Improving Cost Benefit Analysis Guidance

A Report to the Natural Capital Committee

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February 2015

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Summary

The Green Book

The Green Book is a document published by the Treasury that provides guidance for public sector bodies on how to appraise policy, programme or project proposals. The Green Book is supported by a series of supplementary publications that focus on particular issues of project appraisal. The core methodology underpinning the guidance provided in the Green Book is that of cost benefit analysis, though other appraisal methods are occasionally referenced in the text.

As part of the ongoing refresh of the Green Book, this document, commissioned by the Natural Capital Committee, summarises a set of suggestions for improving guidance insofar as it concerns the cost benefit analysis of projects that have impacts on the natural environment. We describe such projects as environmental projects and include within that description projects whose environmental impacts are incidental to the main purpose of the project. Material relevant to this task is encountered throughout the Green Book but more specific advice is contained mainly in Annex 2 of core guidance and in supplementary guidance.

The ongoing refresh of the Green Book provides an opportunity to coordinate better the contents of core and supplementary guidance. It also provides a chance to consider what constitutes an appropriate division of material between core and supplementary guidance, and what material should be included in guidance proper rather than in the references.

Ecosystem services

One of the most important changes to occur in recent years is the widespread uptake of the *ecosystem services* paradigm and the closely related concept of *natural capital*. In essence, the paradigm seeks to characterise nature as a production system in which natural processes (ecological production functions) draw on stocks of natural capital to deliver flows of ecosystem services that in turn affect people's utility or affect production decisions.

An important insight of the paradigm is that an ecosystem service may act as an input to numerous subsequent processes. Some of those processes may be human consumptive or productive activities, in which case they constitute *final ecosystem services*. Alternatively, they may be other natural processes, in which case they are *intermediate ecosystems services*. For the purposes of project appraisal, the economic value of changes in the provision of final ecosystem services can be estimated directly using techniques of non-market valuation. In contrast, the value of changes in the provision of intermediate ecosystem services is only possible when evidence from the natural sciences can establish the resultant impact on flows of final ecosystem services.

We believe that it would be helpful for Guidance to adopt the ecosystem services framework since that framework demands a clear identification of the multiple channels by which the environmental impacts of a project affect human welfare. Likewise it provides clarity as to the division of responsibility between natural science and economics in establishing the value of those environmental impacts.

While the ecosystem services paradigm may provide a useful organising framework for the appraisal of environmental projects, we argue that some of its terminology (mostly developed outside economics) can be confusing or overly narrow in scope. In particular, the concept of an 'ecosystem service' puts undue emphasis on services flowing from biotic systems. Indeed, the original terminology from the economics literature of *environmental goods and services* is broader insomuch as it acknowledges that natural processes may provide both services and more tangible outputs, and because it encompasses outputs from both biotic and abiotic natural systems. For similar reasons we prefer the term 'environmental production function' to the narrower 'ecological production function'. We recommend that this more inclusive (and original) terminology be adopted throughout guidance.

Many outputs from human economic activity are unwanted and unpriced and variously described as pollutants or residuals. In acknowledging the ecosystem services paradigm it is important that these environmental 'bads', which were for a long time the sole focus of environmental policy, are not now forgotten.[1]

Finally, supplementary guidance promotes the provisioning-regulating-cultural-supporting classification of ecosystem services first developed by the Millennium Assessment. There are numerous problems with that classification. One major issue is that it fails to distinguish between *final* environmental goods and services and *intermediate* environmental goods and services and hence is a potential source of confusion for cost benefit analysts. We suggest therefore that it is retired from guidance.

Natural capital

The conceptual framework described above views the stock of natural capital as an input in the production of flows of environmental goods and services. Although economists have (often implicitly) been valuing changes in natural capital current guidance does not mention natural capital at all. Taken at face value it provides no assistance in the cost benefit analysis of projects involving changes in its stock of which there must be many. This is a significant shortcoming of current guidance. Ensuring that the Green Book includes natural capital must be considered a priority.

Guidance should provide a definition so that stocks of natural capital can be recognised as such. But just as for ecosystem services it appears there is no single definition of natural capital in the wider literature. Guidance must therefore define carefully all those terms that may be understood differently by those in different disciplines or where the actual meaning is somewhat different from what a layman understanding of the issues might suggest.

We define natural capital as a stock capable of being measured at the beginning and the end of the accounting period and which serves as an input to some production function or household utility function and which would exist even in the absence of humankind. It should be noted however that stocks of residuals arising out of economic activity would be excluded from this definition of natural capital. Despite this changes in the stocks of residuals do have welfare implications and probably ought to be included in assessments of the stock of natural capital.

[1] A semantic issue arises as to whether one describes these flows of residuals as outputs of human activity that constitute an environmental bad (e.g. generating pollution) or whether one thinks about that human activity as using as an input quantities of an environmental good (e.g. using up clean air). Both descriptions are equally valid.

Knowing the value of goods and services produced using natural capital is necessary but not sufficient to value changes in the stock. This knowledge must be supplemented by scientific information regarding the role natural capital plays in the production of goods and services and how the stock changes as a result of dynamic processes both in natural and human systems which, to make things that bit more difficult, may exhibit nonlinearities and discontinuities. Accordingly, valuing changes in natural capital stocks may often be complicated and is likely to be an interdisciplinary undertaking.

Under certain circumstances, the value of marginal changes in the stock of natural capital can be calculated with relative ease. Indeed, those marginal values fall out naturally from the set of models developed by natural resource economists to examine economic systems that depend on natural capital. Applications include the study of fish stocks, timber stocks, deposits of mineral and energy resources and stocks of pollutants in water and air. The simplifying assumption underpinning these models is that human behaviour can be approximated by a dynamic optimisation model often seeking to maximise social value from the use of a natural capital stock, an assumption that will often be indefensible. Encouragingly recent contributions to the economics literature have highlighted methods for estimating the value of marginal changes in natural capital stocks that do not rely on assumptions of optimising behaviour.

We recommend that new supplementary guidance be developed to support practitioners in appraising impacts on natural capital. That guidance could contain a list of some of the most important stocks of natural capital and the environmental goods and services they support as well as the roles that they play in the economy. It should outline the principles for valuing changes in natural capital stocks, describe the various methods available for obtaining those values and make recommendations about the accuracy of approximations that might be made if an exercise in exact valuation is not possible.

Sustainability

A project's impact on natural capital stocks is also a key consideration in assessing issues of sustainability. It would be useful if new supplementary guidance on natural capital directed practitioners in providing a sustainability analysis of their projects. That analysis would entail documenting and attempting to value all impacts on natural capital. It should also identify how those impacts are distributed over different forms of stock and over different periods of time. As with standard distributional analysis in cost benefit analysis, such information will allow decision makers to better understand the sustainability implications of a project and consider the case for implementing compensating investments (perhaps in establishing new stocks of natural capital).

A taxonomy of values

Apart from proposing a classification of environmental goods and services supplementary guidance also spends time describing the concept of total economic value. Total economic value represents all the different sorts of value that households can derive from the environment. The major division of total economic value is traditionally into use and non-use values with further subdivisions identifying additional sorts of values. Historically this has been used to illustrate the diverse ways in which households benefit from the environment. But despite its enduring popularity this classification has several well-known shortcomings.

In particular it seems doubtful that option value constitutes a separate sort of value. And it is similarly unclear in precisely which out of several competing senses indirect values for environmental goods and services should be considered indirect. Furthermore the different sorts of values normally said to comprise non-use values cannot be separately estimated. Most importantly, the problem with the total economic value classification is that it examines value from the point of view of household and not the cost benefit analyst. That perspective may be useful for conveying the fact that individuals gain value from environmental goods and services in a variety of ways, but it fails to provide the essential information that cost benefit analysts require in making decisions about how to estimate the value of environmental goods and services. Because of these and other problems the Green Book might wish to consider retiring the concept of total economic value.

We suggest an alternative framework that is based on establishing the fundamental economic characteristics of the environmental good or service and then defining precisely how that good or service enters the household's choice problem. The express purpose of this framework is to guide analysts to appropriate methods of environmental valuation. For example, we maintain that the division of values into use and non-use continues to be critically important since it determines which nonmarket valuation technique is appropriate.

Apart from dividing values for environmental goods and services into use and non-use values we also suggest classifying environmental goods and services according to whether they enter household utility functions or production functions. This distinction is important because households do not possess values for intermediate goods and services i.e. those which do not enter household utility functions. Guidance should note that there is no purpose in asking households about their willingness to pay for intermediate goods and services. Environmental goods and services that enter production functions possess value only insofar as they affect the production of final goods and services.

These classifications are fundamental to cost benefit analysis of environmental projects they help to ensure that there are no overlooked ways in which environmental change might impact welfare. This classification also makes it clear when particular nonmarket valuation techniques are required.

Techniques of nonmarket valuation

One very surprising omission from the Green Book is a clear statement of the normative basis of cost benefit analysis. This weakness is most keenly felt in the sections dealing with non-market valuation where the theoretical case for deriving measures of willingness to pay (WTP) and willingness to accept (WTA) is not made. Without a clear explanation of the justification for using those measures in project appraisal it is difficult for analysts to understand why methods that derive other measures of value are not compatible with cost benefit analysis. We strongly recommend that guidance be updated to provide an account of the normative foundations of cost benefit analysis.

Both core and supplementary guidance describe a variety of nonmarket valuation techniques. In core guidance the various techniques are illustrated by means of examples. It is not clear whether these examples have any special status but the refresh provides an opportunity to consider whether these need to be updated or perhaps even replaced with descriptions of the sorts of situations in which particular nonmarket valuation techniques might prove useful.

The refresh also needs to consider the adequacy of the explanations that accompany the different techniques and whether it would be helpful to identify instances when particular techniques are actually variants of some more general technique.

It is our opinion that there would be considerable advantage in expanding the supplementary guidance to provide a comprehensive overview of the range of techniques for environmental valuation with as much emphasis given to the production side of the economy as is currently afforded the consumption side. Moreover, we believe that the guidance should provide much more practical advice regarding the circumstances in which the different methods might usefully be employed, their data requirements and their key advantages and limitations.

The treatment of risk

In addition to the issues identified above which are largely specific to the cost benefit analysis of environmental projects we now go on to consider a range of other matters. Some of these are relevant to the appraisal of environmental projects (where appraisal refers to a body of techniques of which cost benefit analysis is simply one approach). Other issues of particular relevance to environmental projects such as uncertainty and irreversibility have a bearing even on the cost benefit analysis of non-environmental projects and are therefore arguably matters for core rather than supplementary guidance.

Projects whose main objective is to reduce risk should employ as a measure of benefits option values rather than expected damage if these risks are both large and uninsurable. Option values are defined as the maximum payment that the household would make across all possible states of the world rather than face the certain prospect of damage. Guidance might also wish to include a definition of option values as well as option price and outline a methodology for calculating these values. It would be desirable for guidance to include a description of the circumstances under which risks are uninsurable.

The cost benefit analysis of irreversible projects needs to be approached carefully when there is uncertainty which is likely to be resolved at some point in the future. In such circumstances the consequence is a reduction in the value of any irreversible decision for example to develop (destroy) a natural area. Project appraisal involving irreversible decisions is often best approached by constructing a decision tree with decision nodes and probabilistic outcomes. Guidance should continue to encourage a mode of thought that sees the value in postponing decisions and in building flexibility into environmental projects.

Closely related to the problem of uncertainty is the concept of the (quasi-option) value of information. Uncertainty serves like a constraint essentially forcing policymakers to adopt the same policy across all possible states of the world. The effect of information regarding the true state of the world is effectively to remove this constraint and the value of information represents the cost of this constraint.

Implementing the value of information concept might save money by preventing the commissioning of research which would have no possible impact on the optimal decision (and which is therefore worthless) or by supporting the case for commissioning research which increases the expected net benefits of a project by an amount greater than the cost of the research. Whilst supplementary guidance contains statements about the need to ensure that information gathering exercises are proportionate this message could be much strengthened by explicitly appealing to the value of information concept.

The distribution of environmental outcomes

Another issue of growing importance is the distribution of the costs and benefits of environmental outcomes. Guidance describes analysing the distributional outcome of projects having an impact on household income as an important adjunct to cost benefit analysis. Given that DEFRA has commissioned several pieces of work on distributional issues it seems appropriate that guidance should now refer to the distributional impact of environmental projects on the environmental outcomes experienced by households. This should be distinguished from the wider task of determining the distributional outcomes of environmental projects per se which would include consideration of both the distribution of the costs and the benefits rather than one particular outcome.

Existing techniques of analysing distributional outcomes are readily extended to environmental outcomes. These include techniques for merely describing changes in the distribution of environmental outcomes as well as for describing changes in the equality of environmental outcomes. Techniques also exist for exploring changes in the environmental outcomes across groups of interest e.g. different income categories. Guidance might refer to some of the studies that DEFRA has commissioned. At the same time it should be acknowledged that not every environmental project will have distributional consequences worth bothering about and even for those that do it might be impossible to model them.

Modelling approaches

Particularly for those environmental projects implemented specifically to address distributional concerns it is important to be aware that the outcome will ultimately depend on behavioural response. For example, the implementation of a project to improve environmental quality in an area may alter rents and wage rates and therefore the demographic composition of the area. Sophisticated equilibrium sorting models are required in order to anticipate these responses.

Guidance might care to acknowledge the fact that unless behavioural responses are accounted for environmental projects intending to address distributional concerns might be frustrated. Guidance should identify the circumstances under which the significant additional effort involved in properly addressing these issues is likely to be justified e.g. when addressing distributional concerns is an environmental project’s sole purpose.

In equilibrium sorting models the focus is on simultaneous equilibrium across different locations and different markets. In general equilibrium models by contrast the focus is on simultaneous equilibrium only across different markets. The strength of general equilibrium models is that they are a numerical implementation of a theoretical model whose properties are well understood. Such models however focus on longer run outcomes and not the transition between equilibria. Despite this they have nevertheless found widespread application in the evaluation of policies to investigate the costs of restricting GHGs and in many other areas unrelated to environmental economics.

Although current guidance is quite rightly focussed on a partial rather than a general equilibrium approach general equilibrium models may occasionally be required particularly when an environmental project significantly changes the current distribution of income or alters the market prices upon which the partial equilibrium approach to cost benefit analysis is based.

Whilst the appraisal of environmental projects is often an interdisciplinary endeavour many appraisals adopt a single-disciplinary perspective. What this means is that although several disciplines are involved information might be shared between them in a way that does not always guarantee consistency. In integrated assessment modelling by contrast information from different disciplines is combined in a coherent manner thereby producing insights not separately available from each discipline on its own.

Integrated assessment models have an important role to play in the appraisal of environmental projects. Their most obvious but not only role is in capturing important feedback effects thereby yielding more accurate appraisals.

An important distinction exists between integrated assessment models in which interventions are user-specified and those that may be termed policy optimisation models. In policy optimisation models policy variables are chosen in order to maximise the objective function subject to constraints. When the objective function is specified in terms of economic benefits variables associated with the optimal solution often possess interesting economic interpretations. As explained integrated assessment modelling – or as it is more often referred to in that context bio-economic modelling – may have an important role to play in the valuation of natural capital.

Guidance recommends being alert to the possibility of altering the specification of the project e.g. its scale or timing in order to increase further its net benefits. Normal practice here is to evaluate a small number of alternatives for the project and to select the best. It is nevertheless hard to be certain that such a process actually results in a project specification which is really the best out of all those that could be implemented. Although seldom attempted approaching the problem with a model capable of policy optimisation would make it much easier to find the unique best project specification.

Temporal issues

It is common to encounter projects whose environmental impacts are spread over future time periods. The costs and benefits of such impacts are customarily converted into their present value counterparts. This however assumes that the future value of these impacts is known. An alternative procedure is to discount the impacts themselves using a special ecological discount rate in order to convert future impacts into present impacts which may then be valued. This assumes that the ecological discount rate is known. The informational requirements in order to implement either approach are identical but typically exceed what is available.

Whilst there is currently no satisfactory solution to the problem of discounting future environmental impacts guidance should point out the wholly unsatisfactory nature of any approach which relies upon the values of environmental goods and services remaining constant especially in a situation where consumption is increasing and the quantity of environmental goods and services decreasing.

Spatial issues

The location of an environmental project will often have significant implications for its costs and benefits. Different locations may be endowed with different quantities of environmental goods and services. Furthermore environmental goods and services cannot often be transported from one site to another. The question of space and location is touched on several times in core guidance but not mentioned at all in supplementary guidance.

The importance of geographical location is most obviously apparent in the appraisal of projects that require an environmental good or service as an essential input. Likewise the value of environmental goods and services often depends on their proximity to centres of population. Spatial heterogeneity also ensures that the distribution of substitutes and complements varies across space. Finally the spatial interconnectedness of environmental systems means that a project could change the flow of environmental goods and services in other locations.

Over recent years it has been increasingly common for researchers to use Geographical Information Systems to aid decisions regarding the location of environmental projects. The most sophisticated analyses involve value surfaces seeking to identify the location where a project would provide the best benefit cost ratio.

1 Introduction

The purpose of this report is to review and where appropriate recommend changes to current official guidance on the appraisal of public sector projects impacting the environment. These impacts may be incidental to or alternatively the main purpose of the project. The word “project” should be interpreted to include regulations and strategies.

Although much of the report deals with cost benefit analysis this is of course not the only tool used to evaluate environmental projects. The word “appraisal” refers to the task of evaluating environmental projects using a larger set of techniques than just cost benefit analysis e.g. environmental impact assessment. Obviously some of these provide important inputs for cost benefit analysis.

Official guidance on the appraisal of environmental projects is contained in the collection of documents known as the Green Book or just “guidance”. When we want to distinguish between the different parts of the Green Book we will refer to “core guidance” and “supplementary guidance”.[2] Guidance specific to the appraisal of environmental projects is contained in Annex 2 of core guidance. The document *Accounting for Environmental Impacts: Supplementary Green Book Guidance* deals entirely with the appraisal of environmental projects and most of our interest is consequently in the contents of this supplementary guidance.

This report is concerned with whether guidance regarding the appraisal of environmental projects is technically correct and unambiguous. It is also concerned with whether guidance is comprehensive and appropriate to the needs of those involved. Lastly the report is concerned with whether guidance is well organised and appropriately divided between core and supplementary guidance and other more specialised reports.

Certain publications have been especially influential on Green Book thinking. In particular it is evident that the National Ecosystem Assessment (2011) has been extremely important in framing supplementary guidance. Both supplementary guidance and the National Ecosystem Assessment attach considerable importance to the concept of ecosystem services and adopt a very particular classification of the same.

But although both the National Ecosystem Assessment and supplementary guidance are consistent in their use of the term ecosystem services there is no unique definition provided by the wider literature and given the number of disciplines using this concept it would be surprising if there were. What constitutes an appropriate definition for one purpose or from the perspectives of one discipline may not be appropriate for another. For some the idea of ecosystem services amounts to little more than a metaphor. Another hoped for contribution of this report therefore lies in its attempt to clarify the sometimes confusing terminology that has grown up to describe the contribution of the environment to economic activity and the fulfilment of human wants and desires.

[2] These appear as HMT (2003) and HMT (2012) respectively.

The entire technique of cost benefit analysis is based upon a highly stylised model of the economy. Only by extending this modelling framework to include the environment will it ever become clear how the environment should be treated in cost benefit analysis. Incorporating the environment into this model is however very difficult but it is a task the necessity of which has not gone unnoticed by others. Supplementary guidance has arguably not fully engaged with this task and as a consequence the multiple channels by which the environment affects welfare are left unspecified. This makes valuing changes in ecosystem services very difficult.

Out of the attempt to integrate the environment into the model of the economy underlying cost benefit analysis emerges a definition of ecosystem services or as we prefer to call them for reasons explained later “environmental goods and services”. This definition is not identical to the definition of ecosystem services contained in guidance but it is more helpful for the purposes of cost benefit analysis. It also results in classifications of environmental goods and services that differ from the classification of ecosystem services contained in supplementary guidance.

This report has been commissioned by the Natural Capital Committee to explore amongst other things the treatment of natural capital in current guidance. The concept of natural capital is mentioned only once in supplementary guidance where it is referred to as “environmental assets” – a term used by others to refer to something different. This omission is of concern because there must be many projects which involve changes to the stock of natural capital. Many similar issues arise as in the case of ecosystem services e.g. the existence of conflicting definitions and the need to explain how natural capital fits into the stylised model of the economy that underpins cost benefit analysis.

In order to value natural capital one possible point of departure is to treat everything as if it were part of one giant factory under the control of a social planner. This analogy however could be interpreted by only the most superficial reading of the report to suggest that the environment is in any way less important than the economy. Valuing changes in the stock of many forms of natural capital turns out to be a necessarily interdisciplinary activity and the value of these changes depends on the institutional arrangements for managing stocks of natural capital. This report proposes a further special report on the valuation of changes in the stock of natural capital to accompany *An Introductory Guide to Valuing Ecosystem Services*.

Although official guidance on the appraisal of environmental projects is contained within the Green Book there are many other reports dealing with particular environmental impacts / special topics. Of these the most important are included in the annex to supplementary guidance. Some such as An Introductory Guide to Valuing Ecosystem Services (DEFRA, 2007) and What Nature Can Do for You (DEFRA, 2010b) are indispensable – without them it is not possible to understand certain parts of supplementary guidance.

Given that material is already divided between core and supplementary guidance the constant reference to other documents makes it appropriate to ask whether Green Book guidance is convenient to use and easy to update. Guidance must also consider for whom the Green Book is intended and what is the appropriate depth of treatment to afford the various issues. This is particularly important when one looks at the explanations provided for the various nonmarket valuation techniques mentioned in the Green Book.

Obviously core guidance contains much that is relevant to the appraisal of environmental projects. The focus of this report however is mainly on that part which is specific to the appraisal of environmental projects. Nevertheless this report also includes a number of issues of particular but not exclusive relevance to the appraisal of environmental projects. Some of the issues dealt with in this report were identified by the Natural Capital Committee whereas others are those we have added ourselves. They include issues relating to the Green Book's treatment of uncertainty and discounting.

In order to write this report we have consulted a large number of other reports compiled by supranational organisations, Government reports, academic articles and other documents. We have looked at The National Ecosystem Assessment, Making Space for Nature (DEFRA, 2010b), The Natural Environment White Paper (DEFRA, 2011a), The First Annual Report of the Natural Capital Committee (NCC, 2013), The Second Annual Report of the Natural Capital Committee (NCC, 2014), the Millennium Assessment (MA, 2005), the System of Environmental Economic Accounting: Experimental Ecosystem Accounting (UN, 2013) and The Economics of Ecosystems and Biodiversity (EC, 2008).

Finally note that the remit of the authors of this report extends only to reviewing and if necessary recommending changes to current official guidance. This report does not therefore intentionally contain material intended for any update of official guidance.

The remainder of this report is structured as follows.

Section two summarises the current state of guidance as it applies to environmental projects. Amongst other things it suggests what material specific to the appraisal of environmental projects should be included in core guidance and what material should be included in supplementary guidance.

Section three discusses the concept of ecosystem services. As discussed this concept occupies a central position in supplementary guidance. This section seeks to understand the importance of this concept to the cost benefit analysis of environmental projects and considers alternative definitions. The section then goes on to consider how the environment and the economy are connected to each other. Central to this effort is the concept of the environmental production function.

Section four discusses the concept of natural capital. It provides a definition of natural capital and explains how to value changes in the stock by treating the economy and the environment as if it were one factory under the control of an optimising social planner.

Section five discusses the concept of total economic value and the different techniques of environmental valuation. It explains how these are used for valuing the particular types of environmental impact identified in the preceding section as resulting in welfare change. Comparison is made with the treatment afforded to these issues contained in current Green Book guidance.

