bias in benefit estimates because they incorrectly assumed that incentive-based mechanisms achieve the optimal result.

With the judgement of consequences and hence policy tools adopted to address an environmental issue being largely political (Löwgren 1991, p. 621), it is important when evaluating environmental research to understand how the political process affects actual outcomes. A simple conceptual score to measure the effectiveness of environmental research in terms of it achieving its intended impact on the environment is the ratio between whether a policy matters—difference between the actual performance of a policy (AP) and the no regime counterfactual (NR)—and the degree to which a problem is 'solved'—difference between the best result that could be accomplished (CO) and NR.

$$E = \frac{(AP - NR)}{(CO - NR)}$$

This effectiveness score (E) is an expression of the gains actually achieved by a particular policy as a percentage of the gains needed to appropriately address the problem. As E tends to 1, a policy can be said to be more effective in terms of achieving its desired outcomes or 'solving' the environmental problem (Speth and Haas 2006, p. 100).

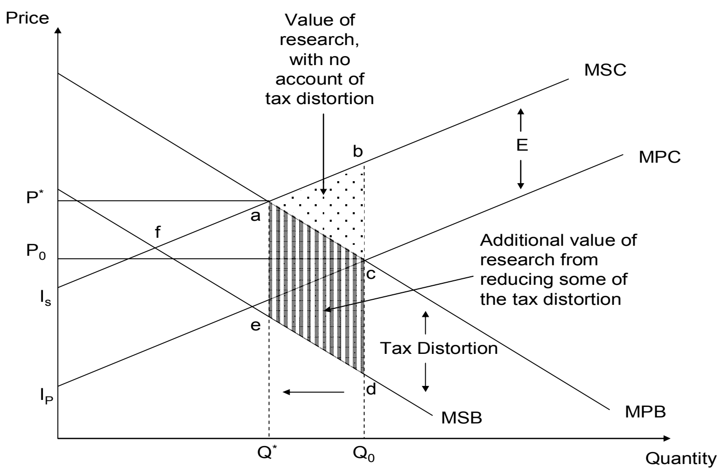
To predict how different policies or management actions influence environmental endpoints, information is clearly required on how agents respond to different policies. According to Zoeteman and Langeweg (1988), most policies are designed to operate at different levels in the environmental cause-effect chain. Policies that are aimed at minimising emissions will usually be source or stressor orientated and therefore hinge mainly on the behavioural responses of producers. Those aimed at minimising effects, on the other hand, are typically receptor orientated and tend to depend more on the behavioural responses of individuals and households. In either case, environmental policies will achieve their outcomes by either discouraging or restricting activities that are harmful to the environment, or encouraging or requiring activities to restore damaged ecosystems. Predicting responses should start with a comprehensive list of response options, including the use of different compliance technologies, changes in operations or consumption behaviour, shutting down a production line, and even non-compliance (U.S. EPA 2000, p. 26).

Economists can predict general behavioural response to most management actions using theory or empirical evidence. However, economic models rely on *a priori* analyses of the making of rational decisions. Policy experts therefore should also be engaged in characterising and quantifying behavioural responses to the variety of regulatory strategies affecting a specific area, particularly to capture the more *ad hoc* or non-systematic responses. Their expertise is especially important when there is the potential for behavioural responses to result in a substitution of the original environmental risks with different risks, such as increases in another stressor or a change in media through which a stressor passes (U.S. EPA 2006, p. 17).

Causal links between research-induced policy and an environmental outcome are made further tenuous with social outcomes always subject to the possibility that they were caused by something else. In particular, other policies and other factors can interfere, either positively or negatively, with the perceived environmental outcomes of the management action. Accounting for the influence of these exogenous variables is necessary to avoid bias in research evaluations, especially *ex post*. Timmer (1997, p. 1545) noted that not all exogenous variables can be held constant, however, even in the most complex bio-economic model, and establishing causation between policy changes and outcomes is a difficult task that can never be done with complete confidence.