Section six considers the problem of cost benefit analysis of projects whose impacts are distributed over future time periods and where these impacts are affected by growing resource scarcity and growth in consumption. It introduces the concept of an ecological discount rate.

Section seven follows on from the discussion of future impacts of projects to assess the issue of how project appraisal might inform on the sustainability implications of a project.

Section eight considers how adequately spatial issues are deal with in the Green Book and looks at the differing perspectives of economists and natural scientists.

Section nine explains how cost benefit analysis should be conducted under conditions of uncertainty and how to value irreversible policy decisions. It provides a definition of option values and addresses the question of when option values rather than expected damage is the relevant measure of benefits for a project which is intended to eliminate the risk of damage. It addresses the issue of the value of information and how much one would be willing to pay for an improvement in information as opposed to complete certainty. Although these issues are already dealt with in the Green Book this section identifies certain shortcomings associated with the treatment that is provided.

Section ten discusses general equilibrium and integrated assessment. The purpose of general equilibrium and integrated assessment modelling is explained. An attempt is made to identify instances in which these approaches are proportionate. Also examined are techniques capable of investigating the response of households to changes in environmental amenities, the tendency of households to relocate and the issues that this raises for evaluation of the welfare impacts of environmental projects.

Section eleven discusses the distribution of environmental outcomes. Parallels are drawn with the guidance contained in the Green Book about investigating changes in the distribution of income and health outcomes. The section illustrates how certain analytical techniques might be extended to deal with the distribution of environmental outcomes.

Each of these sections contains at the beginning a statement about what current guidance says about the issue (if anything). At the end appears a set of recommendations about the way in which we think current guidance might be improved.

Section eleven concludes.

2 The state of current guidance

The purpose of the Green Book is to provide authoritative guidance on project appraisals. All projects undertaken by Government should follow this guidance. Some Departments however have developed further rules on the conduct of appraisals for particular sorts of projects resulting in supplementary guidance.

This section reviews guidance on the appraisal and in particular the cost benefit analysis of environmental projects. It separately discusses the contents of core and supplementary guidance and then presents alternative views on how this guidance might be organised. More detailed discussion of issues arising is deferred until later sections.

2.1 Core guidance

Most of core guidance on the cost benefit analysis of environmental projects is contained in Annex 2 of the Green Book. Obviously much else of what is contained in core guidance will also be of relevance to environmental projects. In that respect of particular interest are the contents of Annex 4 and 5.

Annex 2 deals with the valuation of nonmarket impacts. It begins by explaining that nonmarket impacts extend to much more than the environment. This alone would explain why some material on nonmarket valuation ought to be included in core guidance.

The basic measures of value for changes in nonmarket goods and services are willingness to pay (WTP) and willingness to accept (WTA). Core guidance regards the use of WTP as the appropriate measure of an increase and WTA as the appropriate measure for a decrease. This is not correct since the appropriate welfare measure depends not only on the direction of change but also on property rights. Core guidance therefore implicitly assumes that households have the right to the current level of the nonmarket good.

Core guidance distinguishes between stated preference and revealed preference techniques. The main techniques are explained in two short paragraphs. There are no guidelines as to when each technique is applicable but there is a preference for relying on revealed preference techniques except for the purposes of estimating nonuse values (which are not defined).

Core guidance also raises the possibility of valuing nonmarket goods through their impact on life satisfaction or subjective wellbeing adding that these studies have not yet reached the point where they are acceptable for use in cost benefit analysis. In ongoing activities it will be important to identify what if anything has changed regarding the acceptability of these techniques. Guidance also mentions the replacement cost technique but cautions that this does not provide a measure of value. Many other techniques are not mentioned e.g. those relating to the value of nonmarket goods and services as inputs to production.

Core guidance discusses whether it is worthwhile commissioning a new study when accurate estimates of value of a nonmarket good or service are not available. This could be an opportunity to introduce the concept of the value of information or the possibility of using value transfer. Preference is given to approaching the problem from a variety of directions in order to cross validate results and guidance acknowledges the frequent existence of impacts that cannot be quantified let alone monetised and recommends noneconomic approaches.

The remainder of Annex 2 looks at valuing time and health before returning to environmental impacts. In this section the reader is warned to check on the Green Book website for up to date guidance e.g. Economic Valuation with Stated Preference Techniques Summary Guide. Particular environmental impacts are discussed including GHG emissions and changes in air quality neither of which are dealt with exclusively by DEFRA.[3]

Turning to landscape impacts core guidance mentions the existence of a set of guidelines from English Heritage. The document then discusses a tool used to value landscape features for the purposes of appraising agro-environmental policy. Given all the intervening changes this landscape valuation tool may now be outdated.

The document notes it is difficult to value water pollution impacts because they are location specific. More detailed guidance is now available on dealing with location specific impacts. Core guidance points to research on the Bathing Water Quality Directive and a range of other work which was at the time of writing scheduled to take place. Whilst referring to work that is scheduled to take place may extend the shelf-life of guidance it is dangerous to assume that such work will result in something one would wish to include in guidance.

Two sentences are devoted to biodiversity impacts. These sentences note that biodiversity is important but that it is the task of DEFRA and the Forestry Commission to investigate these impacts. This is not commensurate with the perceived importance of biodiversity. There is now considerable amount of research on the valuation of biodiversity impacts. There are in addition several different understandings of the word biodiversity.

For noise impacts the advice is to calculate the change in noise exposure caused by projects and then to attach a value of €23.5 per dB per household per year in 2001 prices. It is suggested that more up to date guidance might be available from the DEFRA and DfT websites. It is however unclear whether the value cited has any official status or whether more recent estimates are to be preferred.

For recreational and amenity values for forests the Green Book refers to a study undertaken in 1992 pointing to a value of £1 per visit and to later work in Northern Ireland. Once again core guidance suggests that further work is underway to value the nonmarket benefits of forestry and there is a link to the Forestry Commission website. Once more this work has in all likelihood been superseded and again it is unclear whether this value is included merely to illustrate what is possible or because it has official status.

The final section deals with valuing disamenity. Here core guidance includes a summary of a study into the value of aggregates. Economic values are differentiated by the type of material that is removed and from quarries located in national parks whose identity is not specified. It is apparent by now that all examples refer to work funded by Government. However if the aim is to provide

[3] This report has not evaluated the adequacy of the guidance given in respect of incorporating these impacts into cost benefit analysis.

timeless examples of good practice then it might be helpful to at least consider work funded by others and published in refereed journals.

Annex 4 of core guidance deals with risk. This is clearly ubiquitous to project appraisal but is of particular importance to environmental projects. Most environmental projects have outcomes that are to some degree uncertain. Guidance provides advice on how this aspect is best presented to the policymaker. More importantly however it should spell out those conditions under which it is appropriate to place a value on the reduction of uncertainty and of how to deal with uncertainty over preferences as well as uncertainty over environmental outcomes. Core guidance uses the development of a natural site as an example of an irreversible project given that development cannot be undone and the site restored to how it was.

Core guidance incorrectly associates the issue of irreversibility with the concept of option values which it in turn vaguely defines as the value of knowing that a facility is available to enjoy. It is further wrongly suggested that there is a connection to existence values. The implications of irreversibility are dealt with more fully later on in the report. Here it is merely noted that irreversibility is particularly important when there is the prospect of resolving the uncertainty. Without uncertainty there is no doubt about what is the appropriate decision. And without the prospect of uncertainty being resolved there is never any reason to regret any decision.

Option values are different to problems involving irreversible decisions not least because they depend on risk aversion. They are more closely linked to the concept of the cost of variability of outcomes in the next section of core guidance. That section correctly asserts that an individual may be willing to pay a premium to reduce variability and that this should be included when it is thought appropriate. But it does not make it clear when it is appropriate so to do.

The value of information concept is best illustrated by means of a simple example. The same example can be used to illustrate the consequence of irreversible decisions. Irreversibility is also a feature of many environmental projects. But although this issue is mentioned in core guidance it then fails to explain how projects with irreversible consequences should be appraised.

Finally Annex 5 notes that projects are likely to have distributional impacts. It advises that these should always be investigated in any appraisal. Although the environment is not mentioned the same reasoning that would lead one to consider the distributional impacts of projects affecting household incomes or health would also lead one to consider the distributional impacts of projects affecting environmental amenities and dis-amenities.

Many environmental projects change the equality of environmental outcomes. For some projects this might be the prime motivation. It is plausible to suggest that some environmental projects might benefit particular income groups more than others. When cursory assessment suggests that either of these two impacts is possible then the distributional impacts of the project need to be addressed. Core guidance should extend the call for distributional analysis to include environmental outcomes and recommend the use of particular techniques.

2.2 Supplementary guidance

Further guidance is contained in the document Accounting for Environmental Impacts: Supplementary Green Book Guidance.

The introduction to this document summarises the main steps involved in the cost benefit analysis of an environmental project. For certain environmental impacts such as arising from the emission of GHGs and changes in air quality the reader is however once again directed to more specific guidance.[4]

Chapter 2 commences with a reference to the UK National Ecosystem Assessment indicating how influential this piece of work has been. It then notes the importance of identifying the full range of environmental impacts associated with each option so that all of them can be taken into consideration. The document then goes on to state that decision making will be improved by considering the natural environment as an interconnected system. Throughout the chapter it refers to ecosystem services and an ecosystems approach.

Ecosystem services are defined in supplementary guidance as services provided by the environment that benefit people. Later in this report it is argued that this definition is not adequate.[5] The chapter also divides ecosystems services into four categories arguing that this offers an improved understanding of how policies impact on the environment. Later on in this report it is argued that even with a different definition of ecosystem services this categorisation is unhelpful at least for the purposes of conducting cost benefit analysis. Those seeking further information are directed to An Introductory Guide to Valuing Ecosystem Services.

Supplementary guidance should from the outset better explain how environmental impacts result in welfare change. It will later be argued that this involves introducing the concept of an environmental production function. This concept connects the flow of ecosystem services with the stock of natural capital. It is analogous to the production function concept that is central to the economic model that underpins cost benefit analysis. The story of how environmental impacts result in welfare change involves understanding the concept of intermediate and final outputs and recognition that economic production and household utility depend on more than produced capital and economic goods and services, and that they may also include natural capital and environmental goods and services.

This framework will ensure that no potentially important linkages between the economy and the environment are overlooked. Identifying the channel(s) through which environmental impacts affect welfare assists in determining which technique or set of techniques is best able to value these

[4] Guidance on valuing changes in the stock of natural capital should also be dealt with in a separate document because it is a technically challenging and necessarily interdisciplinary endeavour. Any such document will also need to explain how institutions affect the value of natural capital. Supplementary guidance should however acknowledge the value of natural capital and explain why it is difficult to quantify the value. It will then refer to this document serving as a companion to the report on valuing ecosystem services.

[5] Further evidence of the importance of providing a solid definition of ecosystem services comes with the fact that the concept of natural capital is ignored by supplementary guidance despite the fact that natural capital provides flows of ecosystem services . There is however brief mention of environmental assets but without any definition. It follows that no advice is offered on the valuation of changes in the stock of natural capital.

welfare changes.[6] Ensuring that nothing is overlooked and that impacts are valued using the right set of techniques has to be a fundamental goal of supplementary guidance.

Chapter three is intended to be used alongside Annex 2 of core guidance and deals with techniques used to value non-market environmental effects. It acknowledges that not every environmental impact can be valued in monetary terms. Economic values are divided into use and non-use values. Use values are then further divided into direct use, indirect use and option values whilst non-use values are further divided into altruism, bequest and existence values. Not every environmental project will include every sort of value.

Great importance is attached to the classification of economic values. This classification remains popular but suffers from a number of well-known shortcomings. This classification is anyway of use only if the different categories of value e.g. use values are defined. The lack of an explanation as to what constitutes indirect use value is especially problematical since the ability to value it is described as representing a particular advantage of several nonmarket valuation techniques.[7]

The remainder of the chapter is devoted to discussing different nonmarket valuation techniques. These are divided into revealed preference and stated preference techniques. The former includes market prices, averting behaviour, hedonic techniques, travel cost and random utility modelling (which might more properly be described as a theory of choice rather than a valuation technique). The latter includes contingent valuation and choice modelling. A diagram shows how each of these can be used to measure different components of total economic value.

Dealing first with revealed preference techniques, market prices are described as providing proxies for direct and indirect use values with the price as a minimum expression of WTP. The averting behaviour technique suggests that the cost of water filtration can be used as a proxy for the value of groundwater pollution damages. The hedonic technique is described as being able to capture both direct and indirect use values. The travel cost method is described as using the costs incurred by individuals taking a trip to the site as a proxy for the recreational value for the site. The production function approach is described as exploiting the relationship that may exist between an ecosystem service and the production of a market good. Environmental goods and services are considered as inputs. The technique is described as capable of capturing indirect value.

Turning now to stated preference techniques contingent valuation is described as a survey-style approach capable in principle of valuing both use and non-use values. Choice experiments are described as another survey-based approach in which the focus is on the attributes of the ecosystem in question.

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[6] For core guidance providing such an account is probably unnecessary. Core guidance should merely refer to supplementary guidance for those seeking a more detailed account of the different ways environmental impacts result in welfare change.

[7] We will argue that the most important purposes of a classification of values are to (a) understand how does the change in question impact on wellbeing and thus what measurement techniques are appropriate (b) what reasons might people have for valuing this change and (c) what defines the population of those who derive (dis)benefits from the change.

Helpful examples are provided of the types of studies that could be undertaken using each different technique (rather than references to specific studies). The descriptions of the various nonmarket valuation techniques are extremely brief and occasionally inaccurate. It is for example not true that the costs incurred by individuals taking a trip to a site are a proxy for the recreational value for the site.[8]

It is not clear what purpose is served by such brief descriptions. For those already equipped with a rudimentary knowledge the descriptions are redundant; for those who do not have even a rudimentary knowledge the descriptions are inadequate. In this respect there is no evidence of sufficient consideration being paid to the identity of those needing to consult supplementary guidance or to their requirements. For supplementary guidance there is no reason why the list of available nonmarket valuation techniques should not be complete.[9]

The document then turns to discuss the possibility of obtaining values not from primary studies but from previous studies and refers to guidelines on the use of value transfer techniques. It argues that any primary study should be designed with its potential use in future benefits transfer studies in mind and undertaken with regards to the DEFRA valuation protocol. And where conventional valuation techniques fail the document draws attention to the existence of guidelines on the use of participatory and deliberative techniques.

The final chapter offers advice on identifying and then valuing the environmental impacts arising from a project beginning with a list of those impacts most commonly encountered. Where these effects could be significant and wide ranging the use of an ecosystem services framework is recommended. But precisely what the ecosystem services framework involves is not spelled out.

The document also recommends attempting to identify all of the environmental impacts at as early a stage as possible in order that the project might be redesigned in order to minimise negative impacts. Efforts to value environmental impacts should be staged and proportionate. Sensitivity analysis is to be undertaken along with a transparency regarding what are the risks and the gaps in the evidence. Properly appraising environmental projects involves people from different disciplines.

A checklist approach is used to determine if a project has significant environmental effects. Particular attention must be paid to the spatial and temporal extent of any impacts but it is unclear how this is to be achieved.

Similar to the report on value transfer, guidance on valuing certain sorts of environmental impact is currently dealt with in separate documents rather than in guidance. These are impacts which are complicated but important and frequent features of many environmental projects. Examples include the value of health impacts arising out of changes in air quality and the value of impacts arising out of GHG emissions.

Where multiple environmental impacts exist the document advises to use a further checklist to determine which ecosystem services have been affected. Clearly it is important to provide a list of

[8] Travel costs are of course a proxy for the price of visiting the site.

[9] But because there are many techniques most of which are used only infrequently core guidance need refer to only the most popular.

the most important ecosystem services as an *aide memoire*. But there should also be a list of the most important forms of natural capital too. Furthermore there is no checklist to help determine which ecosystem services are relevant to which economic activities.

The document then advocates quantification and if possible monetary valuation of the environmental impacts before finally reporting the impacts. Further sources of information are also provided in Annex A.

2.3 Comments on the overall structure and content of current guidance

Core and supplementary guidance could be strengthened through greater coordination. This is challenging since (a) core guidance is revised only infrequently and (b) supplementary guidance has been appended only recently. This makes it difficult to use them in conjunction with one another as things stand.

Significant changes have occurred in the way that people conceptualise the interaction between the economy and the environment. Supplementary guidance has fully adopted the ecosystem services approach whereas core guidance has not. As a result it is currently quite hard to reconcile the contents of these two documents. At a minimum they should adopt the same conceptual framework for thinking about interaction between the economy and the environment. Without a shared way of understanding the issues there is always going to be a tension between the two documents.

It is necessary to address the question of how material should be divided between core and supplementary guidance. Core guidance might be appropriate for those who have to conduct cost benefit analyses of environmental projects only infrequently whereas supplementary guidance might be appropriate for people regularly undertaking cost benefit analyses of environmental projects.

If it is agreed that supplementary guidance is for people conducting cost benefit analysis of environmental projects on a regular basis and for projects where the environmental impacts are of greater significance, it should be more comprehensive in its coverage. Core guidance by contrast must help individuals determine when the project under appraisal involves significant environmental impacts and when they should accordingly consult supplementary guidance.

There must be no ambiguity about the meaning of any of the terms employed in guidance. Everything must be clearly defined and the reader warned about use of nonstandard terminology. This is critical because the appraisal of environmental projects is for many reasons an interdisciplinary endeavour and different disciplines have their own terminology. Above all it is important that any definitions make sense when viewed from the perspective of cost benefit analysis since this is the ultimate objective. Some organisations e.g. the OECD have addressed this through an online glossary.

Both core and supplementary guidance need to refer to other documents e.g. those dealing with particular sorts of environmental impacts. But doing so too frequently risks fatigue on the part of the reader (especially without page references). One must also be mindful of the affect that referring to other documents has on the ability to retire or to update other documents. There are benefits from having everything together but there are also benefits from keeping some things separate. The objective must be to create a guidance document that is both easy to use and which will endure.

A great deal of guidance is devoted to explaining the various techniques of nonmarket valuation. The treatment offered must be appropriate for someone who is not specialised in environmental valuation – simply because this is not currently a requirement for Government officials in order for them to become involved in cost benefit analysis of environmental projects. These techniques must be described in sufficient detail that such people can obtain an intuitive grasp. Those using guidance to help commission research should be given enough knowledge to enter into dialogue with consultants.

One of the best ways of nurturing understanding is through examples. Problems in uncertainty such as option values, the value of information and the consequences of irreversibility are for example all readily explained through simple examples (unfortunately lacking in current guidance). There is however a danger that using specific valuation studies as examples results in them receiving undue attention whilst becoming outdated.

Core guidance contains numerous examples of nonmarket valuation work commissioned by Government in the late 1990s shortly before the Green Book was revised. The status of these studies is unclear but they are certainly no longer examples of best practice.

It may be more appropriate merely to discuss those types of studies that are possible using particular techniques and then refer the reader to places where recent nonmarket valuation studies appear such as on the webpages of Departments commissioning research or the EVRI database. And if examples are to be included in core guidance there is no reason why they should refer to work commissioned by Government.

2.4 Recommended changes to guidance

- Core and supplementary guidance should adopt the same conceptual framework for understanding the connections between the environment and the economy
- A clear rationale must be sought for dividing material between core and supplementary guidance
- Care must be taken to define technical terms and consideration should be given to developing an online glossary
- Greater concern must be shown to the needs and capabilities of those for whom guidance is intended
- The status of any examples should be made clear and consideration should be given to whether particular examples will stand the test of time

3 Ecosystem services

Much of the advice contained in supplementary guidance on the conduct of cost benefit analysis of environmental projects is presented in terms of the need to value ecosystem services. It may however be noted that the concept of ecosystem services arises largely from outside economics. Furthermore, whilst this concept has been widely adopted it is not the case that there exists a unique definition of ecosystem services (Haines-Young and Potschin, 2009).

An obvious first question therefore is what are ecosystem services? Can the term ecosystem services be used interchangeably with term environmental goods and services and if not how do these differ? What does it mean to adopt the “ecosystem services approach” recommended by supplementary guidance? And how does such an approach differ from whatever was previously standard practice?

Ecosystem services are defined in supplementary guidance as “services provided by the natural environment that benefit people”. These benefits are illustrated by means of examples. Supplementary guidance further suggests that ecosystem services can following the Millennium Assessment be divided into provisioning, regulating, cultural and supporting services (henceforth PRCS). Supplementary guidance also refers the reader to two other documents for further information on ecosystem services: What Nature Can Do for You and An Introductory Guide to Valuing Ecosystem Services.

What Nature Can Do for You offers the same definition of ecosystem services as contained in supplementary guidance. It also recommends the PRCS categorisation proposed by the Millennium Assessment but, critically, acknowledges that there is no single best system for categorising ecosystem services. The document defines an ecosystems approach as a framework for incorporating ecosystem services and their value into decision making. This definition originated with the Convention on Biological Diversity and DEFRA has developed several principles for its application.[10]

An Introductory Guide to Valuing Ecosystem Services once more defines ecosystem services as those services provided by the natural environment that benefit people. It describes the PRCS categorisation of ecosystem services as being both widely accepted and useful but, once again, acknowledges that this is not the only way of categorising ecosystem services. The definition of ecosystem services contains more detail in that ecosystem services are characterised as a flow arising from environmental assets which are similar to other capital assets. The document draws to the attention of the reader the importance of distinguishing between intermediate and final ecosystem services. The document also distinguishes between ecosystem services and the benefits that they provide.

[10] These include: Taking a holistic approach to policy-making, Ensuring that the value of ecosystem services is reflected in decision making, Ensuring that environmental limits are respected, Taking decisions at the appropriate spatial scale, Applying adaptive management of the natural environment, Identifying and involving all relevant stakeholders.

According to An Introductory Guide to Valuing Ecosystem Services there is no single definition of what it means to adopt an ecosystem services approach. Instead it refers to a set of principles that can be applied in a range of contexts. These principles appear in Securing a Healthy Future: An Action Plan for Embedding an Ecosystem Services Approach and are the same as those referred to by What Nature Can Do for You.

Having described the current position the concept of ecosystem services is now discussed in greater depth.

Any explanation must do more than merely assert that ecosystem services generate welfare – it must also explain how this happens. This explanation will help to identify all the different channels through which changes in ecosystem services (however defined) result in changes in welfare. Explaining how changes in ecosystem services result in changes in welfare will moreover make it clear which valuation technique or techniques are required in order to value these changes.

In order to achieve this goal it is necessary to extend the same conceptual model of the economy that underpins the technique of cost benefit analysis. Out of this exercise emerges a more precise definition of ecosystem services and a clarification of the role that they play in supporting the economy.

The basic model of the economy upon which the rules for cost benefit analysis are based divides the economy into firms and households. Households maximise their utility functions subject to a budget constraint and own all factors of production. Household income comprises the rent on (produced) capital and wages for labour supplied. Associated with this utility maximisation problem is a set of demand functions. The production side of the economy comprises firms that maximise profits subject to the price of inputs and outputs and a production-function constraint. Accompanying this profit maximisation problem is a set of input demand functions. Prices are determined by markets which equate supply and demand. In the absence of certain market failures market outcomes are Pareto optimal in the sense that the sum of consumer and producer surpluses is maximised.

We seek now to extend this model to include ecosystem services. This is achieved through incorporating a set of ecosystem services and a corresponding set of environmental production functions. Luck et al (2009) has used the phrase environmental production function to describe any environmental process resulting in a flow of ecosystem services.[11]

Environmental production functions and (economic) production functions both refer to processes that convert inputs into outputs (Boyd and Krupnick, 2009). Environmental production functions have as their inputs stocks of natural capital in the same way that economic production functions has as their inputs stocks of produced capital (and labour).

[11] Environmental processes comprise a range of interactions resulting in an output of some description. Sometimes the output of an environmental production function is very similar to the underlying process e.g. water purification processes provide purified water. Note that some ecosystem services can be substituted by labour and physical capital. Thus for example, the water filtration services provided by a watershed can be substituted by a water treatment plant and the services provided by mangrove swamps in preventing damaging storm surges can be substituted by sea defences.

The critical difference between environmental production functions and economic production functions is that environmental production functions refer to processes that would exist even in the absence of humans. That these processes are naturally occurring does not however mean that humans do not interfere with them.

It is now time to make several important points of clarification.

There is often confusion as to whether ecosystem services are the outputs of environmental processes or the processes themselves. The Millennium Assessment in particular has been accused of confusing ecosystem processes and ecosystem services. To be perfectly clear: environmental production functions are to flows of ecosystem services as economic production functions are to flows of goods and services (Brown et al, 2007).

Another source of possible confusion is between the benefits which arise from the outputs of environmental production functions and the outputs themselves. The Millennium Assessment for example, defines ecosystem services as the benefits that the ecosystem provides. Fisher and Turner (2008) argue that this is to confuse the outputs of the processes and the values that they may have for households. As with other goods and services, the values that households may have for ecosystem service outputs may differ according to how many units are provided and when and where they are provided.

Another possible confusion is created by the injudicious use of the word 'services'. This sounds odd because environmental production functions can result in both tangible and intangible outputs. To an economist it would seem more appropriate to refer to tangible outputs as 'goods' rather than services. The unfortunate use of the word services to cover both the tangible and intangible outputs from ecosystem production functions appears to emanate from Costanza et al (1997).

A further source of confusion is the fact that what some people refer to as ecosystem services actually arise from processes that are not naturally occurring. For example many of what the Millennium Assessment refers to as ecosystem services e.g. modern agriculture require significant inputs of produced capital and labour. It is confusing to refer to the output of modern agriculture as an ecosystem service rather than as the output of an economic production function. Fisher and Turner (2008) regard this as a second key weakness of the Millenium Assessment. Modern agriculture requires ecosystem services in abundance as inputs but is not itself an ecosystem service.

Lastly it is time to consider whether bringing ecosystem services into the stylised model of the economy results in a complete account of all flows of welfare significance.

Economic production processes involve multiple inputs and outputs only some of which are priced by and transacted in markets. Some inputs are simply taken from the environment without payment and some outputs are the unwanted consequences of production and simply disposed of. The latter are probably most commonly referred to as 'emissions' but they could also be described as 'residuals' or 'waste'. They may interfere with ecological processes and directly or indirectly impact households or disrupt other production activities as in the textbook example of the smoky factory and the nearby laundry. The traditional focus of environmental policy was dealing with such flows either through the creation of incentives for the adoption more benign but more expensive production processes or simply mandating them.

The existence of a range of unintended outputs arising from production processes initiated by humans makes it clear that it is not only changes in ecosystem service flows that result in changes in welfare arising outside the marketplace. The unintended outputs of production processes initiated by humans also cause a potential welfare change and these flows need to be considered too. It moreover seems strange to refer to these flows as if they have anything to do with the ecosystem.

It may at this point be appropriate to draw attention to an esoteric disagreement about whether it is better to model emissions as an output from or an input to a production function. The reason for this disagreement is that it is usually assumed that reducing one sort of output in a multiple-input multiple-output production function can increase the amounts of all other outputs even if none of the inputs change. This however obviously cannot happen with pollution: pollution cannot be reduced whilst increasing output and holding constant all inputs. Although therefore in an engineering sense pollution cannot be considered as an input some economists (e.g. Baumol and Oates, 1988) prefer to view it in this way; firms generating emissions can therefore be regarded as if requiring services from nature (in order to dispose of pollution). So viewed it is then possible to regard flows of pollution associated with production processes as ecosystem services. Note however that modelling pollution as an input also has its problems most fundamental of which is the violation of the principle of mass balance. Furthermore it is possible to resolve the problem of modelling pollution as an output by reformulating the production function in the manner described by Forsund (2009).

It is interesting to note that An Introductory Guide to Valuing Ecosystem Services discusses the subtle shift in emphasis between valuing environmental impacts arising from human production activities to instead highlighting the services provided by the natural environment. And it is there acknowledged that not all of the impacts currently taken into consideration in cost benefit analyses e.g. noise and pollution fit a purely ecosystem services framework i.e. one which does not acknowledge the existence of unwanted outputs from human production processes. Guidance on the cost benefit analysis of environmental projects must deal with both.

Because ecosystem services do not include the typically unwanted outputs from human production processes it is desirable to find some more comprehensive term that covers all flows of goods and services outside the production boundary. We suggest that the term 'environmental goods and services' be adopted to include both ecosystem (goods and) services and also unwanted outputs of outputs from production processes controlled by humans.[12] This term also serves to acknowledge that some of these flows are tangible. Furthermore this term is already commonly encountered in environmental economics textbooks.

3.1 How the economy and the environment are linked

Having defined environmental goods and services, and explained that they will include both the tangible and intangible outputs of environmental processes, and the unwanted outputs of human production processes, it is now possible to describe precisely how changes in the quantity of

[12] Even here the use of the phrase "environmental good" may sound a little strange to describe a flow of harmful residuals pollution is a negative 'good'.

environmental goods and services affects welfare and the economy. For the moment the role of natural capital as an argument in environmental production functions is downplayed.

Environmental goods and services affect welfare and the economy in a number of different ways. First environmental goods and services can enter as direct arguments in household utility functions. Second environmental goods and services can enter as arguments in economic production functions. Some of these economic production functions will be for intermediate rather than final goods and services.[13] The third way in which environmental goods and services might affect welfare and the economy is as arguments in environmental production functions.

We have already hinted at the importance of distinguishing between final and intermediate environmental goods and services. The difference between final and intermediate environmental goods and services is entirely analogous to the difference between final and intermediate economic goods: intermediate environmental goods and services are those that do not enter as arguments in household utility functions or economic production functions.[14] Intermediate environmental goods and services are nonetheless important in that they may provide inputs into the production of other goods and services. Some environmental goods and services may serve as both final and intermediate goods and services. This could occur when an environmental good or service is both an argument in household utility functions as well as an argument in an environmental production function.

It is clear that households do not have preferences for intermediate environmental goods and services any more then they have preferences for intermediate economic goods and services (an important point explained by Boyd and Krupnick, 2009). It is accordingly at best meaningless and at worst dangerous to ask households how much they are willing to pay for a change in the quantity of them. Despite this there may be many occasions where researchers have in the past asked individuals about their willingness to pay for intermediate environmental goods. Households are capable of valuing only final environmental goods and services.

3.2 Classifying environmental goods and services

The final task is to classify environmental goods and services.

We begin however by examining some of the numerous attempts to classify ecosystem services (notwithstanding the different definitions that exist and the fact that we have decided to eschew use of this term). These classifications are reviewed by Haines-Young and Potschin (2009). The approach to constructing a classification appears to involve either identifying a set of benefits and then

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[13] Much economic activity involves the production of intermediate goods and services. The value of these is not counted as part of national income: only final goods and services should be counted. For example, the production of steel should not be counted as part of economic output since it is already counted in the production of automobiles. Distinguishing between final and intermediate goods and services is fundamental and failure so to do risks double counting. The situation is the same for final and intermediate ecosystem goods and services. Many ecosystem goods and services will be intermediate in nature.

[14] For a discussion of the importance of final ecosystem services and the development of accounting units for ecosystem services see Boyd and Banzhaf (2009).

determining which ecosystem services contribute to these benefits or, alternatively, starting with a list of ecosystem services and grouping them in some manner.

Many contributors argue that different classifications are required for different purposes e.g. Costanza (2008). But along with the National Ecosystem Assessment supplementary guidance appears to have adopted the PRCS categorisation of ecosystem services associated with the Millennium Assessment.

Here we once more draw attention to the important ambiguity in supplementary guidance: the question of whether supplementary guidance intends that ecosystem services merely *can* or positively *should* be categorised according to PRCS. By contrast earlier DEFRA publications to which supplementary guidance refers as we have seen argue that ecosystem services might be categorised according to the PRCS classification but this is not the only way of classifying ecosystem services. This is an important point because in the cost benefit analysis of environmental projects the PRCS definition is not at all helpful. The basic problem is that the PRCS categories have no counterparts in the economic model underlying cost benefit analysis.

Despite this concern regarding the classification of ecosystem services various alternative classifications of environmental goods and services are useful.

In order to ensure that none of the ways in which changes in environmental goods and services might impact welfare are overlooked it is helpful simply to classify environmental goods and services according to whether they enter as arguments in household utility functions or economic production functions or other environmental production functions (or all three).

There are two other important properties of environmental goods and services: excludability and rivalry in consumption. Environmental goods and services which are excludable may be marketed. These are things for which it is possible to define property rights such that users who do not pay the owner of the environmental good or service may be excluded at low cost from enjoying its benefits. It may be helpful to classify environmental goods and services according to whether they are excludable or not since this determines whether the environmental good or service can be marketed; if it is then market prices might be observable and could be used as measures of value without having to resort to nonmarket valuation techniques.

Rivalry in consumption refers to a situation in which environmental goods and services used by someone are then no longer available for use by anyone else. The alternative situation is environmental goods and services that may be used repeatedly. For those environmental goods and services that are not depletable there is no user cost.

3.3 Recommended changes to guidance

- Define ecosystem services in terms of the outputs of environmental production functions which are themselves analogous to economic production functions

- Explain that production function processes initiated by humans result in multiple outputs some of which are unwanted and that these flows are not naturally occurring

- Introduce the wider concept of environmental goods and services to account for the fact that some ecosystem outputs are tangible and that some flows occur independently of ecosystems
- Remove any suggestion that the PRCS is the only or even a necessarily helpful way of classifying ecosystem services at least for the purposes of cost benefit analysis
- Classify environmental goods and services according to whether they enter as arguments in household utility functions, economic production functions or environmental production functions

4 Natural capital

The preceding section described natural capital as an input to environmental production functions. A significant omission from current guidance however, is that nowhere does it even mention the concept of natural capital. Although it would be going too far to claim that as a consequence current guidance does not assist with the cost benefit analysis of those environmental projects involving changes in the stock of natural capital – of which there must be many – this is nevertheless a matter worthy of note.[15]

But despite its failure to mention natural capital supplementary guidance does albeit very briefly refer to 'natural assets' and in so doing provides an example of the use of nonstandard terminology. In fact official literature from DEFRA and elsewhere regularly refers not only to natural capital and natural assets but also to 'ecosystem assets' or even to 'green infrastructure' and others too. Often they appear to mean the same thing and are used interchangeably merely to avoid fatigue whereas on other occasions there may be subtle but nevertheless important differences e.g. whether the term is intended to include both biotic and abiotic resources. To avoid spreading further confusion we use the term natural capital to the exclusion of all others.[16]

There is widespread agreement that natural capital generates a flow of ecosystem services and that the value of natural capital (e.g. a wetland) is equal to the present value sum of benefits from these ecosystem services. Although we will go on to provide a fuller definition of natural capital immediately this suggests that there ought to be an intimate relationship between the value of a change in the flow of ecosystem services and the value of a change in the stock of natural capital. More specifically if one knows the value of a change in ecosystem services it might be possible to determine the value of a change in the stock of natural capital and vice versa (although additional information might also be required).

The position taken here is similar to that taken in the section on ecosystem services: in order to see how both natural capital and ecosystem services ought to be incorporated into cost benefit analysis one must adopt the same conceptual model underlying cost benefit analysis. This in our opinion results in a clearer definition; one which does not involve defining (incorrectly in our view) natural capital as that which produces a flow of ecosystem services whilst simultaneously defining ecosystems services as that which results from a stock of natural capital. This same conceptual framework moreover helps to explain why in some instances the same resource e.g. fish can legitimately be viewed as an ecosystem service, natural capital and an economic good – something which would otherwise cause confusion.

4.1 Why value changes in natural capital?

Before attempting to provide a definition of natural capital one may well ask why it is necessary to expand the scope of current guidance given this is a big step. There are two basic reasons why this is desirable.

[15] Guidance has patently been used to value changes in the area of forests or unspoiled areas.

[16] This is a good example of the potential benefits of an official online glossary.

First to confine guidance to dealing only with the value of environmental goods and services would seriously limit its scope. Many environmental projects do involve changes in the stock of natural capital and it is currently unclear how such impacts should (or indeed are) being valued.

Second the value of environmental goods and services, and the value of natural capital upon which their production depends, are related, so it is appropriate to deal with them together.

It may also be noted that exercises in modified national income and wealth accounting of the type conducted by the Office for National Statistics both require information on the value of unit changes in the stock of natural capital. There is a risk of inconsistency with different values being used for different purposes through lack of guidance about the correct procedure. Furthermore maintaining the stock of natural capital is an important policy objective retrospectively monitored through wealth accounting.[17] This serves as a constraint on the application of cost benefit analysis in the sense that whilst individual projects may pass the test if all of them are then implemented this may reduce the overall stock of natural capital.[18] Such an outcome may be avoided at the project appraisal stage but not without guidance on the valuation of natural capital.

4.2 What is natural capital?

Prior to offering a definition of natural capital and considering some alternative definitions currently in circulation it is helpful to review the standard definition of produced capital. Along with land this is the sort of capital traditionally dealt with by economics. Other sorts of capital exist e.g. human and social but we do not investigate them here. It is we believe helpful to develop a definition of natural capital out of the definition of produced capital.

Produced capital is used in the production of other goods and services. It is traditionally thought of in terms of buildings and machinery. Unlike intermediate goods it is not exhausted through use but may depreciate and is prone to obsolescence. It can also be augmented by the production of capital goods. The total quantity of produced capital is referred to as the stock and is usually measured at the beginning and at the end of the accounting period.

The value of a unit of produced capital depends on the flow of goods and services derived from its application. These benefits typically accrue to the owner. The benefits of some forms of produced capital are however much harder to appropriate. This form of capital is often referred to as infrastructure. Produced capital is distinguished from durable goods that provide a flow of utility to households but which are not used in the production of other goods and services. Capital is also distinguished from goods and services stored rather than consumed and which are referred to as inventories.

The stock of produced capital can be regarded as a state variable. State variables are defined as the smallest subset of variables which can together represent the status of a system. In terms of the economy the end of period stock of produced capital is a member of the smallest subset of variables providing a sufficient indicator of future levels of utility. Durable goods and inventories would also

[17] For some the requirement is to maintain stocks of capital such that a reduction in natural capital can be compensated by an increase in produced capital.

[18] Sustainability issues imply additional shadow prices which would need to be considered.

be regarded as state variables. The flows of goods and services during the preceding accounting period are by contrast not state variables. The concept of state variables is obviously important to those who are concerned about future levels of utility and the prospects for sustainable development.

One may now enquire how satisfactory a definition of natural capital is obtained simply by adapting the above definition of produced capital. More specifically what happens if one changes the definition to capital not produced by humans and which would exist even in his absence? To anticipate the outcome simply adapting the definition of produced capital in this manner does not result in the complete set of state variables. Important state variables are overlooked and because environmental projects impact these omitted state variables they cannot be ignored.

Adapting the definition of produced capital a preliminary definition of natural capital is as follows. Natural capital is not produced by humans but something that would exist even in the absence of humans. Natural capital is an argument in economic production functions and environmental production functions. Natural capital constitutes a stock which may be measured at the beginning and at the end of the accounting period. Natural capital is a state variable.

Further similarities and differences between produced capital and natural capital are now discussed.

Similar to produced capital the value of natural capital depends as we have already suggested on the flow of goods and services derived from its application. But some of these goods and services are not priced by the market. This obviously makes it more difficult to determine the value of a unit of natural capital.

With produced capital the benefits usually flow to the owner. Natural capital by contrast may have no owner. And even for natural capital which is owned by someone it may be legally or physically impossible to exclude potential beneficiaries. The consequence is that whilst produced capital may be bought or sold there may be no market for natural capital or if there is a market it may not reflect the full value of the resource. This too makes it more difficult to determine the value of a unit of natural capital.

Even with some forms of produced capital it may be impossible to exclude potential beneficiaries. Such forms of capital are normally referred to as infrastructure. If one wished one could similarly refer to natural capital whose benefits cannot be appropriated as green infrastructure. It is not clear however whether those who have been using the term intended it in precisely this manner. We prefer to avoid the use of this term.

Some forms of natural capital can be augmented by flows from ecosystem services. An example of this is the reproduction of species. Reproduction is properly viewed as an ecosystem service. Reproduction is a flow of recruits that depends on a breeding stock of natural capital.

It has already been noted that produced capital is often distinguished from durable goods that provides a flow of utility to households but which are not themselves used in the production of goods and services. At the same time however we noted that durable goods should be considered a state variable.

It may be desirable to expand the definition of natural capital such that it can be an argument in utility functions. There are many variables that are arguments in household utility functions which possess other important characteristics of natural capital: they would exist in the absence of humans and constitute stocks that can be measured at the beginning and the end of the accounting period. For example utility might depend on the number of elephants.

Produced capital is distinguished from inventories. The key difference is that an inventory has value only if it is liquidated. Inventories arise when there is a surplus of production over consumption. This prompts the question of whether a surplus of environmental goods and services may be stored and if so how to treat the resulting inventories. Our view is that inventories of environmental goods and services are another form of natural capital; they possess several of the characteristics namely they can be measured at the start and end of the accounting period, and they are state variables and would exist even in the absence of humans. Many forms of natural capital possess a value only when they are liquidated. These stocks are not an argument in any environmental production function. They do not produce flows of environmental goods and services. Mineral deposits are for this reason best described as inventories but nonetheless constitute a stock of natural capital.

Certain remarks are due on the manner in which natural capital enters economic and environmental production functions and utility functions. It is (almost) invariably assumed that the value of an additional unit of produced capital is positive. This is because the act of producing produced capital is deliberate. With natural capital however there can be no such assumption: there may be forms of natural capital the unit value of which is negative e.g. vermin (even if they play an important role in the ecosystem).

Most problematic of all perhaps is insisting that natural capital is that which would exist even in the absence of humans. The reader may consider whether the stock of waste contained in landfill sites should be considered a form of capital along with the quantity of GHGs in the atmosphere in excess of preindustrial levels. Both constitute a stock that may be measured at the beginning and the end of the accounting period. Both represent an argument in economic or environmental production functions and utility functions. But quite clearly neither sort of capital would exist in the absence of humans. Despite this the accumulated quantity of GHGs in the atmosphere in excess of preindustrial levels is frequently regarded as a form of negative natural capital whereas landfill waste is ignored.

The proper resolution of this inconsistency lies with expanding the definition of produced capital. Produced capital is the result of a deliberate decision. But as discussed in the preceding section many economic activities generate unintended outputs such as waste products and the emission. Furthermore whereas the value of a unit of produced capital is positive the value of a unit of landfill waste and GHGs is negative. Conventional accounting procedures do not account for the accumulation of unintended outputs to the environment.

The view taken here is that classifying capital into either produced or natural according to whether it would exist the absence of humans is satisfactory as a procedure provided it is appreciated there are other forms of produced capital beyond those normally presented as such. Bodies such as the Natural Capital Committee should then determine whether they wish to first quantify and then value any form of capital unaccounted for by conventional accounting procedures or only those that would occur in the absence of humans.[19]

This discussion leads one to the following revised definition of natural capital. Natural capital is necessarily something that would exist even in the absence of humans. It is also a stock which may be measured at the beginning and at the end of the accounting period. Lastly it is a state variable. Stocks of natural capital may furthermore be an argument in economic production functions, environmental production functions and household utility functions. Certain stocks of natural capital may have a value only if they are liquidated. Natural capital may comprise an accumulation of the output of environmental production functions. There is no requirement that the value of an additional unit of natural capital be positive. There are important forms of capital not included as either natural or produced capital due to conventions relating to the definition of the latter.

It is interesting to review a number of other definitions of natural capital.

In its first annual report the Natural Capital Committee (2013) defines natural capital as: "[those] elements of nature that produce value or benefits to people (directly and indirectly), such as the stock of forests, rivers, land, minerals and oceans as well as the natural processes and functions that underpin their operation".

In a later Working Paper the Natural Capital Committee (2014) further states that natural capital represents a stock which facilitates a flow of ecosystem services, and that it includes physical, chemical and biological processes. It also states that natural capital is available without human intervention of any kind. The same Working Paper also provides a more streamlined definition of natural capital: "The elements of nature that directly and indirectly produce value of benefits to people including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions".

Although there is a lot in common with the above it is clear that the definition of natural capital in our report differs slightly from that provided by the Natural Capital Committee. In particular there is a difference of opinion regarding whether natural capital is necessarily only a variable or possibly also a process. This same issue was discussed in the section on ecosystem services where a distinction was made between environmental goods and services and environmental production functions. There is also a difference of opinion about whether natural capital is important only in the production of ecosystem services or in the production of other things besides (elsewhere the Working Paper indeed argues that natural capital is an input along with other sorts of inputs in the production of goods and services). One also notes the assumption that natural capital produces benefits whereas above was discussed the case of vermin where the value of unit increases in particular forms of natural capital is negative.

One may further note an inconsistency in that whereas the Natural Capital Committee apparently defines natural capital as that which is available without human intervention it also includes in its list of natural capital some things which exist only because of humans most notably the stock of GHGs in excess of preindustrial levels.

[19] Admittedly it sounds strange to refer to landfill waste and GHGs as produced capital even if upon reflection that is what they are.

DEFRA (2011b) adopt the following definition of natural capital. Natural capital is the stock of natural assets in their role of providing natural resource inputs and ecosystem services for economic production. Natural capital comprises renewable and non-renewable resources that enter the production process and satisfy consumption needs. Natural capital is an environmental asset that possesses amenity value and productive use and includes natural features such as the ozone layer which is essential for supporting life.

This definition is very similar to the one that we have proposed. Note that natural capital, natural assets and environmental assets are terms used interchangeably. Natural capital is an input to both economic and environmental production functions as well as to household utility functions. It is fair to assume that DEFRA views natural capital as neither made nor caused by humans. This definition of natural capital therefore excludes unwanted outputs discharged into the environment. It is also assumed that the unit value of natural capital is necessarily positive.

The Parliamentary Office of Science and Technology (2011) defines natural capital as "...environmental assets such as soils from which beneficial services flow supplying services to the economy, for example, agricultural crops and disposing of its wastes such as treated sewage effluent". The same note also refers to natural capital as a stock offering a return.

This definition too shares a number of similarities with the one developed above. Here too there is the assumption that natural capital supplies only beneficial services. Environmental assets and natural capital are clearly equivalent. What is particularly interesting about this definition however is that natural capital aids with the disposal of waste. Out of all the definitions that we have reviewed it is the only one so to do.

The OECD (2014) defines natural capital as: "natural assets in their role of providing natural resource inputs and environmental services for economic production".

The World Bank (2014) defines natural resources as those gifts of nature used either for production or consumption. Natural capital is the stock of natural resources excluding those such as sunlight which constitute a flow rather than a stock and those which cannot be used in production (such as a picturesque landscape).

This definition is interesting since it apparently excludes the possibility that natural capital could serve as an argument in household utility functions. The definition emphasises that natural capital is a stock whereas sunlight and presumably other forms of renewable energy constitute flows.

Lastly the United Nations Statistical Commission (2013) refers to ecosystem assets which are spatial areas containing a combination of biotic and abiotic components functioning as a whole. Ecosystem capital and ecological capital both refer to the stock of ecosystem assets. Ecosystem and ecological capital are however different from natural capital since the latter includes energy and mineral resources. Environmental assets include not only naturally occurring resources but also biological resources undergoing cultivation.