Principally, it is the diffuse character of many environmental problems that adds to the difficulty of establishing clear causal relationships between outcomes and policy (Gysen *et al.* 2006, p. 102). Policy outcomes are also difficult to isolate and measure when an environmental threat has trans-boundary or trans-jurisdictional characteristics. In such instances, the effectiveness of a particular environmental policy—and consequently the value of research informing that policy—will rely on the capacity for coalition building with other states or nations.

Figure 10 **Additional efficiency effects in markets with distortionary policies**



Another important consideration when measuring research-induced policy outcomes is to include the distortional effect of other regulations in the market. This is demonstrated in Figure 10 where the presence of a tax concession to producers (represented as the divergence between MSB and MPB) is shown to increase the amount of benefits derived from environmental research. That is, by internalising the environmental externality, it can be seen that environmental research inadvertently reduces some of the policy distortion in the market caused by the tax, increasing the overall value of the research by area *aced*.

Finally, related to the ancillary efficiency effects in distorted markets is the double-dividend hypothesis. The revenue raised from selected environmental policies (e.g., a pollution levy) can be recycled and used by government to reduce the marginal rates of other taxes in the economy. Provided that these taxes are (Laffer) inefficient or have distortionary effects, then reducing their rate will produce additional efficiency gains. The end result is that the revenue-neutral environmental policy has a double dividend in the sense that it improves the environment and provides efficiency gains to the whole economy. Accordingly, so too will the science underpinning the policy.

6 CONCLUSION

Economists have made important contributions to understanding the benefits of productivity enhancing research such as agricultural research. But there are fewer contributions to understanding how to estimate the value of environmental research.

Performance evaluation and reporting arrangements for environmental science require adoption of an outputs/outcomes approach. While knowledge is the immediate output of environmental research, its effect or outcome is to improve decision makers' information sets and allow them to improve either the quantity or quality of specific environmental resources. The value of environmental research therefore stems from the institutional changes it fosters, and its economic consequences can be described as the efficiency gains research generates by reducing uncertainty about the optimal way to allocate society's scarce resources for solving environmental problems.

Notwithstanding the ability of science to improve decision makers' information sets and affect the environment, environmental research is only one of many inputs into environmental decision making. When evaluating research, it important to assess the proportional impact of research on policy decisions and how instrumental the research is in causing the policy change and any attendant stream of benefits and costs.

The influence of environmental science on policy depends largely on society's will to confront and resolve environmental problems. Environmental science will therefore only contribute to efficiency through changes in institutions (understood as in North 1991) if there is sufficient demand for institutional change.

The value of environmental science is also linked to many other factors influencing environmental management, especially the effectiveness of other research disciplines, such as economics and policy analysis. This linkage occurs because achieving environmental outcomes is inextricably linked to the design, effectiveness and efficiency of the technologies, institutions and regulations devised to solve these problems. The reliance of environmental science on other disciplines demonstrates that for science to have greater value, research efforts, planning and funding should not narrowly focus on the physical sciences only.

Making quantitative evaluations of environmental research is difficult. Establishing science-policy-outcomes links is extremely complicated, both *ex ante* and *ex post*. Moreover, the outcomes that science generates in terms of environmental and economic endpoints affected are difficult to identify and quantify, suffer from uncertainty, and often require non-market valuation techniques to measure their value.

Lindner (2004, p. 167) stated that "the danger with any formal system of research evaluation is the onset of diminishing and even negative returns to effort, the opportunity cost of which is actually doing research". Lindner's remark does not disparage the importance of undertaking evaluations, but is rather counsel to not 'split hairs' when evaluating research, given the obvious difficulties. If environmental research is to be genuinely evaluated then it should be clear that the research is amenable to evaluation. That is, the environmental outcomes ought to have clear economic consequences, and adequate resources should be devoted to the task so that effective evaluation is possible.

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