Mainly what the preceding paragraph demonstrates is the need for careful definition of terms. Some may be tempted to use terms interchangeably for stylistic reasons unaware that to others adhering to the definitions developed by the United Nations Statistical Commission they already mean different things.

4.3 How does one value natural capital?

It has already been noted that natural capital can be classified according to whether the benefits it yields can be appropriated. This distinction is most important when it comes to the task of valuation. If the benefits of natural capital are appropriable to the owner it may be possible to use market prices as a measure of value. But despite the attraction of using market prices for natural capital whose benefits are appropriable because of market distortions this is not always a reliable means of determining their value. Furthermore certain types of natural capital provide a range of benefits only some of which are appropriable whilst others simply have no owner (consider, for example, an upland forest which produces a flow of marketable timber but also provides a non-market flow of flood protection benefits by regulating run-off in a river's headwaters).

When market prices are unavailable valuing natural capital becomes much more difficult. This difficulty arises because a change in the stock of natural capital has consequences for the stock prevailing in future time periods and therefore the benefits that it provides. These difficulties are further compounded by the fact that some forms of natural capital are required in the production of environmental goods and services that have no market price. Worse still some forms of natural capital are needed in the production of intermediate rather than final ecosystem outputs. And lastly some forms of natural capital are ubiquitous meaning that they are arguments in the production of many different goods and services (including environmental goods and services) whilst also serving as arguments in household utility functions.

To illustrate these problems consider a situation in which natural capital is required in the production of some good or service. The value of a unit change in the stock of natural capital is its marginal product multiplied by the value of the good or service. For now, suppose that the value of that good or service may be established by reference to market prices. But as discussed, changes in the stock have consequences for the stock in future time periods. Accordingly, calculating the full value of the impact requires knowledge not only of current prices, but future prices as well.

To add to the difficulties, a unit change in the current stock may also have complex impacts on the future levels of the stock of natural capital. Consider, for example, a reduction in the stocks of fish in a fishery. If the stock levels are relatively healthy then that reduction may increase the availability of food resources increasing the survival chances of offspring and precipitating rapid stock regeneration. If the stock is precipitously low however, the opposite might happen. A small reduction may be sufficient to compromise the reproductive viability of the fish population leading to a collapse in the stock.[20]

Matters are more complicated if the stock of natural capital is needed in the production of some final environmental good or service that is not traded in a market. In this case there are no market prices to which one might refer and nonmarket valuation techniques are required to value the resulting change in the flow of goods or services (see Section 5). Again, it is not sufficient to know those values only for the current time period. Rather, one must establish the values of flows of those goods or services for all future time periods impacted by the stock change.

[20] Things are made yet more complicated by human behavioural responses. A reduction in fish stocks, for example, may precipitate increased levels of effort from fishermen with concomitant implications for future levels of stocks.

If one now assumes that the stock of natural capital is needed for the production of some intermediate environmental good a further step becomes necessary which is to calculate the change in the level of the intermediate environmental good or service and then calculate the resulting impact on some final good or service (which is then valued as before). And if the same stock of natural capital is simultaneously needed in the production of many different goods and services these steps must be repeated many times over.

Under certain assumptions, it is in fact possible to write down an expression that brings all these elements together and defines the net present value to society of holding more natural capital stock in situ (Fenichel and Abbott, 2014). That expression first calculates how a marginal change in stock impacts on values in a single period. That value change consists of two elements; an element reflecting the value of the extra environmental goods and services produced by the stock in a period (the change in dividend) and an element reflecting the change in the value placed on the stock over that period (the capital gains or losses). The net present value of that single period value accumulated over all future time periods is then calculated by dividing by a social discount rate adjusted for the effect that adding a little more natural capital has on the growth of the stock. Those growth effects may arise both through natural processes and through human changes resulting from behavioural feedbacks.

While the expression is quite general, it is often far from straightforward to establish values for the various elements and attempting to do so is an inherently interdisciplinary undertaking. Natural science will be needed to establish the link between changes in stocks and the production of final environmental goods and services; ecologists will need to advise on rates of natural stock regeneration; economists to apply techniques of non-market valuation and advise on social discount rates; and social scientists to establish patterns of human behavioural responses. Indeed, these complex undertakings are examples of integrated assessments a subject we discuss further in Section 10. Fenichel and Abbott (2014) attempt such an exercise for a reef fishery in the Gulf of Mexico using a numerical approximation method to estimate the capital gains term.

For some relatively simple cases the value of marginal changes in the stock of natural capital can be calculated without recourse to numerical approximation. Indeed, measures of that marginal value fall out naturally from the set of classic models developed by natural resource economists (a field of study where natural capital is often just referred to as “resources”) to examine economic systems that depend on natural capital (Conrad, 2010). Applications include the study of fish stocks, timber stocks, deposits of mineral and energy resources and stocks of pollutants in water and air. The simplifying assumption underpinning these models is that human behaviour can be approximated by a dynamic optimisation model often seeking to maximise social value from the use of a natural capital stock.

Typically natural resource economic models comprise a handful of equations including a demand curve for some good or service. They also include a production function relationship linking the production of this good or service to the stock of natural capital and a state equation describing the change over time in the stock of natural capital. The demand curve might be constructed from market data or some stated preference exercise. Parameterising the production function and state equation relationships by contrast requires scientific information.

To consider an example the value of a marginal change in the stock of fish may be derived from knowledge not only of the demand for fish but also from scientific knowledge related to harvesting and the rate of reproduction. With this information the implied value of a marginal change in the stock of fish can be calculated in a straightforward manner.[21, 22]

It could be that the same set of equations could be used to value other forms of natural capital too. Many different types of natural capital can be placed into one of a small number of categories according to the characteristics of the state equation i.e. the way in which the stock of natural capital changes over time. These categories correspond to four prototypical models much used in natural resource economics. Each of these prototypical models is now described in turn.

A constant resource is one which is available in constant amounts. It is impossible to increase or decrease the amount of the resource. Land is an example of this type of resource. Some people suggest that tidal wind and solar should be treated as natural capital but it seems to us that these are better regarded as environmental goods and services because they represent flows.

Exhaustible resources are those whose stock is determined by an initial endowment and cumulative exploitation. Mineral resources are exhaustible resources although there are also cases where the stock of the resource is available in almost limitless quantities but declining in quality. One might also distinguish resources merely transformed by use rather than destroyed such that they can be recycled. There is also the situation in which the resource can be augmented through costly discovery.

Renewable resources can be enjoyed in perpetuity. The change in the stock of renewable resources is dependent on reproduction (often modelled as a logistic function) minus the harvest. The modelling of reproduction is obviously critical and some renewable resources may possess a depensated growth function meaning that if the stock falls too far extinction is inevitable. For other renewable resources the growth of the stock may depend on its age of its constituent cohorts rather than on its biomass. And in some instances the cost of harvest is a function of the stock size. To some extent exhaustible resources can be thought of as a special case of renewable resources where the rate of reproduction is zero.

[21] To answer the question posed earlier in this example the same fish can represent both a marketed good and also a unit of natural capital and it will be valued differently in each role.

[22] Associated with the solution to dynamic optimisation problems is a set of costate variables. These variables can be interpreted as the change in the value of the objective function associated with a unit change in the state variable. If as is often the case the objective is in terms of monetary values and the state variable is the stock of natural capital then the costate variable represents the monetary value of a unit change in the stock of natural capital. These values can be used to value changes in wealth or to produce modified estimates of national income as well as valuing changes in the stock of natural capital arising through some project. In natural resource economics the shadow prices pertaining to the state equations for natural capital are often referred to as scarcity rents. Rental values may change over time through changes in relative scarcity. There is meant to be a correspondence between these rents and the market prices that would prevail if the benefits of natural capital were fully appropriable.

Lastly there are stock pollutants in which pollution is created as a by-product of some production process.[23] The change in the stock of pollution is typically equal to new emissions minus any natural decay in the stock of the pollutant. Pollution causes damage related to the stock size. This damage may be valued using market prices or nonmarket valuation techniques. In some cases the stock of pollution might never decay whilst in others clean up is possible but costly.

The Natural Capital Committee (2014) has already noted the importance of classifying different forms of natural capital depending on whether they are renewable or exhaustible. And it has also recognised that some forms of natural capital (constant resources) are not subject to anthropogenic change and has decided to exclude these from its analyses on grounds of pragmatism.

Despite its appeal it is important to acknowledge some problems with the optimising approach to obtaining values. First some of the mathematical relationships may be uncertain resulting in very different values. Second many stocks of natural capital cannot be studied in isolation. This is most obvious in the case of stocks of species involved in a predator prey relationship. This does not mean that the approach cannot be used but that it will be much more complicated to apply. Third not all natural systems are optimally managed. Marginal values ought properly to reflect the deficiencies in institutions governing their management. Many fish stocks are for example not optimally managed but are instead subject to open access in which case the value of an additional unit of stock would be different.

Since the valuation of natural capital is a complex undertaking and will not be necessary for every environmental project, detailed discussion of how to value natural capital is probably not necessary for / beyond the scope of guidance. Instead valuing changes in the stock of natural capital deserves its own report similar to those valuing the health effects of changes in air quality or valuing changes in GHG emissions.

4.4 Recommended changes to guidance

- Provide a definition of natural capital which refers to the fact that natural capital potentially endures from one period to the next and is potentially an input to household utility functions, production functions and environmental production functions and unlike physical capital would exist even in the absence of humans.

- Explain that stocks of waste and other forms of residuals would strictly be considered as a form of produced capital

- Note that environmental projects can involve a change in the stock of natural or produced capital and these valuations are also of interest to those involved in wealth or modified national income accounting

- Explain that natural capital can be readily valued using market prices only if its benefits are fully appropriable but that in general the valuation of natural capital is an interdisciplinary endeavour

[23] As noted earlier it is moot whether stocks of pollutants arising out of human production processes should be referred to as produced capital or natural capital.

- Attempt to classify resources and develop extended guidance on how optimising models can be used to value unit changes in the stock of natural capital
- Explain that the value of unit changes in the stock of natural capital requires an assumption about the adequacy of institutions over the duration of the project and beyond

5 Valuing environmental goods and services

Environmental projects result in changes in the flow of environmental goods and services into the economy. While some of those goods and services may command prices in markets (for example, coal, aggregates, timber and fish) others, as a result of their public good nature, do not (for example, clean air, quiet environments and wildlife). The Green Book is very clear in its insistence that the valuation of these non-market environmental goods is central to project appraisal: "Environmental costs and benefits for which there is no market price also need to be brought into any assessment. They will often be more difficult to assess but are often important and should not be ignored simply because they cannot easily be costed" (para 5.12, p. 19).

In this section, we review the advice provided by the Green Book and the supplementary guidance regarding how analysts should proceed in the task of valuing changes in flows of environmental goods and services. The section goes on to suggest a number of areas where that advice might be improved. The through-running theme of those suggestions is the creation of coherent and comprehensive guidance that is firmly grounded in economic theory and reflects current best practice in environmental valuation.

5.1 State of current guidance

Advice on the valuation of environmental goods and services is spread across the Green Book and across a number of documents making up the supplementary guidance. Of primary relevance is Annex 2 of the Green Book which deals with *Valuing Non-market Impacts* as well as supplementary guidance provided in the documents *Accounting for Environmental Impacts: Supplementary Green Book Guidance* published in 2012, and *An Introductory Guide to Valuing Ecosystem Services* published in 2007.

In Section 2 of this report, we provided a discussion of that documentation and highlighted some general areas where we felt it might be improved. A number of those comments relate to issues concerning the valuation of environmental goods and services. Here we provide a more detailed assessment of several specific issues regarding how the guidance deals with the subject of environmental valuation. In particular, we discuss the question of whether the Green Book provides appropriate guidance on the theoretical justification for the economic valuation of environmental goods and services. We also review the categorisation used in the Green Book to organise notions of value, particularly the concept of Total Economic Value. Finally, we review the advice provided in the Green Book and supplemental guidance regarding the techniques of environmental valuation and consider whether that advice provides analysts with an accurate and comprehensive overview of the field.

We begin with the question of the justifications that the Green Book presents for the economic valuation of environmental goods and services. Annex 2 on 'Valuing Non-Market Impacts' opens by introducing the concept of utility and suggesting that the purpose of valuing changes in the provision of non-market goods is to establish "the impact that these things have on utility" (para 2, p. 57). The ensuing discussion makes the case that utility is hard to observe and hence economists use money measures of willingness to pay (WTP) and willingness to accept (WTA) to proxy for utility changes. It is our opinion that this advice provides at best a muddled, and at worst a misleading account of the role of non-market valuation in cost benefit analysis. In particular, it mistakes the normative basis of cost benefit analysis as being an implementation of utilitarian social choice.[24] Rather, most economists contend that cost benefit is a tool for the assessment of projects according to the Hicks-Kaldor criterion (also known as the potential Pareto improvement criterion).

One of the consequences of this confusion is that WTP and WTA are presented to the reader as if they are merely surrogates for the true measure of value that we are seeking to recover. In fact, for cost benefit analysis they are the exact measures. Likewise readers are informed that since WTP depends to a large extent on levels of income, "valuations are usually obtained by averaging across income groups" (para 3, p. 57). Again, the implication is that WTP is an imprecise measure of economic value; its exactness being muddied by income variation. Again that characterisation is misleading. WTP (and WTA) are expressions of the value change experienced by some particular individual (or household or other economic agent). We would expect them to vary across individuals both because of differences in income and because of differences in preferences. Far from providing better information on the value of a non-market good, averaging measures of WTP or WTA results in information being lost. Indeed, understanding how measures of WTP and WTA vary across individuals is crucial for determining the distributional impacts of projects (see Section 10).

It is our opinion that the Green Book's reticence in describing the normative basis for project appraisal using social cost benefit analysis is a general weakness of the guidance. This weakness is most keenly felt in the sections dealing with non-market valuation where the theoretical case for combining market prices with measures of WTP and WTA is not well made.

As discussed in Section 2 of this report, the supplementary guidance advises analysts to adopt an ecosystem services approach to the task of valuing environmental projects. It also presents the provisioning-regulating-cultural-supporting (PRCS) categorisation of ecosystem services. In addition, both supplementary guidance documents introduce the subject of valuation through the medium of the Total Economic Value (TEV) framework. TEV attempts to categorise the different types of value that are generated by an environmental resource. For example, value flows can come in the form of direct use values, indirect use values, option values and existence values, amongst others. Within the guidance attempts are made to relate the TEV framework to the PRCS categorisation. Likewise, further attempts are made to relate TEV to various techniques that might be used to estimate those values.

As we discuss subsequently, we have a number of concerns with this material and the way it is presented in the guidance. We have already considered the limitations of the PRCS categorisation of ecosystem services, it turns out that there are also significant issues with TEV. For example, it is now widely accepted that option values, as presented in the standard presentation of TEV, do not constitute an independent category of value (an issue we will return to discuss in the subsequent section on uncertainty). Likewise, there are logical inconsistencies in the standard presentation of TEV, for example, in the way in which the values provided by environmental resources through indirect channels are assumed only to provide benefits through use and not through non-use. In addition, real tensions are created in the guidance through attempts to present the PRCS

[24] An assumption that also implies that the economic theory of value is based on a notion of measurable, cardinal utility which is absolutely not the case.

categorisation of ecosystem services and the TEV categorisation of values as compatible bedfellows. These two categorisations attempt to do two very different things. It is simply not possible to bring them together in a way that provides analysts with coherent guidance as to how to proceed with the task of valuing environmental goods and services. Indeed, it is our opinion that to achieve that task the material on the categorisation of ecosystems services and types of value needs to be radically overhauled.

Finally we turn to the advice provided in the guidance regarding the methods that might be employed to value environmental goods and services. The Green Book and the supplementary guidance draw distinction between revealed preference methods that infer values from observed market behaviour and stated preference methods that elicit values through directly questioning individuals using structured questionnaires. Both supplementary guidance documents then provide brief descriptions of a variety of methods: namely, hedonic pricing, travel cost, random utility, contingent valuation, choice modelling, cost-based approaches and production function approaches. While there are some inaccuracies in this material and the descriptions could be more informative, our biggest concern is that the list of valuation methods is very far from complete. In particular, the methods listed focus almost exclusively on the consumption side of the economy. Almost no guidance is provided for valuing environmental changes that impact on firms or the productivity of factors of production. Indeed, the only method discussed with relevance in this context is the production function approach and this, as we shall discuss, can only provide approximate measures of economic value.

It is our opinion that there would be considerable advantage in expanding the supplementary guidance to provide a comprehensive overview of the range of techniques for environmental valuation with as much emphasis given to the production side of the economy as is currently afforded the consumption side. Moreover, we believe that the guidance should provide much more practical advice regarding the circumstances in which the different methods might usefully be employed, their data requirements and their key advantages and limitations.

5.2 Cost benefit analysis and environmental valuation

The fundamental justification for the application of cost benefit analysis (more correctly *social* cost benefit analysis, but we omit that qualification for the sake of simplicity) is that it allows policy makers to assess whether a project delivers gains in economic efficiency. The notion of efficiency being evoked here is that described by the Hicks-Kaldor criterion: namely that a project is an improvement over the *status quo* if it is possible for those that benefit from the project to compensate those that lose, and still be better off themselves. The Hicks-Kaldor criterion is alternatively known as the potential Pareto improvement criterion or simply the compensation principle (Just et al., 2005).

Social cost benefit analysis provides a means of evaluating the compensation principle by enumerating households'[25] preferences for the changes resulting from a project in money terms.

[25] Here we use the term 'household' to describe the relevant decision-making unit understanding that in some cases that unit may be one individual but in others it may be a group of individuals whose preferences for the changes resulting from the project are jointly determined.

Those households that prefer the outcome of the project to the status quo gain welfare from the project. A monetary measure of those gains is their *willingness to pay* (WTP): that is to say, the maximum amount of money the household would give up to enjoy those gains. Those households that prefer the status quo to the outcome of the project lose welfare from the project. A monetary measure of those losses is their *willingness to accept* (WTA): that is to say, the minimum amount a household would need to be paid to put up with those losses.

Accordingly, in an economy with N households considering a project in which N^+ of those households stand to experience a gain and N^- households stand to experience a loss, the decision rule for cost benefit analysis amounts to establishing whether the following inequality holds;

$$\sum^{N^+} WTP > \sum^{N^-} WTA$$

In words, if the sum of WTP amounts exceeds the sum of WTA amounts then, following the project's implementation, money could be transferred from gainers to losers in such a way that no one is worse off than they were in the status quo and at least one person is better off.[26]

At its core, therefore, cost benefit analysis is an exercise in estimating WTP and WTA for the outcomes of a proposed project. In the next section, we review the current advice given by the Green Book regarding how that task might be performed for outcomes that result in environmental changes. In preparation for that discussion, we first need to develop a somewhat more detailed understanding of how environmental change can impact on household welfare and then establish exactly how those changes in welfare define the WTP and WTA measures.

Economic theory makes the basic assumption that households attempt to organise their consumption so as to realise the most utility. Let us suppose that utility is derived from consuming increasing levels of man-made goods and services, quantities of which we shall label x, and final environmental goods and services, quantities of which we shall label q. Indeed, in a highly simplified example in which there are two man-made goods, x_1 and x_2, and one final environmental good, q, we might write the households' utility function as;

$$Utility\ Function:\ u(x_1, x_2, q)$$

[26] The WTP and WTA measures described here assume that the question we wish to answer is whether society should move away from the situation its members currently enjoy. Since the status quo is the baseline, our welfare measures assume gainers should pay for their gains (WTP) and losers should be compensated for their losses (WTA). Economists describe those measures as measures of *compensating variation*. Alternatively, it might be more natural to assume that the project should proceed. In that case, our motivating question is not whether we can justify a move away from the status quo, but whether there is a case for sticking with the status quo. From that point of view, the relevant welfare measures are the compensation that those that stand to gain from the project would need in order to forego those gains (WTA) and how much losers would pay to avoid their losses (WTP). Economists describe these alternative measures of welfare change as measures of *equivalent variation*. The decision rule of cost benefit analysis is not changed when answering this alternative question just which group (gainers or losers) do the paying and which require the compensation.

Generally, we are going to assume that households can choose the levels of man-made goods that they consume by purchasing units of those goods in a market. In contrast, as a result of its public good characteristics the environmental good is not traded in a market and the household has little or no control over the level of q that they enjoy.

In choosing how many units of x_1 and x_2 to purchase at prices of p_1 and p_2 respectively, the household is constrained by their income. The budget constraint imposed by their income might be written as;

$$Budget\ Constraint: \quad y \equiv w(q)K(q) + \tilde{\pi}(q) \geq p_1 x_1 + p_2(q) x_2$$

Here household income, y, is derived from two sources[27]:

- First, from the household's ownership of quantities of factors of production, K, from which they receive the per unit payment w. Typically that factor of production will be the household's supply of labour such that w can be interpreted as a wage. It is perfectly possible, however, for a household to own additional forms of capital perhaps in the form of savings from which they earn interest or in the form of land or property from which they earn rent.[28]
- Second, from the household's ownership of productive enterprises from which they receive profit income given by $\tilde{\pi}$. Ultimately all private firms are owned by households, for example as a partner or a shareholder, and that ownership entitles a household to some share of the firm's profits. Of course, many households will not receive any income from this source.

Notice that it is possible for environmental goods to enter as arguments in the budget constraint as well as (or instead of) entering the utility function. In our presentation we have identified four possible ways in which that may happen;

- First, the quality of a factor of production might depend on levels of q, for example, if a household owns land then its productivity in agriculture may change as a result of changing environmental quality .
- Second, the payment for factors of production might depend on levels of q, for example, if firms located in areas of lower environmental quality have to pay more to attract employment to their business.
- Third, profit income may depend on q if the profits of firms owned by the household depend on levels of environmental quality.

[27] Households may have other sources of income perhaps from benefits payments but for the sake of simplicity we ignore those other sources.

[28] For simplicity of presentation, we make the assumption that the quantity of factors of production that the household owns and supplies to the economy is exogenously determined. A more sophisticated presentation would have the household making choices over that quantity; in the case of labour, for example, choosing whether to undertake training to improve quality and choosing how many hours to work.

- Fourth, the price of market goods may depend on q, for example, in the way that the rent payable on a household's home may increase if the environmental quality of the area in which their home is located increases.

According to economic theory, households will choose to purchase those levels of x_1 and x_2 that maximise their utility within the constraints imposed by their budget.[29] Indeed, it is possible to imagine a function which describes what this maximum level of utility would be given certain values for all the exogenous elements of the choice problem; namely the prices of market goods, the level of provision of the final environmental good and household income. This is the indirect utility function which we denote;

$$Indirect\ Utility\ Function\colon\ v(p_1, p_2, q, y)$$

We now have all the elements we need in order to present WTP and WTA as monetary measures of welfare change in the context of household consumption decisions. In particular imagine a project that changes the level of provision of the final environmental good from its status quo level, q^0, to a new level, q^1. WTP and WTA can now be defined as the quantity of money C that establishes the following identity;

$$v(p_1, p_2, q^0, y) = v(p_1, p_2, q^1, y - C)$$

Notice that if the project improves the environment such that $q^1 > q^0$, then C is positive and describes the household's WTP for the improvement; it is the maximum amount of money that would have to be taken away from the household to reduce their utility back to the levels it was before the environmental improvement. On the other hand, if the project leads to a fall in provision of the final environmental good such that$q^1 < q^0$, then C is negative and describes the household's WTA for the loss in environmental quality; it is the minimum amount of money that the household would have to receive in compensation to make sure that their utility was returned to the levels experienced before the environmental deterioration.[30]

Since q can enter the utility function and budget constraint in many different ways, it is clear that a variety of methods will be needed in order to derive measures of C, an issue we shall return to in the next section.

It is worth noting at this juncture, however, that changes in q that impact on households through changes in profit income can be measured in a comparatively simple way. To illustrate, first expand income in the indirect utility function into profit and factor income. Then our welfare measure, C, is defined as;

$$v\left(p_1, p_2, wK^M + \tilde{\pi}(q^0)\right) = v(p_1, p_2, wK^M + \tilde{\pi}(q^1) - C)$$

Observe that for the two sides of the identity to be equal it is must be such that $wK^M + \pi(q^0) = wK^M + \pi(q^1) - C$. In other words;

[29] In more sophisticated presentations the household might also optimise with regards to the quantity of labour they supply to the labour market given a time constraint and their preferences for leisure.

[30] The measure of welfare change defined by the quantity $C$is the compensating variation (see footnote 26).

$$C = \tilde{\pi}(q^1) - \tilde{\pi}(q^0)$$

that is to say, the exact monetary measure of welfare change reduces to the change in profit income enjoyed by the household. That finding is rather important, insomuch as it suggests that changes in household welfare resulting from changes in the profitability of productive enterprises can be determined by simply calculating how changes in q impact on firms profits.

To complete the story of welfare measurement, therefore, we need to take a brief look at the firm's production problem. A firm, it is assumed, brings together factors of production, denoted K^M in our presentation, in order to produce quantities of a marketed good, x. Since production may also be dependent on the use of final environmental good, we can write the firm's (simplified) production technology as;

$$Production\ Function: \quad x = x(K, q)$$

The benefits to firms of producing is that they can sell their output at the market price p. To achieve that production, however, a firm must also employ factors of production at a cost determined by each factors market price, w. A firm's profits, therefore, are determined by the difference between revenues and costs;

$$Firm\ profits: \quad px(K, q) - w(q)K$$

In many cases it is reasonable to assume that firms choose a level of production so as to maximise their profits. Indeed, it is useful to define the firm's profit function which describes those maximised profits as a function of the exogenous elements in the firm's choice problem;

$$Profit\ Function: \quad \pi = \pi(p, w, q)$$

Notice that we denote a firm's profits as π to differentiate them from the profit income of households, $\tilde{\pi}$. A household may have ownership stakes in a number of different firms each of which contribute to its profit income. Likewise, a firm's profits will often be spread across a number of different households. No matter which households those profits accrue to, it must be the case that the total welfare impact of an environmental change that impacts on a firm's operations can be calculated using the profit function according to;[31]

$$\sum^{N} C = \pi(p, w, q^1) - \pi(p, w, q^0)$$

In other words, by calculating the profit changes experienced by productive enterprises we have an estimate of the aggregate welfare impact of that environmental change on households in the economy.

[31] Welfare measures from firm's activities are often alternatively presented in terms of differences in quasi-rents or producer surplus. Profits differ from those measures only by an additive term reflecting fixed costs which drops out of the calculation of welfare changes since it remains constant before and after the project. Accordingly, except in unusual circumstances, differences in profits equate to measures of welfare change based on quasi-rents or producer surplus.

5.3 Total economic value and PRCS: Complementary or competing classifications?

The concept of Total Economic Value (TEV) is discussed in many environmental economics textbooks and given due prominence in the Green Book. Much like the PRCS classification from the ecosystem services literature, the TEV concept attempts to identify the various pathways through which the environment delivers value to the economy.

There are differences between the TEV and PRCS categorisations that to a large extent reflect the difference in focus of the academic disciplines from which the two have arisen;

- *PRCS*, arising primarily from the natural sciences, focuses on the different environmental pathways and processes that link the natural environment with the economy.
- *TEV*, arising from the economic sciences, focuses more closely on the way in which households perceive value from the goods and services emanating from the environment

Despite those different focuses, there is significant overlap between PRCS and TEV and the separate contribution of the two categorisations to the task of valuing environmental change is not at all apparent. Indeed, we are concerned that the presentation of both TEV and PRCS within the guidance is the source of confusion.

The distinction between the two categorisations has obviously been an issue with which the authors of the current guidance have struggled; at one juncture, valiant attempts are made to map one classification to the other. For example, it is claimed that provisioning services include direct values and option values whilst regulating services include indirect use values and option values and so forth. Such attempts are, in our opinion, very misleading and it is not clear what fresh insights, if any, are provided by combining these two classifications. Indeed, the efforts to combine the PRCS and TEV classifications presented in the supplementary guidance results in numerous peculiarities. For example, is it plausible to suggest that regulating services, which amongst other things provide air quality and climate regulation, are ecosystem services which are *not* of direct use to households?

It is our opinion that for the purposes of advising analysts evaluating environmental projects, the two categorisations need to be rethought and reconfigured to remove overlap and provide a clear distinction in focus and purpose. Our suggestion is that that distinction is drawn along the disciplinary divide as follows;

- The role of an *ecosystem services* categorisation for environmental valuation should be to guide analysts through the natural science that links a project's impacts on the environment through environmental production functions and intermediary environmental goods and services to the final environmental goods and services that enter economic considerations.
- The role of an *economic categorisation* for environmental valuation should be to guide analysts with regards to the ways in which a final environmental goods or service can generate value in the economy and, from that understanding, advise on which methods of environmental valuation are appropriate for quantifying those values.

We have already discussed the limitations of the PRCS categorisation and how that might be better constructed so as to fulfil the first role. As we go on to discuss, it is also our opinion that the TEV categorisation, as currently conceived, is only partially successful at fulfilling the second role.

5.4 The problems with Total Economic Value

According to the taxonomy provided by the TEV framework the environment provides values to households in the economy that can be decomposed into a number of constituent parts often subdivided further into additional components. The main distinction is invariably between use value and non-use values but with the former typically subdivided further into direct consumption, indirect consumption and option values; the latter into bequest values and existence values. Such indeed is the classification that is employed in the supplementary guidance to the Green Book.

Let us consider first, the core dichotomy of the TEV taxonomy which differentiates values gained through 'use' from values gained from 'non-use'. While not made explicit, the idea of 'use' appears to relate primarily to the notion of physical interaction with the resource. Care is taken to clarify that values from use do not have to be consumptive: while the consumptive use of environmental goods and services (for example, the consumption of natural resources such as food, timber and coal) is certainly a use value, so is the non-consumptive use (for example, from breathing clean air, recreating in natural areas or enjoying the amenity of the natural landscape). In contrast, non-use values are characterised by a lack of physical proximity to or interaction with the environmental good or service from which value is derived.

Within the guidance, the TEV classification of values into use and non-use underpins an important issue of practical advice. Readers are informed that while non-use values can only be estimated through *stated preference* methods of valuation, it may be possible to estimate use values by application of *revealed preference* methods. To be clear, revealed preference methods are those in which the value of the environmental good or service can be inferred from observable behaviour: primarily, observable behaviour in the purchasing of goods in markets. Stated preference methods, on the other hand, are those in which consumers, through various methods of direct interrogation, are asked to divulge the value they place on an environmental good or service.

Unfortunately, things are not that simple. A central problem with the TEV classification, and one that can result in considerable confusion, is that the division of value into use and non-use does not neatly map onto the application of revealed and stated preference methods. For example, consider a person who gains value from nature as an incidental part of their daily routine; for example, from the wild birds or animals that they see from the windows of their house or from the river that they pass besides while sitting on the bus on the way into work. There is little doubt that such values are derived from use, but that value leaves no signature in their market behaviour; they would pay the rent on their house with or without wildlife, they would pay their bus fare with or without the river. Likewise, consider the individual who values a natural resource not because they currently use that resource, but because they expect that they might wish to make use of it in the future. Whether this is a use or non-use value is not at all clear (as we shall discuss shortly, in the TEV classification it tends to be categorised as a use value and is consigned to the ill-defined sub-category of an option value). The only thing that is clear is that this value cannot be estimated by observing their current market behaviour.

For the purposes of guidance on the appraisal of environmental projects, therefore, our contention is that whether individuals regard their value as emanating from the use or non-use of an environmental good or service is neither particularly helpful nor particularly relevant. Rather the fundamental distinction that analysts must make is between values that can be estimated from observable behaviour in markets and those that cannot. If changes in the flow of a final environmental good or service results in observable changes in market behaviour then values can be estimated using revealed preference methods. In the absence of a behavioural response in markets, values must be estimated using stated preference methods.

Of course, what determines whether an environmental good or service results in observable market behaviour, can be made technically precise by thinking about the way in which it enters the household's choice problem. For example, consider the choice problem;

$$\max\ u\left(u_x(x_1, x_2) + u_q(q)\right) \qquad \text{subject to:}\ \ y \geq p_1 x_1 + p_2 x_2$$

where the final environmental good or service contributes to utility solely through the additively separable function u_q. In this case, changes in q have no impact either on income or on the utility realised from the consumption of market goods. It follows that, although changes in q affect utility, they leave no record of this impact in a household's market behaviour: to estimate the value of changes in q, an analyst would have to adopt the methods of stated preference valuation.

The TEV categorisation goes one step further attempting to subdivide the source of non-use value for an individual into finer categories. Now it may well be true that individuals have different motives for non-use values, but it is also true that environmental valuation techniques are unable to distinguish between non-use values arising from those different sources. Operationally there is no purpose in separately identifying altruistic and bequest values from existence values.

There are also problems in the way in which the TEV taxonomy attempts to partition the use values derived from some particular environmental good or service. For a start, included as part of use values are 'indirect' use values: a poorly defined ragbag of a category in which the nature of "indirectness" is not made clear.

One way in which an environmental good or service might deliver indirect use value, for example, is if it is used as a productive input by a firm. People get value from the final outputs of that firm's production, and as such are getting indirect use value from the environmental good or service. While that provides a useful reminder of the multiple routes through which environmental goods and services provide value, it is not of immediate practical use to the analyst wishing to understand how to measure those values. What is most relevant for that analyst is that the final environmental good or service enters a firms' production function. As we have already seen, with that information an analyst would know that the appropriate way to estimate the environmental good or service's value is by measuring its contribution to firms' profits.

Another source of indirect use value arises when rather than appearing in a *firm's* production function, an environmental good or service appears as an argument in an *environmental* production function; that is to say, it is an *intermediate* environmental good or service rather than a *final* environmental good or service. Indirectness in this case leads to a very different prescription of how to proceed with valuation. In particular, the analyst would need to establish the natural science relationships linking the changes in provision of the intermediate environmental good or service, which cannot be valued, to changes in provision of final environmental goods and services, which can be valued. Doubly confusing, is the fact that the TEV categorisation assumes that this source of value is a form of use value. While it is perfectly possible that an intermediate environmental good or service may contribute to some other final environmental good or service from which households gain use value, it is equally credible to suppose that those final environmental goods and services may be the source of non-use values. To suggest that indirect values fall exclusively under use values is incorrect and might result in overlooking an important source of the TEV of an environmental good or service. Indeed, in line with our early comments, one might argue that a more logical taxonomy would promote this form of indirectness to the primary division of value flows. That classification would provide analysts with the clear direction that an environmental good or service might impact on the economy through more than one environmental pathway, and that each of those different pathways may result in flows of use and non-use value.

Finally, consider the usual practice in the TEV taxonomy of including option values as another distinct component of use values. There are two difficulties with the inclusion of option values as a component in TEV. First, they do not represent a separate source of value per se and exist only in the presence of uncertainty. Second, once option values are properly understood it becomes apparent that they may exist for final environmental goods and services for which households possess non-use values. We defer further discussion of option values until a later section.

The above discussion makes it clear that the frequently attempted subdivision of the values that together comprise the TEV of environmental goods and services is potentially misleading. In addition, it is our contention that there is a more fundamental problem with the TEV categorisation. In particular, TEV examines value from the point of view of the household and not the analyst. That perspective may be useful for conveying the fact that individuals gain value from environmental goods and services in a variety of ways, but it fails to provide the essential information that cost benefit analysts require in making decisions about how to estimate the value of environmental goods and services.

5.5 A classification for environmental valuation

An important requirement for any document offering guidance on the cost benefit analysis of environmental projects is to provide advice on what valuation technique is appropriate for particular environmental goods and services. For a variety of reasons the Green Book provides only limited help in this respect. This is primarily because the chief organising frameworks presented in the Green Book are ecosystem services classified by PRCS and value flows classified through the TEV taxonomy. As we have seen, neither classification provides a suitable organising framework within which to present information guiding analysts on appropriate methods of environmental valuation.

Eschewing the PRCS and TEV categorisations, most intermediate and advanced presentations of environmental valuation in the economics adhere to a quite different organising framework (Freeman et al., 2010; Bockstael and McConnell, 2007). The unambiguous intention of that framework is to direct the analyst to the most appropriate method to apply in valuing changes in the provision of an environmental good or service.

The core organising themes of this alternative framework revolve around establishing the fundamental economic characteristics of the environmental good or service and then defining precisely how that good or service enters the household's choice problem. With regards to the economic characteristics of the environmental good or service, the key questions are:

- Is this an *intermediate* or *final* environmental good or service? If it is an intermediate environmental good or service then, with the help of natural scientists, it will be necessary to establish how changes in its provision impact on the flow of final environmental goods and services into the economy. A change in the provision of an intermediate environmental good or service is valued according to the value of the resulting changes in provision of final environmental goods and services. The relationships linking intermediate with final environmental goods and services may be highly complex perhaps triggering adaptation in natural and human systems. If that is the case then methods of integrated modelling may be required, a subject we discuss in section 10.
- Is the final environmental good or service derived by drawing down a *stock of natural capital*? If so then the value of the environmental good or service must also include its user cost: that is to say, the value of the future output of the environmental good or service that is foregone because that capital stock is consumed in the present period. We addressed these issues in the previous section on Natural Capital.
- Are the changes in provision of the environmental good or service *marginal* or *non-marginal*? If the changes are marginal then values based on prices or shadow-prices will be appropriate. If the changes are non-marginal, then values should be based on measures akin to consumer surplus that account for adjustments in human behaviour. Values for non-marginal changes might also have to consider potential adjustments in natural systems. Again, such adjustments might require modelling endeavours as we describe in section 10.
- Is the final environmental good or service traded in a *market*? If so then the price it commands in that market (perhaps adjusted for market distortions) provides a suitable measure of its value.

For final environmental goods and services that are not traded in markets, estimating values will require the application of techniques of non-market valuation. The particular technique to apply depends on the answers to a series of further questions that establish how the good or service enters the household's choice problem;

- Do changes in the flow of the environmental good or service potentially result in observable changes in market behaviour? If they do then methods of *revealed preference* can be applied, if not then the value must be established through the application of *stated preference* methods.
- While not having its own market price, is the environmental good or service an attribute that determines the price of a differentiated market good or service? If so then methods based on Lancaster's (1966) characteristics model of differentiated products such as the *hedonic pricing method* or the *random utility model* method might be used for the purposes of valuation.
- Does the environmental good or service enter the household's choice problem through profit income? If so then its value can established on the production side of the economy by examining how changes in provision of the good or service impact on *firm's profits*.

- Does the environmental good or service impact on a consumption choice regarding how many units of a market good to purchase? If so then one of various methods based on estimating *demand curves* for market goods can be used to establish values.
- Does the environmental good or service impact on a discrete consumption choice regarding which market good to purchase? If so then the *random utility model method* can be used to estimate values.

We propose that for the purposes of guiding analysts to appropriate methods of environmental valuation it is these questions and not TEV that should be the organising framework adopted by the Green Book.

In proposing this decision process we note that some environmental goods and services may enter both household utility functions and firms profit functions. The same environmental goods and services moreover can enter these functions in more than one way (i.e. as separable and inseparable components). Certain environmental goods and services can enter the profit functions of firms in multiple different industries and finally, some environmental goods and services serve as both final and intermediate environmental goods. The implication of all this is that more than one valuation technique may be required to obtain the full value of a change in particular environmental goods and services.

Because of these complexities, any estimate of changes in the supply of environmental goods or services is likely to be incomplete. It is also the case that some techniques are able to provide only upper or lower bound estimates.

5.6 Methods of environmental valuation

We now proceed to discuss the way in which different nonmarket valuation techniques are presented in the Green Book. An obvious question is how much guidance should be provided regarding the use of any particular technique given that far greater information is available elsewhere? We believe that the guidance on the use of valuation techniques should adhere to the following minimal list of requirements.

- First of all we believe that the list of available valuation techniques to assist with the valuation of nonmarket environmental goods and services should be comprehensive and that the descriptions afforded to each of these techniques should reflect best current understanding.
- Moreover, the descriptions afforded to each of these techniques should provide sufficient intuition that an intelligent person can understand how they work typically with the view of commissioning a valuation study.
- In terms of the analytical framework adopted it should be clear when each of these techniques is appropriate as well as the chief limitations.
- Advice should be provided regarding the advantages and disadvantages of the different techniques e.g. that the technique is data-intensive or that there is not much experience in its use.

- Where linkages exist between different techniques and where some meaningful categorisation is possible that fact should be mentioned in order to promote greater understanding of these techniques. Some nonmarket valuation techniques given prominence in the Green Book, for example, are just particular applications of more general methods.

What is striking about the current guidance is that much of this information is absent. Accordingly, drawing on the organising framework described in the previous section, we proceed by providing a brief summary of the methods of environmental valuation that we believe should be described in the Green Book. Obviously we will dwell much longer on valuation techniques that that are underutilised or not even mentioned at all in current guidance either because they have been forgotten about or because they are, incorrectly in our view, deemed not to be useful.

5.7 Production side of the economy

The current guidance is almost entirely silent regarding the valuation of environmental changes that impact on productive enterprises in the economy. In fact, the only method afforded a mention is the *production function method*. In reality, there are a variety of different methods that the analyst might turn to, most of which we now briefly review.

As we have already established, when production is impacted by changes in the environment, the welfare impacts of those changes can be exactly measured by the profit changes experienced by productive enterprises. We term this the *profit function method*. Unfortunately, estimating a firm's profit function, especially the responsiveness of that profit function to changes in the environment, is a difficult and data-intensive task.

A more manageable undertaking is provided by the *supply curve method*. This method derives from the fact that the impact of environmental change on a firm's profits can be estimated by calculating areas between shifting supply curves for a firm's output. The supply curve method is somewhat less data intensive, relying only on establishing the relationship between output, price and environmental quality. Strictly speaking the method will only reveal the complete profit change experienced by the firm when the supply curve is for an *essential* output. By essential we mean that the profits of the firm fall to zero if production of this output ceases: a condition that will be trivially true of a single-output firm, but not necessarily true for firms that produce numerous outputs. The requirement of essentiality is necessary to ensure that that the entire impact of the environmental change on the firm's profits can be captured by the supply curve method. If the output were not essential then it may be the case that the environmental change impacts on firms profits through its production of other outputs.

Changes in profits from environmental change can also be estimated by looking at shifts in demand curves for marketed inputs. For this *input demand curve method* to return a complete measure of profit change it must be the case that the input is essential to the production of the firm's output (and, once again, that the output is itself essential).

An alternative strategy is provided by looking at the market value of firms themselves. It is assumed, that in a competitive market, the value of a firm will reflect its expected future profits. Accordingly, differences in the value of firms that result from differences in environmental quality inform on how environmental change will impact on a firm's profits. This method has seen most application in the agricultural sector under the guise of the *Ricardian technique*. Here it is assumed that the profits from agricultural enterprise are completely expropriated by the owner of its underpinning factor of production: land. The price at which land sells, therefore, reflects expected future profits from agriculture. Moreover, differences in the value of land resulting from differences in environmental quality provide information on how agricultural profits might be impacted by a project that brought about changes in the environment.

Given that agriculture is the sector arguably most reliant on ecosystem services the Ricardian technique appears to us to be underutilised. Evidence of its application is to the issue of valuing soil quality. The NCC for example notes that there is no satisfactory means of valuing changes in soil quality despite its obvious importance as a form of natural capital. Another important application of the Ricardian approach is the value of changes in climate to agriculture. The weakness of the Ricardian approach is that agriculture remains an area of significant Government intervention. The actions of Government in supporting certain kinds of agricultural production or production in particular areas where agriculture would otherwise be difficult distorts land prices. Applying the Ricardian technique under these circumstances would produce results that would be difficult to interpret. Application of the Ricardian technique to land used for productive purposes other than for agriculture is largely unexplored but it seems plausible to suggest that there would be a significant discount on land earmarked for productive purposes rather than residential use, and that is at risk from flooding. The technique can be applied to both the rental market (which may also be subject to controls of its own) as well as the sale market. The values that emerge represent the current value of the flow of ecosystem services and the natural capital that provides these services.

The *production function method* (for a comprehensive discussion see Barbier, 2007) proceeds by estimating the technical relationship between a firm's production of output and levels of an environmental input (these relationships are also referred to as dose-response functions). Using that technical relationship, an analyst can predict how environmental change will impact on profits by multiplying the predicted change in levels of output by the market price of output. In agriculture, for example, field experiments might establish the production relationship between rainfall and crop yield. The production function method would value environmental changes that changed the incidence of rainfall by multiplying the predicted changes in crop yield by the price of those crops. The key weakness of this method is that production functions are technical relationships and not behavioural ones (like supply and factor demand curves). In reality, for example, farmers will respond to changing patterns of rainfall by planting at different times of the year, artificially irrigating or perhaps changing crops. We can reasonably assume that those behavioural adaptations will always act so as to increase profits in the changed situation. Accordingly, the production function method will overestimate profit changes that result from reductions in environmental quality and underestimate those resulting from improvements.

A final method that can provide bounds to the profit impacts of a change in an environmental input is the *defensive expenditure method.* Here the welfare gains or losses are approximated by estimating how the cost of producing current levels of output would change as the result of a change in an environmental output. Again the method overestimates the fall in profits when environmental quality is reduced and underestimates the rise in profits when environmental quality improves because it does not allow for the behavioural response of the firm to optimally adjust levels of production under the new conditions. Of course, estimating the full behavioural response of costs and production to changes in an environmental input is the basis of the supply curve method. Accordingly, one can think of the defensive expenditure method as providing a rough approximation to the supply curve method.

5.8 Consumption side of the economy

The current guidance lists a variety of methods that might be used to estimate the changes of value experienced on the consumption side of the economy as a result of changes in provision of an environmental good of service. Those methods include the use of market prices, the averting behaviour method, hedonic pricing, the travel cost method and random utility models. Again that list is far from complete. What is more, the descriptions of many of the methods focus in on one particular application of what is actually a much more general approach. Hedonic pricing, for example, is described as a method based on observing differences in property prices. In reality, the hedonic pricing method can be applied to any differentiated market good or service which has environmental quality as an attribute. Likewise, the random utility model is described as being an extension of the travel cost method when in reality it is a method that can be applied in any situation in which households' make discrete choices that involve combinations of market goods and environmental goods and services.

Using the framework sketched out in the last section, we now briefly review the range of valuation methods that analysts might employ to value changes in the environment on the consumption side of the economy.

When environmental goods and services are traded, then the price that the environmental good or service commands in the market provides a suitable measure of household WTP. As pointed out in the guidance, proper application of the *pricing method* may require some adjustment of market prices to account for distortions, for example, arising from subsidies or taxes.

While it may not be possible to independently buy units of an environmental good, under certain circumstances quantities of that good may form an attribute of some other good that can be purchased in a market. The standard example is property, in which the location of a house determines levels of local environmental quality (for example, levels of noise pollution, air pollution, views of and proximity to natural areas). But that is not the only heterogeneous good through which households might 'buy' environmental quality: cars, foodstuffs, household appliances, holidays, for example, whose different varieties might offer less or more environmental quality. A simplified version of the household's choice problem in this case looks like;

$$\max\ u(x_1, z, q) \qquad \text{subject to:}\ \ y \geq p_1 x_1 + p_2(z, q)$$

where the household can choose the levels of z, a non-environmental attribute, and q, an environmental attribute, that they enjoy through their choice, and a heterogeneous market good that sells at price $p_2(z, q)$. In its simplest form the *hedonic pricing method* requires analysts to examine the selling prices of the heterogeneous good to establish the implicit price of environmental quality. As when facing standard prices, households maximise welfare by choosing a level of q at which their marginal WTP is just equal to this implicit price. Accordingly, implicit prices can be used as measures of WTP for marginal changes in q. When the changes in q are non-marginal, things are significantly more complicated, though those complications will not concern us here (see Day et al., 2007).

The hedonic pricing method is not only applicable to heterogeneous goods and services that a household buys. It also has application in situations where the remuneration a household receives when selling factors of production into the productive side of the economy depends on environmental quality. The standard example concerns labour where consumers may select employment from an array of different jobs that differ in a number of attributes particularly some dimension of environmental quality (for example, exposure to harmful pollution). A simplified version of the household's choice problem in this case looks like;

$$\max\ u(x_1, z, q) \qquad \text{subject to:}\ \ w(z, q) \geq p_1 x_1$$

where the remuneration the consumer enjoys from choosing a job with particular levels of environmental quality, q, and some other job attribute, z, is determined by the hedonic wage function $w(z, q)$. Applying the hedonic pricing method allows the analyst to identify the 'implicit wage' for environmental quality. Again, assuming optimising behaviour, those implicit wages for environmental quality are an estimate of marginal value; they tell us how much money a consumer would have to forfeit in lost wages in order to receive one more unit of environmental quality.

We've dealt with valuation methods appropriate for situations where environmental quality appears as an argument in the household's budget constraint. Now let us turn our attention to situations where environmental quality enters the household's choice problem solely through the utility function.

Our first, case is one we have seen before. That case has environmental quality as an additively separable element in the utility function;

$$\max\ u\big(x(x_1, x_2) + z(q)\big) \qquad \text{subject to:}\ \ y \geq p_1 x_1 + p_2 x_2$$

In this case, changes in q have no impact either on income or on the utility realised from the consumption of market goods. As a result, value can only be revealed through the application of methods of stated preference valuation. As correctly, pointed out in the guidance, the two most widely used method of stated preference valuation are the *contingent valuation method* and the *discrete choice experiment method*.

When choices over quantities of purchases of non-market goods are affected by levels of provision of an environmental good or service, then the analyst might choose to employ *demand curve methods* in order to estimate value. While there are a number of ways to motivate this approach (all of them essentially telling different stories about household preferences that lead to the same observed behaviour) one useful organising concept is provided by the household production framework. The assumption with household production is that households bring together market and environmental goods and services so as to 'produce' quantities of an outcome from which they gain utility. For example, a household might produce outdoor recreational experiences by bringing together the environmental good provided by a natural area with the marketed goods needed to transport themselves to that natural area.

In our presentation quantities of the valued outcome are denote $z = z(x_2, q)$ where the function $z(x_2, q)$ describes the household's production technology. In this case, the household's choice problem takes the form;

$$\max \ u(x_1, z(x_2, q)) \qquad \text{subject to:} \ \ y \geq p_1 x_1 + p_2 x_2$$

To progress, we need to think carefully about the structure of the household's production technology. Consider first the situation where x_2 and q are complements, a situation that implies that demand curves for x_2 shift up when q increases. That 'complements story' perfectly describes the recreation example just discussed. In this case, the demand curve approach is to estimate the value of changes in environmental quality by calculating areas between the shifting demand curves for x_2.

For the demand curve method to completely capture the welfare effects of a change in q, it must first be the case that the household does not gain welfare from q through some other pathway. It must also be the case that $x_2$is an essential input in the household production process. In our recreation example, we might assume that the second stipulation holds for transport expenditures: without travel the household cannot enjoy the recreational experience provided by the natural area. Indeed, this is the basis of the *travel cost model* described in the guidance. It should be clear, however, that the travel cost model is just a specific application of a broader method. Indeed, in a recreational setting it is possible that complements other than transport costs may be viable goods to which demand curve techniques can be applied. For example, to enjoy a natural area a household may have to pay for accommodation or hire specialist equipment for recreational activities. If either of those goods are essential in the production of the recreational experience, then calculating areas between shifting demand curves for those goods will also provide a valid measure of the value of the natural area.

The other possibility is that x_2 and q are substitutes, a situation that implies that demand curves for x_2 shift down when q increases. The standard example of this form of relationship concerns the final service of health. For many types of environmental quality, such as those relating to air and water pollution, it is not the pollution itself that concerns consumers but how that pollution impacts on their health. While the level of environmental quality is out of their control, consumers can purchase other goods and services that act as substitutes for environmental quality in the production of health end points. For example, items including air filters, sun screen and bottled water have been posited as marketed substitutes for environmental quality in producing health.

When the market good and environmental good are substitutes a lower bound to the value consumers put on some change in q can be estimated from observations of the changes in expenditure on x_2 following that change. Intuitively, when environmental quality falls, consumers will respond through making defensive expenditures on the substitute market good. The payments they make in that offsetting will never exceed the value to them of returning q to its original level. This is the *defensive expenditures method* but applied to the consumption side of the economy.

Finally consider the case where households make consumption decisions between discrete consumption bundles containing both environmental and marketed goods and services. The example of such a decision presented in the Green Book concerns choices between trips to different recreational sites. Here each discrete bundle offers the enjoyment of visiting a recreational site offering some particular level of environmental quality and the cost of paying for the transport to reach that site. By observing how households choose between a set of options offering different environmental qualities at different costs, analysts can apply the *random utility method* to deduce the trade-off between money and environmental quality. While the random utility method is described in the Green Book as an extension of the travel cost method, its use in valuing recreational sites is only one of many possible applications. The method has also been applied for example to property data. Here rather than applying the hedonic pricing method, analysts deduce the value placed on environmental quality by observing households' discrete choice between properties offering different levels of environmental quality at different costs. Similarly, in many cases defensive expenditures are more discrete than continuous in nature. Take, for example, the installation of double glazing to reduce exposure to noise pollution. The discrete choice of whether or not to install double-glazing is best analysed using the random utility method than it is the defensive expenditures method.

5.9 Non-economic methods of appraisal

As we have seen, cost benefit analysis is based on a coherent theoretical foundation. That foundation implies that a project's merits can be measured in terms of households' WTP and WTA. Indeed, each of the methods of non-market valuation discussed above attempt to measure just those quantities. There are other methods that bare passing resemblance to the economic methods of non-market valuation but do not attempt to measure WTP or WTA. Examples of such methods include the damage cost avoided, replacement cost and substitute cost methods.

The damage cost avoided method attempts to value the protective services offered by the environment; for example, the service a wetland provides in preventing flooding of adjacent property. The value of that service is taken to be the value of the damages avoided because the flooding is prevented. The replacement cost method suggests that the value of an environmental asset and the services it provides can be estimated by calculating the cost of recreating that environmental asset elsewhere. For example, the cost of destroying a woodland might be estimated as the cost of establishing an identical woodland in another location. In a similar vein, the substitute cost method measures the value of an environmental asset by calculating the cost of creating other assets that provide the same flow of services. For example, the cost of damaging a natural fish habitat and nursery might be estimated by measuring the cost of a fish breeding and stocking program.

Observe that each of these methods uses a cost to proxy the correct measures of value based on WTP or WTA. Unfortunately, costs and values may have little in common. For example, with the substitute cost method, one might reasonably argue that WTP for an environmental good and service could never be more than how much it would cost to provide those services in some other manner. On the other hand, it is always possible that the value derived from those services is significantly less than the cost of creating a substitute. Accordingly, while the Green Book directs practitioners to these methods (Annex 2, para 10) we advise that they should be used with caution and an understanding that they may provide bounds to value but not estimates of value itself.

Another method discussed in the Green Book which has only the most tenuous connection with the theoretical basis of cost benefit analysis is that of multi-criteria analysis. Multi-criteria analysis refers to a variety of related methods that attempt to choose between a set of pre-defined policy options without recourse to valuation. A typical multi-criteria analysis might start by identifying the key dimensions of impact of that set of policies. Subsequently a score, perhaps on a scale between 0 and 100, is assigned to the level of impact of each policy for each dimension. Often the scores are arrived at through discussions held with small groups of invited individuals representing a variety of stakeholder groups. Finally, that same small group of stakeholders decides upon a weight to assign to each dimension of impact. Higher weights indicate that greater importance is attached to impacts on that dimension in choosing between options. With that information, the scores for each policy option can be reweighted and summed and the option with the highest score is the one that has been endorsed through the multi-criteria analysis method of project appraisal.

Proponents of multi-criteria analysis argue that the method allows project appraisal to be carried out without the need to evaluate all impacts in units of money. Ostensibly that claim is correct. However, if one of the dimensions along which projects are judged is a money cost (and it is hard to imagine any project that will not require some element of monetary expense) then the scores and weights are implicitly identifying the monetary values that participants in the exercise place on the non-monetary dimensions. In essence, behind the smoke and mirrors, participants in a multi-criteria analysis are being asked to express money values for environmental goods.

We have other major concerns with multi-criteria analysis. First, unlike cost benefit analysis, it is not based on coherent theoretical foundations. When a project is chosen through cost benefit analysis an analyst knows that that project is delivering an efficiency improvement in the economy. It is not at all clear what distinguishes a project chosen through multi-criteria analysis, except that it was considered the best of the options by those involved in the exercise. Second, the calculations in a cost benefit analysis result from the application of a series of well-documented procedures developed over many years of academic and applied research. In principle, therefore, a cost benefit analysis could be replicated by a separate team of analysts and should arrive at the same conclusion. More importantly, there is a transparency to cost benefit analysis that allows anyone to review the calculations and challenge valuations that they deem to be incorrect. Multi-criteria analysis, on the other hand, is not a replicable analytical tool. If the scoring and weighting exercise were carried out by a different set of stakeholders they could well arrive at a completely different conclusion. Moreover, that conclusion, like the conclusion of the original exercise, cannot be challenged: it is simply an expression of the opinions of the individuals involved in the exercise. That observation leads on to our third criticism of multi-criteria analysis, namely its dependence on the opinions of a small number of selected stakeholders. In stark contrast, cost benefit analysis seeks to evaluate a project by assessing the WTP and WTA of each and every individual in society impacted by that project.

Chapter 5 of the Green Book proposes multi-criteria analysis as method that might be employed to deal with costs and benefits that cannot be easily valued but warns of “pitfalls” with the method. What is not made clear is how the outcome of a multi-criteria analysis applied to unvalued costs and benefits would subsequently be integrated with the cost benefit analysis of the other project impacts. The two methods are not compatible either in a theoretical sense or in the practical sense of being able to meaningfully compare their outputs. It is our opinion that multi-criteria analysis has little merit as a tool for project evaluation (for more discussion see Dobes and Bennett, 2009).

Finally, the Green Book raises the possibility of valuing such goods through their impact on life satisfaction or subjective wellbeing although hastens to explain that these studies have not yet reached the point where they are acceptable for use in cost benefit analysis. Our sense is that little has changed regarding the acceptability of these techniques.

5.10 Recommended changes to guidance

- From the outset, guidance should provide a clear statement of the normative foundations of cost benefit analysis.
- Retire the concept of TEV and replace with a new framework based on thorough economic fundamentals constructed for the particular purpose of directing the analyst to the most appropriate method to apply in valuing changes in the provision of an environmental good or service.
- Extend and revise descriptions of environmental valuation methods to include full range of available techniques on both consumption and production side of the economy.
- While non-economic methods might be reviewed, guidance should make clear that these methods do not provide outputs that are theoretically consistent with cost benefit analysis. They are substitute methods for project appraisal rather than complements to cost benefit analysis.

6 Future Values of Environmental Goods and Services

It is not unusual to encounter an environmental project in which the environmental impacts occur in future time periods. There are two theoretically consistent methods of dealing with such impacts. This section commences by describing the first method and then contrasting it with what may be termed the default method of dealing with future environmental impacts. The second method is dealt with later. It may be noted that there is no explicit discussion of either method in the Green Book.

The first way of dealing with future environmental impacts is to convert the future monetary value of these impacts into their present value counterparts using the consumption discount rate. Quite obviously however the future value of environmental goods and services cannot be directly measured and must instead be inferred from contemporaneous or historical studies.

Future values for environmental goods and services depend upon the future supply and demand for environmental goods and services. One method of obtaining future monetary values is therefore to observe the current value of environmental goods and services in areas in which the supply and demand conditions resemble the conditions that are expected to prevail in the future. Alternatively future values might be taken from some modelling exercise which explicitly models the evolution over time of drivers of changes in the supply and demand for environmental goods and services.

Often however such information is unavailable in which case values from existing studies are using a variety of techniques somehow projected into the future. One way of projecting values into the future might be to combine information on expected changes in per capita GDP with information on the income elasticity of WTP.[32] Such a procedure of course ignores changes in the supply of environmental goods and services. Sometimes the adjustments are even cruder for example scaling according to per capita GDP. The default method however is to use the consumption discount rate to discount current values for changes in the quantity of the environmental good or service. The implicit assumption here is that currently observed values for environmental goods and services will remain constant over time.

It is clear that the default method has serious limitations. More specifically it assumes that either there are no changes in supply and demand conditions for the environmental good or service or that if there are any changes cancel each other out. These assumptions seem hard to accept since it is often suggested that the supply of environmental goods and services is diminishing. Furthermore there is considerable evidence that the demand for environmental goods and services indeed responds to increases in income. If both of these changes occur – growth in incomes coupled with a reduction in supply – it is likely grievously to underestimate the present value of future changes in the quantity of environmental goods and services boosting the prospects of projects incurring future environmental damage and diminishing the prospects of projects offering future environmental benefits.

[32] The value of statistical life used in projects related to transport infrastructure is annually uprated in line with economic growth.

6.1 Ecological discount rates

The first approach outlined above involves discounting future environmental impacts using the consumption discount rate. The second approach attributable to Malinvaud (1953) consists of converting future environmental impacts into an equivalent environmental impact occurring in the present using a special ecological discount rate. These present environmental impacts are then valued. In the first approach the difficulty consists of determining the appropriate future value whereas in the second approach the difficulty consists of determining the appropriate ecological discount rate. Obviously the ecological discount rate is likely to be different from the consumption discount rate. But whilst these approaches might appear different they are in fact equivalent; they result in the same values and possess the same informational requirements albeit differently expressed.

The derivation of the ecological discount rate (r) involves calculating the marginal rate of substitution between a unit change in the quantity of the environmental good or service (e) between adjacent time periods. Then the rate of change of the marginal rate of substitution is calculated by taking the derivative with respect to time (see e.g. Gollier, 2013). The same procedure can be followed in order to determine the appropriate discount rate for consumption (c):

$$r_e = \rho + \eta_{ee} g_e + \eta_{ec} g_c$$

$$r_c = \rho + \eta_{cc} g_c + \eta_{ce} g_e$$

Focussing on the first equation the ecological discount rate comprises three different terms. The first term (ρ) is the rate of pure time preference. The second term is the elasticity of marginal utility (η) of the environmental good with respect to the quantity of the environmental good multiplied by the percentage change in the quantity (g) of the environmental good. The third term is the elasticity of marginal utility of the environmental good with respect to the consumption good multiplied by the percentage growth in the consumption good.

Some contributors to the literature refer to an ecological growth effect and a relative price effect to explain the difference between the discount rate used for discounting consumption and the discount rate used for discounting environmental goods and services.

Note how the formulae resemble the Ramsey formula for the calculation of the Social Discount Rate. Note also that not only is there a special discount rate for discounting environmental impacts there is also a special discount rate for discounting consumption. The discount rate for consumption is affected by amongst other things the growth in the quantity of the environmental good. Depending on how important the environment is this poses a challenge to the continued use of the discount rate calculated using the Ramsey formula and therefore has implications for the appraisal of non environmental projects.

There are two important complications. First many of the parameter values contained in the formulae are unknown. Second whereas the simple theoretical development focuses on two goods if the model were extended to include a multiplicity of environmental goods each would have its own special ecological discount rate.

These complications should not be interpreted as meaning that this second approach to discounting future environmental impacts is impractical since as discussed the informational requirements of the two approaches are identical. Instead these complications serve notice as to the importance of research aiming to identify the values of these currently unknown parameters (see e.g. Hoel and Sterner, 2007). It is not for example obvious why they could not be valued using techniques similar to those already employed for the purposes of estimating the elasticity of marginal utility with respect to consumption. Furthermore evidence about the value of these parameters might be contained in the observed relationship between WTP and WTA and the income elasticity of WTP and WTA in contingent valuation studies.

Despite the fact that many parameters of the formulae are currently unknown researchers have nevertheless used what they regard as plausible values in order to calculate the ecological discount rate. These illustrative calculations seem to imply that ecological discount rates are very different from the discount rates that are normally employed and hence that a proper treatment of these issues could make a substantial difference to the outcome of cost benefit analyses of environmental projects. This work also makes it clear how far adrift of the appropriate treatment might be the default of assuming that the current WTP for a marginal change in the quantity of some environmental good can simply be projected into the future and then discounted using the standard discount rate implied by the Ramsey formula.

6.2 Uncertainty

So far two different approaches have been proposed for determining the appropriate way of tackling projects whose environmental impacts extend into future time periods.

The first method involves knowing the future values of environmental goods and services and applying the standard discount rate for consumption goods. The second method involves applying an ecological discount factor to current values for environmental goods and services. Both of these techniques however assume perfect certainty.

It is known that extending the Ramsey formula to accommodate uncertainty in growth rates generates additional terms.[33] The same is true in the model of the ecological discount rate where there is uncertainty not only about the growth rate of consumption but also about the growth rate of the environmental good or service. Making the appropriate modifications in order to account for uncertainty yields the certain number of current units of the environmental good or service equivalent to a unit change in the future environmental good or service whose future quantity is uncertain – circumstances which are probably the norm.

Because computing the ecological discount rate under certainty already requires making assumptions about what are the appropriate values for unknown parameters it might be thought that seeking to make further adjustments because of uncertainty is at this stage somewhat premature. At the same time however it is interesting to reflect on whether the current adjustments to consumption discounting that arise from uncertainty and which are the focus of much attention

[33] In the case of the Ramsey formula this is referred to as the prudence effect which serves to reduce the social discount rate. In some instances the appropriate discount rate can decline over time.

are quantitatively less significant than the potential changes arising from adopting ecological discount rates.

6.3 Recommended changes to guidance

- Guidance must deal explicitly with the evaluation of projects whose environmental costs and benefits extend into future time periods
- Guidance should describe the two theoretically correct approaches to discounting future environmental costs and benefits and contrast these with the default approach of applying the consumption discount rate to the current value of changes in the quantity of environmental goods and services
- Guidance should anticipate empirical developments which might facilitate the proper treatment of these issues
- Lastly guidance should form a view regarding under what circumstances the additional effort involved in computing the appropriate ecological discount rate for particular environmental impacts is likely to be justifiable

7 Sustainability

As discussed in the Section 5, the fundamental justification for the application of cost benefit analysis for the purposes of policy appraisal is that it allows policy makers to assess whether a project delivers gains in economic efficiency. In particular, the cost benefit assessment rule is based on evaluating measures of WTP and WTA. If the project sum of WTP amounts is in excess of the sum of WTA amounts then the project delivers a surplus. Accordingly, following the project's implementation, money could be transferred from gainers to losers in such a way that no one is worse off than they were in the status quo and at least one person is better off.

In addition to efficiency, decision makers may be interested in other goals including that of sustainability. While the term sustainability implies many different things to different people, here we adopt the specific definition used by economists: a sustainable pathway is one in which the economy has the capacity to indefinitely deliver non-declining levels of well-being per capita (Pearce et al., 1994). Notice that the economics definition is couched in terms of productive capability; that is to say, sustainability depends on the maintenance of the capital stocks that underpin the production of the goods and services from which humans derive well-being. Of course, the notion of 'capital' and 'goods and services' is much broader than as conceived in the everyday usage of those terms; for example, it includes natural capital and the environmental goods and services produced by that natural capital. Accordingly, sustainability amounts to each generation leaving the next generation a stock of productive capacity, in the form of capital assets, that is capable of sustaining well-being per capita at a level no lower than that enjoyed by the current generation.

7.1 Achieving sustainability

The economic definition leads to the simple conclusion that sustainability can be achieved by maintaining a constant capital stock. Indeed, that principle underpins the Hartwick-Solow rule for sustainability (Hartwick 1977; Solow 1986). In brief, the rule is that economic activity that draws down the stock of capital must be compensated for by investments in capital which provide the same productive value as the stock that has been lost.

Implicit in this rule is the assumption that different forms of capital stock are substitutable; for example, it assumes that if the stock of natural capital is drawn down then that loss can be compensated for by investments in man-made capital. The idea that sustainability can be achieved while substituting between different forms of capital is known as *weak sustainability*. In contrast, some commentators take the position that some stocks, particularly natural capital stocks, are critical and that their functions cannot be replaced (for example, the protective services derived from the ozone layer). Those commentators take the *strong sustainability* position that certain stocks of capital should not be allowed to decline over time.

One of the key misapprehensions of the strong sustainability argument is that weak sustainability assumes that the substitution from natural capital to man-made capital is easy and cheap. That is most certainly not the case. Indeed, weak sustainability rests on the principle that the compensating investment in capital must provide the same *productive value* as the stock that has been lost. Accordingly, if losses in natural capital stock (again, think about the ozone layer) result in very large value losses, then weak sustainability would require an extremely large compensating investment.

With those arguments in mind let us return to our core issue; guidance for the appraisal of projects. The first key insight with regards to addressing issues of sustainability is that appraisal must clearly recognise when a project is impacting on capital stocks and ensure that any changes in stocks are correctly valued. As we discussed in Section 4, the valuation of changes in stocks of natural capital must account for several elements that together indicate the net present value to society of that change. Most importantly, that calculation must take account of the values of non-market goods and services and include the value changes induced over all future time periods. At least in that way, the true cost of degrading natural capital stocks will be reflected in cost benefit analysis turning the calculus against projects that draw down critical stocks.

7.2 Cost benefit analysis and potential sustainability

Of course, correctly valuing natural capital stocks in project appraisal using cost benefit analysis does not guarantee that decisions deliver sustainability. There is no stipulation in the application of cost benefit analysis that compensating investments in capital are made by projects that degrade natural capital. On the other hand, one can make an argument that cost benefit analysis delivers *potential* sustainability. That argument is simply the logical extension of the argument used to justify cost benefit analysis as delivering *potential* efficiency.

In a very simple project, one can imagine the impacts confined to just one period. Within that one period some gain from the project and some lose. Cost benefit analysis identifies whether that project is potentially efficient by ensuring that the project delivers a surplus of WTP over WTA, such that gainers could compensate losers. Whether that compensation actually takes place is considered a separate issue that should be decided through a separate decision-making process.

Now imagine a project whose costs and benefits are spread out over multiple time periods, potentially multiple generations. In that case, the decision rule of cost benefit analysis amounts to discounting those flows of costs and benefits and ensuring that the net present value of the stream of WTP amounts exceeds the net present value of the stream of WTA amounts. A completely equivalent way of conceptualising that decision rule would be to think of collecting, in the current period, the net present value of the WTP of all those that gain from the project and investing that money in some form of productive capital. For our purposes it is easiest to think of that investment going into a bank account that pays interest at the social discount rate.[34] The cost benefit decision rule simply indicates that it then must be the case that by reinvesting the interest from that capital investment we can accumulate over time an asset whose value more than compensates the WTAs of those that stand to lose from the project. So for example, if the project degrades natural capital the cost benefit rule indicates that the project must deliver sufficient surplus to enable a compensating investment in alternative capital that could return at least the same value flow as the lost natural capital. Again, the rule only ensures *potential* sustainability, whether the compensating investment is actually made is a separate issue.

Our position with regards to the issue of sustainability is that guidance should ensure that all impacts on natural capital are identified and that those impacts are, where possible, correctly

[34] In which case, it would be the bank's investors who made the decision as to which capital projects that money should go on to fund.

valued. Those valuations should form part of a sustainability analysis which evaluates a project's net impact on capital stocks, enumerating impacts over different forms of stock and over different periods of time. As with standard distributional analysis in cost benefit analysis (see Section 11) that information will allow decision makers to better understand the sustainability implications of a project and consider the case for the actual provision of compensating investments.

7.3 Declining discount rates

One concern with the arguments laid out above is that cost benefit analysis might provide reasonable advice for relatively minor projects over the short-term but struggles when considering potentially non-marginal damages over long time periods or projects that engender the possibility of catastrophic risk (Hepburn and Gosnell, 2014). For example, very major issues such as global climate change policy are likely to have such fundamental impacts on the working of the economy that they may shift underlying growth rates and, by doing so, shift the discount rate. In other words, cost benefit analysis may provide erroneous policy advice if an exogenous discount rate is assumed when that discount rate actually changes as a result of the project. Generally, these considerations lead to the proposal that for very long-lived projects the discount rate should be significantly lower or decline over time. This is a recommendation already incorporated into the Green Book.

7.4 Recommended changes to guidance

- Guidance should provide clear direction to practitioners as to how to undertake an analysis of the economic sustainability of a project that enumerates and correctly values the project's impacts on capital stocks.

- That sustainability analysis should detail how the projects impacts on capital stocks are distributed over different forms of stock and over different periods of time.

8 Introducing space

For environmental projects, location matters. The point in space at which a project is implemented will have significant implications for that project's environmental costs and benefits. As we shall discuss in this section, location matters as a consequence of at least two factors: the spatial heterogeneity of the environment and the spatial interconnectedness of the environment. In short, the natural world not only varies over space but is also intricately connected through space. As a consequence where we implement a project has implications for both its immediate environmental impacts but also ramifications for the supply of environmental goods and services elsewhere.

The question of space is touched on at a number of locations in the Green Book. The Green Book notes that sophisticated environmental models may be required to understand a project's air quality and water impacts over space (pages 16 and 17, respectively). In addition, the Green Book notes that the value of a recreational amenity depends in part on its proximity to population and the spatial distribution of complement or substitute sites (page 66). Space and location are not mentioned at all in the supplementary guidance on non-market valuation.

In the following, we review issues relating to space and location in cost benefit analysis. From that discussion we extract a series of recommendations that represent a general treatment of the issue of space in project appraisal. Those recommendations might form the basis of a section of the Green Book dedicated to directing analysts on how to approach the issue.

8.1 Spatial heterogeneity

Let us consider first, the question of spatial heterogeneity. Here we are in fact dealing with two issues. First, the issue of *variation in supply* across space: that is to say, variation in the quantity and quality of environmental goods and services at different locations. Second, the issue of *variation in value* across space: that is to say, differences in the value attributed to the same particular change in the supply of an environmental good or service at two different locations.

With regards to spatial variation in supply and value there are reasons to suppose that conditions are very different for environmental as compared to man-made goods and services. Consider first, goods that are not spatially fungible; that is to say, goods that cannot be readily transported between locations. For man-made goods, an example might be homes. Of course, homes are market goods such that under-supply in one area will manifest itself as relatively higher local prices. At the same time, homes are the product of economic production processes driven, at least in part, by market forces. Importantly, those market forces incentivise developers to concentrate their construction efforts in under-supplied areas where prices are high. Perhaps homes are not the ideal example because property development is heavily regulated, but the basic intuition remains; market forces will tend to spatially smooth supply, ironing out spatial differences in value. For man-made goods that are traded in markets and are readily transported across space, similar outcomes arise. In this case, simple spatial arbitrage will tend to ensure that their prices remain similar across space.

In contrast, environmental goods and services are delivered by natural forces not market forces. And, unlike market forces, nature has no intrinsic tendency to smooth their provision across space. Moreover, many (if not most) environmental goods and services are not spatially fungible: for example, a river, a population of birds or clean air cannot be transported to another location. Accordingly, even if such goods were excludable so that economic agents might benefit from the exercise, it would not be possible for those agents to redistribute them spatially in order to exploit arbitrage opportunities.[35] As a result, we live in a world where a spatially heterogeneous natural environment delivers markedly different flows of environmental goods and services at each location in space.

8.1.1 Spatial heterogeneity in supply

A consequence of this spatial heterogeneity is that cost benefit analysis must pay explicit attention to the environmental qualities of the location in which a project is implemented. The most trivial realisation of that imperative is in the appraisal of options for the siting of projects that require an environmental service flow as a major input. For example, a wind farm is best located where there is plentiful wind, a factory that requires water cooling near to a ready supply of water and a multi-purpose woodland is best planted in a location endowed with soils suitable for the growth of trees. Correspondingly, project-siting decisions must have mind to spatial heterogeneity in the potential environmental damages that might arise at the project location. For example, in one location a wind farm might displace a breeding bird colony in another it would not. Likewise, a factory built in one location might destroy a rare habitat and in another it would not.

Over recent years, it has been increasingly common for analysts to harness the power of geographical information systems (GIS) to aid in project-siting decisions (Bateman et al., 2002a). In one such form of analysis, electronic maps plotting out the spatial distribution of environmental qualities necessary for the project are overlaid so as to identify locations providing the desired confluence of environmental features (see Bailey, 1988, for a critique). For example, in deciding where to locate a wind farm, analysts might overlay maps of wind intensity with those of undeveloped and unwooded land. Potential locations can be narrowed further by overlaying maps defining locations where the environmental costs of the project are deemed too great. For example, locations with breeding bird colonies or rare habitat might be excluded from the set of possible sites in which to locate a wind farm.

8.1.2 Spatial heterogeneity in value

Analyses that simply overlay maps of environmental features focus solely on the supply element of the spatial heterogeneity issue, but ignore the value element. Clearly for the purposes of appraising an environmental project it is the latter that counts. Accordingly, while analyses based on spatial supply may be useful in narrowing down potential locations for project implementation, the appraisal process must still ascertain which, if any, of those potential locations passes a cost benefit test.

As we have already argued, there is no reason to suspect that the value of environmental goods and services will be the same across locations. For a start, different locations may be endowed with

[35] Indeed, even where such transportation is possible, for example in piping water from one region to another, it would involve an economic production process organised by humans and requiring inputs of man-made goods and capital. Accordingly, by our definition, the water supplied from such a process would be an economic and not an environmental good.

different levels of supply of that good. If the marginal value of the good is decreasing (or potentially increasing) in quantity then it follows that the value of a particular change in supply will be different across locations with different endowments. For example, a project that delivers a particular absolute increase in water quality may deliver different value when implemented in a lake where water quality is low than in a lake where water quality is already high.

For some environmental goods and services, the value they generate depends crucially on the proximity of the individuals that enjoy those values. A good example is the provision of natural areas for the purposes of recreation. Clearly, the closer such a resource is to where people live, the lower the money and time costs those people incur in visiting the site and the higher the value they enjoy from that recreational experience. The decline of value offered by an environmental good with increasing separation is often described as *distance decay*. Recent evidence suggests that as well as values derived from visitation, non-use values may also exhibit significant distance decay(Day et al.,, 2014).

Of course, spatial heterogeneity also ensures that the distribution of substitutes and complements varies across space. Consider the example of a project seeking to establish a new recreational woodland. Locating that woodland in a region well supplied with other such natural areas may generate little by the way of additional value. In contrast, locating that woodland in a region with few direct substitutes will generate much greater value. Greater value still might be realised if the woodland were established adjacent to a lake already managed as a recreational area. A visit that provided individuals with the chance to enjoy both the lake and the woodland might generate significantly more value than a visit to either on their own.

Again accounting for spatial variation in value in implementing cost benefit analysis has been greatly enhanced through the use of GIS. That software enables analysts to calculate the value of an environmental good or service delivered at a particular location accounting for distance decay and complex patterns of population and substitute/complement distribution. Indeed, such exercises have been taken a step further whereby such calculations are done at every location in space so as to create valuation surfaces. Such surfaces can be developed for all the costs and benefits of a project and the GIS used to aggregate across those different layers so as to identify locations offering the best benefit-cost ratio (Bateman et al., 2002b).

A complication arises when the project is looking to make a set of similar interventions at a number of different locations: for example, to establish several separate woodland recreation areas. Substitution (or, in another case, perhaps complementarity) possibilities between sites mean that those location decisions cannot be made independently; the value surface for one new woodland depends on the decisions that are made concerning where to locate the other new woodlands. Various relatively sophisticated techniques exist for solving such combinatorial choice problems so as to identify the particular set of locations in which to plant the new woodlands so as to maximise the value of those investments (Bateman et al., 2014).

The key insight from the discussion so far is that spatial heterogeneity means that the environmental costs and benefits of a project will differ from location to location. Accordingly, careful spatial targeting of investments, probably aided by a GIS, may be a crucial element of the appraisal process. Spatial targeting may entail relatively simple analyses such as overlaying maps describing the supply of environmental goods and services so as to identify locations that provide a desired combination of such goods. More sophisticated analyses replace supply maps with value surfaces and seek to identify the location or locations at which the project would provide the best cost benefit return.

8.2 Spatial interconnectedness

In addition to spatial heterogeneity, the other key spatial issue relating to the appraisal of environmental projects concerns the spatial interconnectedness of environmental systems. What is made abundantly clear by the research of natural scientists is that environmental systems are intrinsically interconnected through pathways provided by, amongst others, the atmosphere, water or biotic dispersal. When we intervene in the environment in one location we must be aware of the consequences that might arise elsewhere.

Three examples serve to illustrate. First, consider projects that generate some form of air pollution. That pollution is dispersed through the atmosphere in ways which are determined by local weather patterns. Appraisal of such a project will require the careful modelling of pollution dispersal in order to understand the costs of the damages caused by that pollution. Second, a similar problem is presented by projects generating water pollution. Here systems may be connected through surface river courses or through infiltration into ground water. In the latter case the dispersal of the pollutant may be a very slow process such that the environmental system not only separates the source of the pollutant from the location in which damage is endured spatially but also over time. Finally, consider a project that establishes a new natural area; say the creation of a new area of salt marsh. The benefits of that natural area will be determined not only by the environmental improvements envisaged at that location but also by the degree to which that new area complements the environmental resources in its surrounding landscape. The greatest benefit from such a project may, therefore, be achieved by locating that new salt marsh adjacent to a previously established protected area. Alternatively, it might be best to locate that new natural area in such a way that it improves connectivity in the natural landscape allowing birds and animals to move easily between areas.

In all three cases, the impact of the project is to change the productivity of the environment elsewhere reducing or increasing the flow of environmental goods and services enjoyed at those other locations. Where such issues are likely to be a major consideration, project appraisal may require the input of natural scientists whose models of environmental processes might be necessary to illuminate the nature of environmental interconnectivity (Wainwright and Mulligan, 2013).

8.3 Spatial dynamics

The final complexity raised by interconnectivity concerns the dynamics of human and environmental systems. To illustrate, imagine a project to establish a no-take marine reserve in part of a fishery. Within the reserve fish may enjoy greater reproductive success with more young fish surviving to adulthood. Of course, the reserve is connected to the wider fishery such that through migration it might be hoped that fish populations may increase across the fishery and the increase in catch resulting from this process would be considered one of the benefits of the reserve. The complexity here is that fishermen are not oblivious to these changes. Indeed, in response, fishermen may change the intensity and spatial pattern of their fishing activities, which in turn will impact on the pattern of fish stocks across the fishery. Accordingly the outcome of the reserve depends on a complex set of dynamic environment-economy interactions that play out over time and space. When the outcomes of those processes are a central component of the projects impacts, it may be necessary to develop spatial bio-economic models to compare and appraise different configurations of the project, for example, in determining the size and location of the marine reserve (Conrad and Smith, 2012).

A second comparable example, concerns projects that have a localised impact on environmental quality. As we shall discuss in detail in Section 8, another way in which such projects may have a spatial impact is through the property market. Changing the quality of one particular location, for example by building an incinerator plant, will alter demand for properties in that area sending out a ripple of adjustments through the property market that will ultimately change the spatial distribution of prices and the locations in which households choose to live.

8.4 Recommended changes to guidance

- Analysts should be advised that spatial heterogeneity in the natural environment means that the choice of location may be a crucial decision in ensuring the best returns from an environmental project.
- Location decisions may be aided by analyses that identify locations providing some desired combination of environmental goods and services by overlaying maps that describe their different spatial distributions. Geographical information systems (GIS) provide a powerful tool for performing such analyses.
- More sophisticated analyses replace supply maps with value surfaces and seek to identify the location or locations at which the project would provide the best cost benefit return.
- Value surfaces reflect the value that humans derive from the environmental goods and services of a project. Accordingly, patterns of value are driven by the distribution of people across space and must reflect distance decay, and the spatial distribution of substitutes and complements.
- Appraisal must consider not only the environmental impacts at the project site but also its impacts at other locations that arise through the interconnectedness of environmental systems. Where those impacts are considered significant it may be necessary to develop a better understanding of the project’s consequences through the development of environmental models (for example, of the hydrological and atmospheric dispersal of pollutants arising from the project).
- Where the environmental impacts of a project may precipitate significant behavioural change, a project’s impacts might be further understood through the development of spatial bioeconomic models or of equilibrium sorting models.

9 Uncertainty irreversibility and the value of information

This section deals with the impact of uncertainty on the cost benefit analysis of environmental projects. It also examines the problem of irreversible decisions and the concept of the value of information. The prime issue nevertheless is that of uncertainty; without uncertainty there would be no reason to hesitate before making an irreversible decision and the value of information would not be an issue.

Although uncertainty is an omnipresent feature of many sorts of projects uncertainty is a particular issue for projects with environmental impacts. Natural variation is present in the environment and due to the lack of scientific understanding not all of the impacts can be foreseen. Uncertainty also arises because of difficulties in establishing the value of nonmarket goods and services from a finite sample of respondents.

The existence of uncertainty results in to two key issues for guidance. First, the outcomes of projects are rarely known with certainty; for example, many projects are intended to reduce the damage associated with uncertain events over which humans have no control e.g. extreme weather events and disease outbreaks. For the purposes of project appraisal it is desirable that the benefits of such projects are properly valued and reflect individuals' attitudes to the changed risks that a project imposes on them.

Second, even leaving aside the issue of attitude to risk many environmental projects are moreover irreversible: once a natural area has been developed it cannot be undeveloped. If the costs or benefits of that irreversible project are not known with certainty what value should be ex ante attached to information capable of reducing the uncertainty surrounding the actual outturn of particular projects (this is sometimes referred to as the quasi-option value)? For completeness we could also address the situation of uncertainty regarding future preferences.

Although core guidance identifies all of these issues the discussion therein is somewhat uneven and not necessarily focussed on the task of appraising environmental projects.

Before getting underway note that the sort of uncertainty we are addressing refers to a situation where probabilities can be attached to particular outcomes rather than uncertainty proper. There is no satisfactory basis for decision making when not even the probabilities are known although certain strategies covering such situations are dealt with in core guidance. For example, one such strategy is to adopt the precautionary principle i.e. one which avoids altogether the possibility of a bad outcome. We have nothing further to add on dealing with such situations. Nor do we have anything to say on the subject of applying cost benefit analysis when there is the probability of catastrophe. In what follows we look at option values, the value of information and irreversible decisions.

9.1 Option values

Issues pertaining to the valuation of projects under uncertainty are contained in Annex 4 of core guidance. There it is argued that uncertainty in outcomes generally cancels out particularly where these risks are uncorrelated with each other and uncorrelated with the performance of the economy.[36] It nevertheless acknowledges that there are instances in which it is appropriate to place a premium on projects which offer low risk and worth paying for a reduction in the variability of outcomes. These include instances such as flooding in which the risks are very large in relation to the incomes of the individuals who would bear the risk and cannot be diversified across the whole economy.

Also included in guidance is the suggestion to conduct a Monte Carlo analysis in which the analysis is repeated many times drawing random values for the uncertain parameters from distributions which may be independent or correlated. This results in a distribution of outcomes for the project.

Although many projects e.g. flood relief schemes have the explicit goal of reducing the damage associated with uncertain events current guidance leaves unanswered the question precisely how to value the benefits of such projects ex ante. One established approach is to measure such benefits using option values. However, supplementary guidance fails to provide a proper definition of option values. Indeed it argues incorrectly that they are a component of Total Economic Value. Overall guidance requires a more detailed explanation of how and under what circumstances some adjustment for risk is warranted in environmental projects like those hoping to reduce the damage associated with uncertain events.

To understand the issues surrounding the valuation of the benefits of such projects it is helpful to consider a simple example. Assume that there is a project capable of eliminating the threat of damage from an uncertain event and the issue is whether the implementation of the project offers a potential Pareto improvement. There are two possible states of the world: one in which there is a probability p of damage D occurring and one in which there is probability 1-p of no damage occurring. The decision whether to implement the project has to be taken in advance of knowing the true state of the world. The obvious measure of the benefits of the project is expected damage $p \times D$. But although this might be the preferred measure of benefits it is neither the only measure nor necessarily the correct one.

We are now ready to provide a definition of option values. Option price is defined to be the maximum state-independent amount that the household would be willing to pay to remove entirely the threat of the damage. Because of risk aversion, option price will exceed expected damage. Option values are defined by the difference between the option price and expected damage. Option price provides a second estimate of the benefits of the project. In fact the choice is not merely between the expected damage and the option price. The third candidate measure of benefits is what is referred to as the fair bet point.

To understand what the fair bet point represents note first that that there is in fact an infinite combination of state dependent payments between which the household is indifferent in the sense that they all generate the same level of expected utility as in the absence of the project. Together these result in what is known as the maximum willingness to pay locus. The option price is merely that point on the maximum willingness to pay locus where the same payment is made across all different states of the world. The expected damage is also another point on the maximum

[36] This is the Arrow-Lind theorem which states that the risk premium for most publicly-funded projects should be zero (Arrow and Lind, 1970).

willingness to pay locus specifically where the household pays an amount equal to the damage in the event the threat materialises (Graham, 1981).

Although any point on the maximum willingness to pay locus generates the same level of utility as in the absence of the project different state dependent payments may result in different levels of potential revenue. In particular the definition of the fair bet point is that it is the point at which the expected revenue raised is maximised. This amount can be compared to the cost of the project. More specifically the fair bet point allows the individual household to make a higher payment in the state of the world in which the adverse effect does not occur and in which case the household would otherwise be much better off.

Which of these three different concepts provides the appropriate measure of the benefits of the project? This is an important question since there is evidence from simulation experiments that these can (but do not always) result in very different measures.

With well-functioning insurance markets the appropriate measure of benefits is expected damage. The reason for this is that the household can use insurance to spread the expected damage across different states of the world such that ex post the marginal utility of income is the same in either state of the world. More specifically with insurance the household pays a premium equal to the expected damage in all states of the world and receives an amount equal to the value of the damage if the threat materialises. The expected damage is less than either the option price or the fair bet measure.

The expected damage measure however is appropriate only for insurable risks and for this certain conditions have to be met. These include that the damage done should have a readily observed market value. It should also be possible to observe at low cost whether or not the damage has actually occurred. There should be no scope for moral hazard.

If it is not possible to purchase actuarially fair insurance then the appropriate measure of benefits is either the option price or the fair bet point. Which of these is most appropriate depends on the feasibility of state contingent payments. If the Government can raise revenue conditioning its charges on the state of the world then the fair bet point represents the appropriate measure of benefits. If on the other hand the Government cannot condition its charges on the state of the world then the appropriate measure of benefits is the option price.

What this simple example demonstrates is that it matters whether or not actuarially fair insurance is available and how the Government proposes to finance the project. Given the difficulty of providing examples of this happening, it appears most likely that the Government will not be able to condition its payments on the state of the world although according to some perspectives it matters only that there is the potential for payment not that the payment is actually made.

With an estimate of expected damage in hand calculating the option price is conceptually straightforward but unless one is to use the approximation contained in core guidance it requires an estimate of the elasticity of marginal utility. Evidence suggests that this is especially important when the expected damage could be a significant proportion of household income and when households are more risk averse.

9.2 The value of information

Current guidance recommends that analysts appraising projects with uncertain outcomes consider whether additional information might be useful. For example, the decision as to whether to proceed with a large-scale flood mitigation project would benefit from information that clarified the damages resulting from possible flooding events and/or information clarifying the probability of such events occurring. The expected value of a project might be increased by paying for information about the true state of the world before the decision is taken whether or not to proceed with the project. The question therefore arises: what is the maximum one would pay for information before knowing what it says. Alternatively put, what is the value of information? Guidance however does not explicitly discuss the value of information concept.

The formal definition of the value of information is the expected value of a project if the true state of the world is known before the project has to be implemented minus the expected value of a policy if it has to be implemented prior to the true state of the world being known (see e.g. Manne and Richels, 1992). In the literature the value of information is sometimes referred to as the quasi option value although note that it is very different from the option values described in the preceding section. Another way of understanding why information has a value is to note that because the policy maker does not know the true state of the world they are constrained to select a single policy robust across all possible states of the world. For example the value of damage from climate change may be high or low. But because the true state of the world is unknown policy must choose an abatement strategy which is robust across both states of the world but ideal for neither. The value of information represents the cost of this constraint. If by contrast the policy maker knew the true state of the world they would obviously adopt a more tailored response. Notice that unlike option values, the value of information is not dependent upon risk aversion.

There are likely to be numerous instances where calculating the value of information would help decide whether a project should proceed on the basis of current evidence or whether it would be worthwhile obtaining improved information. The outcome may be that improved information has no value in that it could make no difference to the desirability of implementing the project. The value of information might also be less than the cost of obtaining the information.

Up to now the value of information concept has been presented as an extreme case: one in which all uncertainty can be eliminated. With most research however there is an omnipresent risk of inaccuracy. For example scientists might declare the value of an uncertain parameter to be high when it is actually low. But even in this situation it is possible to calculate the expected value of information although the fact that such "information" is little better than a guess greatly diminishes its value.

Although the value of information concept is straightforward, the idea that information has a value and that this value can be determined even before it is known what that information says to some seems hard to believe. It is difficult to discover cases where those involved in appraisal have embarked on an attempt to infer the value of information. We suspect it would be useful to include in guidance an illustration of how to calculate the value of information.

9.3 Irreversible decisions

Most projects often involve irreversible decisions. But irreversible decisions are a particularly important feature of many projects. For example, once a natural area has been developed it is impossible for it to be undeveloped. Once a pollutant has been emitted it is impossible for that decision to be reversed and clean-up might be prohibitively costly. In some instances there is no sharp distinction between reversible and irreversible decisions but to reverse a decision instead involves significant cost.

It has been suggested that cost benefit analysis is biased against the environment because the technique incorrectly values irreversible decisions. In a classic paper Arrow and Fisher (1974) argue that the problem lies in the application of cost benefit analysis rather than the technique itself. And to be perfectly clear there is no problem per se with projects environmental or otherwise having outcomes that are irreversible.

We have already noted that irreversible decisions are an issue only when there is uncertainty. This uncertainty must moreover be resolved at some point. Without either of these there is no cause ever to regret an irreversible decision. Although guidance does not deal explicitly with the question of how to appraise projects involving irreversible change it does advise analysts to consider amongst other things whether a project can be postponed. And this turns out to be the key to appraising correctly projects involving decisions which are irreversible.

Projects involving irreversible decisions are in the first instance best approached using a tree diagram. This illustrates the decisions available to the policymaker in each time period conditional on information available and any decisions made earlier. These decisions include irreversible ones and the analysis will obviously involve multiple time periods. Each decision results in an uncertain outcome.

The immediate task of the analyst is to calculate the optimal decision in the first time period. For example, consider a project to develop a natural area. The decision to implement the project (develop) involves irreversible change which might be regretted. The alternative of never implementing the project (preservation) avoids any irreversible change but might also be regretted. One thing however is quite clear. The choice is not between implementing the project now and never implementing the project. There is a third option: to postpone the project. And if postponing the project allows for the resolution of uncertainty over the true state of the world then this may be the best course of action. Note however that postponing the decision to develop would only ever make sense if there was a possibility that the value of preservation might be higher than the value of development.

The simplicity of this example belies the fact that in many real world applications the decision to preserve or develop is not a binary choice. In many cases information becomes available only as a result of some level of development. At a minimum guidance should encourage a mode of thought that sees the value in postponing decisions and in building flexibility into projects.

9.4 Recommended changes to guidance

- When a project is intended to reduce the risk of significant damage a proportion of which cannot be insured it should include option values

- Guidance should include a list of circumstances under which option values are likely to deviate substantially from expected damages
- Analysts should consider the value of perfect or improved information when they appraise projects whose outcome is subject to uncertainty
- Projects involving irreversible decisions, uncertainty and learning should be appraised using a tree diagram
- Guidance should encourage a mode of thought that sees the value in postponing decisions and in building flexibility into projects

10 Dealing with Market and Non-Market Interactions and Feedbacks

Invariably the first step in a cost benefit analysis is to identify and then quantify the impacts of a project or policy on consumers and producers in the economy. In a *partial equilibrium analysis*, the analyst focuses on those consumers and producers that experience the immediate impact of the project allowing only for changes that might play out in those parts of the economy or environment immediately impacted by the intervention. In effect, those immediately impacted parts are considered in isolation with everything else assumed to remain constant.

In reality, of course, those initial impacts ripple out across the economy through a number of pathways. Economists have a long tradition of examining one of those pathways: that which arises through the interconnectedness of markets. But interactions can also occur through changes in non-market behaviours and, most pertinently for this report, through the interconnectedness of environmental systems. Indeed, an area of intense and on-going research is that of *integrated assessment* in which models of economic behaviour are explicitly linked with models of environmental systems so as to explore these interactions (Harfoot et al., 2014).

Understanding how these multiple interactions play out is complicated by the fact that they can potentially feedback inducing further changes in the economic and environmental sectors originally impacted by the project. Rather than a simple linear sequence of impacts and outcomes stepping out from the original intervention, these feedbacks require analysts to solve for the new equilibrium of the entire system. Indeed, a *general equilibrium analysis* of a project would look to identify the suite of welfare effects that arise in the move from the equilibrium before the intervention to the equilibrium established after the project's implementation.

This section reviews the guidance provided to analysts on the use of integrated assessment models and general equilibrium analysis for the purposes of evaluating environmental projects. It goes on to provide a brief review of developments in methods and approaches used to perform those analyses before providing some preliminary suggestions as to when those methods might make important contributions to project appraisal. The section finishes with recommendations regarding changes to the Green Book and its supplementary guidance.

10.1 Green book and supplementary guidance

The Green Book is surprisingly reticent with regards to general equilibrium analysis. Paragraph 5.25 of the Green Book (p. 21) provides perhaps the clearest steer to analysts that they should consider more than just immediate impacts; "In principle, appraisals should take account of all benefits to the UK. This means that as well as taking into account the direct effects of interventions, the wider effects on other areas of the economy should also be considered." However, the guidance fails to explain the difference between partial and general equilibrium analysis. And, more importantly, no advice is forthcoming regarding when a general equilibrium analysis may be important, nor on the methods by which such an analysis might be undertaken. It is our opinion that some advice in these matters would be a useful addition to the Green Book, not only in the context of guidance for the appraisal of environmental projects but also for the appraisal of projects more generally.

In a similar vein, the supplementary guidance for environmental projects makes no explicit (or, for that matter, implicit) mention of integrated assessment modelling. In *An Introductory Guide to Valuing Ecosystem Services* analysts are introduced to an assessment method described as a "simplified impact pathway". The impact pathway encourages analysts to first identify the impacts a project has on ecosystems then quantify changes in ecosystem services before estimating the economic value of those changes. The document acknowledges that "Integrated working with policy, science and economics disciplines will be essential in implementing this approach in practice" (para 3.6, p. 22). Later, analysts are also warned of "the complexities of being able to fully account for all changes to ecosystems and services in a policy appraisal" and reminded of the "need to clearly identify all the linkages over the impact pathway" (para 3.21, p.26).

It is our opinion that the impact pathway approach is an appropriate simplification for the level of expertise at which the guidance appears to be directed. At the same time, we believe that analysts would also benefit from access to information that outlined the range of more sophisticated tools, particularly *integrated assessment models* that have been developed by economists and natural scientists to evaluate environmental impacts. In particular, that information should explain the range of application of such models, their capabilities and under what circumstances such tools should and should not be considered for use in policy appraisal.

10.2 Modelling interactions and feedbacks for project appraisal

In ignoring interactions and feedbacks, partial equilibrium analysis makes the appraisal of projects considerably easier. In essence, one can deconstruct the appraisal problem into a series of independent welfare change calculations. Each of the various immediate impacts of the intervention, be those costs or benefit flows, can be addressed in splendid isolation.

When interactions are taken into consideration, things become considerably more complicated.[37] In particular, the analyst has to carefully describe the way in which the immediate impacts of the project link to wider economic and environmental systems. In practice, that translates into defining those relationships in the form of one or more mathematical functions. Those mathematical functions encapsulate the analyst's best understanding of how changes in one part of the system impact on the functioning of other parts of the system; for example, how changing prices in one market, impact on demands for other commodities. The more interactions are taken into account the more complex the analysis becomes such that invariably such analyses are undertaken using custom-built computer models, often in the form of *computable general equilibrium (CGE) models*.

If interactions also include feedback loops then the level of complexity increases once again. To model feedback loops requires the notion of an equilibrium in which adjustments in the system ensure that mutual interactions achieve a steady state; for example, interacting markets are brought into equilibrium through the adjustment of prices. In this case, the analyst's model of economic and environmental systems not only has to accurately describe interactions between different parts of the system, but must also be capable of solving for a steady state of that system. Indeed, one of the first tasks in creating a model of this type is to ensure that the model accurately predicts the present state of economic and environmental systems as a steady state.

[37] There is also the propensity for different projects to interact with one another.

Clearly, accounting for interactions and feedbacks in project appraisal is heavily reliant on the development of coherent computer-based models of an inter-linked economy and, in the case of environmental projects, its interactions with the environment. Of course, a very large number of different models of this type have been developed, each dealing with a different appraisal problem using some particular modelling approach. With regards to our central focus on interactions in economic and environmental systems, however, we can distinguish between models according to three critical features; [38]

- *Modes of interaction*: whether a model allows interactions through market behaviour, non-market behaviour, through environmental systems or through some combination of those different conduits.
- *Spatial Disaggregation*: whether the model ignores the spatial dimension or attempts to capture the consequences of a spatially-defined project through proximity-mediated interactions across multiple heterogeneous locations.
- *Unidirectional causality or feedback loops*: whether the intervention outcomes can be calculated from a single pass through the model from intervention to consequences or whether the model first has to be solved for a new equilibrium in order to calculate outcomes as contrasts with the pre-intervention equilibrium.

Based on differences in those dimensions, we identify and briefly discuss three broad (and overlapping) categories of model that have seen application in project appraisal.

10.3 Standard General Equilibrium Models

When economists talk about general equilibrium modelling they are usually referring to an approach which acknowledges the linkages between different markets. Policies or projects that impact on prices in one market will almost inevitably result in price changes in other related markets. General equilibrium models capture these market interactions, solving for the price vector which, after the intervention, clears markets and brings the economy back to a steady state

The difference between a general and a partial equilibrium assessment is not that the former looks at many markets and the latter only one. It could be that a partial equilibrium analysis looks at many markets each in turn whilst systematically ignoring linkages between them. Nor does the scale of the modelling endeavour define a general equilibrium; what constitutes an appropriate spatial or temporal scale or the degree of aggregation of goods and services in the analysis is a separate issue. What distinguishes general equilibrium analysis from partial equilibrium analysis is that the former explicitly recognises linkages and feedbacks between markets.

To fix ideas, imagine a policy introducing a green tax on an industry emitting a harmful pollutant. The tax will drive up firms' costs encouraging them to adopt less-polluting production technologies. Accordingly, the immediate impacts of the tax policy are two-fold. First, consumers will benefit from

[38] Of course models differ in many other aspects for example whether they are linear or non-linear, whether they allow for uncertainty and stochasticity and whether they capture adjustment dynamics, but those dimensions of difference are less important with regard to the connectedness of economic and environmental systems which forms the focus of our discussion.

reduced levels of pollution. Second, increasing production costs will shift supply curves establishing new and higher equilibrium prices for the industry's products. A partial equilibrium analysis would take the welfare impacts of the project as resulting solely from the air quality improvements and these price changes. In contrast, a general equilibrium analysis would recognise that changes in the prices of commodities from the polluting industry may have important repercussions on the demand for other commodities or factors. Prices in those other markets will adjust, potentially impacting on yet other markets and feeding back to impact on demand for commodities from the polluting industry. Eventually, a new set of market prices would arise that would bring the economy back into general equilibrium. Accordingly, a more comprehensive assessment of the project would attempt to identify the welfare impacts of these *general equilibrium* responses.

General equilibrium analysis of this form has been a mainstay of applied economics endeavour for over forty years. Such analyses are generally carried out through the use computable general equilibrium (CGE) models (Bergman, 2005). A CGE model describes numerically how the economy behaves in a manner consistent with assumptions of economic theory. For example, at the core of a CGE are a set of mathematical functions that describe demand and supply functions for the different goods, services and factors of production in the economy. The CGE imposes economic theory by assuming that markets in those different items are cleared by a price that is established by the intersection of aggregate supply and demand. CGEs may go beyond simply modelling the interaction of households and firms in markets, frequently also allowing for a government sector and for trade. CGEs differ in scale from those that model the global economy down to those that model regional economies. Some CGEs are multi-regional. Likewise CGEs will differ in sectoral focus providing, for example, a disaggregated representation of a particular part of the economy while ignoring other sectors or treating them in a highly aggregated fashion.

In project appraisal, CGEs of this type are important tools with which to examine interventions that are likely to have large and far-reaching general equilibrium consequences. For many environmental projects such considerations may not be of paramount importance. Standard CGEs have, however, found widespread application in evaluating the general equilibrium economic costs of policies to abate pollution: most prominently acid rain and greenhouse gas pollution (see, for example, Turner and Hanley, 2011). In both these cases, policies under consideration demand significant emission reductions in order to mitigate environmental damages. Likewise, a major source of emissions is the production of energy: a sector with a ubiquitous presence in the economy.

Notice that within CGE models of this type, the environment is treated in a very basic manner linkage between the environment and the economy is assumed to be one-way. The analysis of a pollution tax policy, for example, would simply use the CGE to compute the general equilibrium repercussions of that tax in the economy. Levels of output in that new equilibrium could subsequently be used to calculate pollution emissions after the intervention. It is not the case that the changing levels of pollution themselves have any impact on the workings of the economic system.

10.4 CGE models: When might they be needed in environmental project appraisal?

Clearly, there will be a case for using a CGE model if a proposed project or policy is likely to have significant impacts across a variety of sectors of the economy. For example, as we have seen there is a good case for appraising policies that propose significant cuts in emissions of greenhouse gases with the help of a CGE. Likewise, in economies other than the UK which are highly dependent on natural resources like forests, fisheries or agricultural land, changes in the natural resource management regime may have economy-wide effects, and appropriately designed CGE models may be needed to elucidate and quantify these effects.

We believe that a general equilibrium modelling approach is only likely to be justifiable when the following circumstances arise:

- A partial equilibrium analysis indicates that the welfare impact of the proposed project or policy is likely to be extremely large
- The changes that are being considered directly impact numerous markets
- The changes being considered are non-marginal in nature

Although these circumstances might suggest that a general equilibrium approach to modelling is required this does not necessarily imply a substantial effort required to analyse the project. It might be that a general equilibrium model already exists that is suitable or can be adapted, or that a general equilibrium model should be created but it does not need to be especially detailed in order to address the perceived deficiencies of a partial equilibrium modelling approach.

In undertaking CGE modelling, it should be noted that general equilibrium analyses are heavily dependent on the theoretical and mathematical assumptions upon which the model is constructed. In addition, key parameters of the CGE, such as those describing supply and demand for commodities, may be derived from only limited data. As a result, the findings of CGE analyses may often be called into question. Also, since CGE analyses simply calculate the new equilibrium of the system they reveal very little regarding how the economy will transition from the current equilibrium to the new steady state or how long that transition might take. All these issues may be problematic for policymakers who seek transparency in the appraisal process.

Fortunately, many environmental projects are likely to have relatively localized impacts as, for example, with projects creating new green space or reducing noise pollution in an urban area. Likewise, the impact of many environmental projects are often marginal in nature or confined to relatively specific sectors of the economy as, for example, with projects that encourage farmers to create wildlife habitat on their land. While those policies may be locally significant or constitute major changes for some firms and households, the repercussions for the rest of the economy are likely to be minimal.

Even for non-marginal projects, partial equilibrium analysis may be preferred on the grounds of simplicity and cost. Partial equilibrium analysis can still provide estimates of the welfare impacts of such projects, just the larger the general equilibrium response the project precipitates, the more likely those estimates are to be inaccurate – precisely how inaccurate is impossible to say.

As a final aside, we note that the Green Book provides analysts with no guidance as to how to undertake partial equilibrium analyses of non-marginal projects. Analysts are informed that “costs and benefits should normally be based on market prices” (para 5.11, p.19), but no guidance is forthcoming regarding how to proceed if the project is of sufficient magnitude to precipitate changes in those market prices.

10.5 Spatial General Equilibrium Models – Equilibrium Sorting Models

Another form of general equilibrium modelling deals with a somewhat different set of market interactions. Rather than analysing interactions across markets for multiple different commodities, this approach focuses on interactions across multiple different markets in the same commodity. In the vast majority of applications that commodity is housing (or land) where, across a heterogeneous landscape, local differences in the supply and demand for properties result in spatially-discrete neighbourhood property markets.

In contrast to CGEs, models of this nature tend to be highly disaggregate. The population of households in the region are taken to be independent decision-makers each characterised by a particular income and a particular set of preferences. Likewise, the spatial landscape is divided up into a multitude of neighbourhoods each with different qualities (for example, amount of green space, proximity to a good school, transport connections etc.). Given the prices of properties in the different neighbourhood property markets, the model's equations describe each household's choice of residential location. An equilibrium in these interacting property markets is assumed to be a set of prices that matches the supply of property in each neighbourhood with the demand for property in that neighbourhood. A solution to the model, therefore, describes both that set of neighbourhood property prices as well as a sorting of the heterogeneous households across neighbourhoods. Indeed, as a result of predicting this sorting behaviour this form of model is often described as an *equilibrium sorting model* (ESM).

While ESMs are a relatively recent addition to the economist's toolkit, they have a potentially important role to play in the high-resolution appraisal of environmental projects (Kuminoff et al., 2013). In particular, many environmental projects deliver changes in environmental quality at some particular geographical location. Imagine, for example, a project that establishes a new urban wildlife reserve by reclaiming an abandoned and contaminated industrial site. A partial equilibrium analysis would measure the environmental benefits of that project as being the welfare increases enjoyed by the current residents of that location. Unfortunately, that analysis ignores the fact that location-specific environmental quality is a commodity that is bought and sold in the property market. Improving environmental quality will push up local property prices encouraging some residents to move out of the neighbourhood and new households to move in. Of course, those movements change the conditions of supply and demand for property in other neighbourhoods. Indeed, after a period of adjustment the property market should reach a new equilibrium characterised by a changed set of market-clearing prices across neighbourhoods and changes in the composition of households living in those different neighbourhoods. Accordingly, the welfare impacts of a localised project can have widespread repercussions, and perhaps the only way to adequately appraise those general equilibrium outcomes is through the use of an ESM.

10.6 ESMs: When might they be needed in environmental project appraisal?

Many environmental projects have significant localised impacts. Consider the development of a bypass that directs traffic away from the middle of a town, or a project looking to construct a new incineration plant in a particular location, or an investment that creates new recreational green space in an urban neighbourhood. There is plentiful evidence to support the contention that changes of environmental quality of this type have consequences for property prices and that households re-sort themselves across the urban space as a result. Consequently, ESMs may have broader applicability to the appraisal of environmental projects than CGEs.

The arguments against using ESMs are similar to those presented for CGEs and these derive from concerns regarding the strong dependence of ESMs on mathematical and theoretical assumptions, the level of robustness of the model parameters and uneasiness with regards to the transparency of the appraisal process. Moreover, while practitioners are increasingly positive regarding their potential role in policy evaluation (see Kuminoff et al., 2013), ESMs are still very much at the cutting edge of academic research and have a limited track record in terms of their application to real world policy appraisal.

Given those reservations, we are of the opinion that ESMs are currently unsuitable for widespread application in project appraisal. However, under the following circumstances we contend that the construction of exploratory ESMs may be justified;

- When the project results in a non-marginal change in environmental quality in a localised region
- When a substantial local population is impacted by the project
- When a major justification of the project is to deliver welfare improvements for the local population, improvements that may be dissipated if the project precipitates substantial adjustments in property markets.

10.7 Integrated Assessment Models

Although the appraisal of environmental projects is an interdisciplinary endeavour many such exercises adopt an inherently single disciplinary perspective: whilst information is shared between different models or disciplines it is done so in a manner which does not guarantee consistency. Integrated assessment modelling by contrast combines information from different disciplines in a coherent manner. That integration allows for insights not separately available from each discipline in isolation.

To understand better the capabilities of IAMs imagine, for example, a policy which restricts agricultural pesticide use because of its damaging impacts on local wildlife. A partial analysis would appraise the welfare impacts of that policy to consist of changes in profits from agriculture once farmers have adapted to the new restrictions, as well as the benefits realised by people in general from an increased abundance of wildlife. Of course, reducing agricultural pesticide applications will also reduce the export of pesticides from farm land into water courses and aquifers potentially benefiting downstream economic uses of water such as abstraction for public water supply. An IAM would allow such linkages to be modelled and the wider impacts of the project appraised. In this case, an IAM would need to integrate economic models of farming practices with environmental models of pesticide export and transport through hydrological systems with a further economic model of raw water processing costs in the public water supply industry.

The pesticide example represents a relatively simple form of IAM in which the linkages between economic and environmental models are unidirectional: in other words, outcomes of one model become inputs of a subsequent model such that the impacts of an intervention can be evaluated by stepping out from one model to the next without feedbacks. Other environment-economy interactions may not be quite so straightforward. As an example, consider a policy seeking to limit fishing quotas in the Alaskan fishing industry in order to restore populations of an endangered species of sea lion.[39] Sea lions prey on fish and in turn are preyed on by killer whales. Indeed, the marine ecosystem can be described by a general equilibrium relationship in which populations adjust as a result of predator-prey interactions. The marine ecosystem also interacts with the economic system providing fish for the fishing sector while supporting an ecotourism industry specialising in viewing sea lions and killer whales. Again those two major Alaskan industries interact with both labour and capital able to migrate between fishing and ecotourism. Clearly, a policy that limits fishing catch has ramifications that can emanate through the economy impacting on the relative profitability of fishing and ecotourism, through the environment by disturbing the balances between predator and prey populations, and back to the economy by increasing the populations of sea lions and killer whales and raising the productivity of ecotourism. An IAM for this policy requires the coupling of economic and environmental models and the solution of that integrated system for a new economic and ecological equilibrium.

IAMs are potentially important tools for appraising interventions that have significant or widespread implications for environmental systems. Like CGEs, IAMs differ radically in scale, aggregation and complexity. Some of the most basic of IAMs, those referred to by economists as bioeconomic models of fishery management and of forestry management, reduce to a few straightforward equations in a handful of economic and ecological parameters. A more complex IAM is reported in the recent UK National Ecosystem Assessment – Follow On project. That IAM provides a detailed spatial model in which the impacts of land use policy changes can be appraised through their impacts across a range of economic (agriculture, forestry and recreation) and environmental (water quality, greenhouse gas emissions, bird species diversity) outcomes across Great Britain (Bateman et al., 2014). Some of the largest IAMs are those that explore the economic and environmental impacts of climate change at the global scale (van Vuuren et al., 2012).

IAMs adopting a higher spatial resolution and multiple time periods provide greater realism. But demonstrating ex ante that the results are significantly better than those that would emerge from a simpler model is impossible. Particularly with the bigger models it can be difficult to provide an intuitive explanation of the results that emerge. IAMs have tended to handle issues of uncertainty in rather crude ways, but more sophisticated approaches are increasingly evident in the literature (Golub et al., 2014)..

An important distinction arises between IAMs in which interventions are user-specified and what might be termed policy optimisation models. It is easy to illustrate the difference between the two in bio-economic models of the fishery. With one sort of IAM one may investigate the effect of a user-specified limit on fishing but with an IAM capable of policy optimisation one may enquire about optimal fishing limits.

[39] This example is describes the dynamic economic and ecological general equilibrium model of Finnoff and Tschirhart (2008).

10.8 IAMs: When might they be needed in environmental project appraisal?

The majority of environmental projects do not require the construction of an IAM. They can be satisfactorily addressed by means of a single disciplinary approach in which information passes from one disciplinary analysis to another along with the possibility of inconsistency. But whatever inconsistency arises is not thought to be sufficient to imply that the results which emerge are unreliable.

There may however be occasions when integrated assessment modelling has an important role to play in the appraisal of environmental projects. This is most obviously the case when there is a not insignificant feedback effect between the economy and the environment. In such instances environmental project appraisal should consider utilising an IAM notwithstanding the cost of constructing such a model (assuming one is not already available) which will often be significant in terms of both time and resources.

There are a number of other reasons for wishing to use an IAM in the process of appraising an environmental project both of which are specific to policy optimisation IAMs.

The solution to an optimising model provides not only an estimate of the maximised value of the objective function but also the value of the Lagrange multipliers associated with each of the model constraints. Because of the existence of theorems associating the solution of a maximisation problem with that provided by a decentralised system these Lagrange multiplier variables often have interesting economic interpretations.

More specifically in those models whose objective is to maximise economic benefits or minimise economic costs the Lagrange multipliers represent the monetary value of a marginal relaxation of each constraint. Some of these constraints may be associated with the flow of environmental goods and services or the stock of natural capital. Accordingly these Lagrange multiplier values correspond to the prices that would be charged if environmental goods and services or natural capital could be sold in competitive markets. These values are appropriate for use in cost benefit analysis. Guidance should mention policy optimising IAMs as a means of valuing environmental goods and services or stocks of natural capital.

The other way in which policy optimising IAMs can help in the appraisal of environmental projects is when the optimal scale of the project is otherwise hard to determine.

Some environmental projects have the characteristic of being all or nothing projects. There is essentially no choice about the scale of these projects. The only issue is whether to implement the project or not. To evaluate such a project requires only that the analyst calculate the benefit-cost ratio of the project. Only slightly more complicated are those projects that because of their nature possess a number of discrete variants.

Some projects however can be the subject of infinite variation which might result in them being more or less preferred. An obvious example is a project that can be varied continuously in terms of its scale. Determining the optimal scale of a project poses more of a challenge.

The guidance contained in the Green Book advises that the analyst should consider altering the specification of the project in order to see whether so doing might improve the benefit cost ratio.

Normally this requirement is held to be satisfied if a small number of project specifications is analysed. There remains the problem that the "best" project so selected could actually be quite inferior to the best project in the universe of possible project specifications.

There are however far more complicated projects in which the number of project attributes is large and interact with one another. Common project attributes include the scale of the project and the time at when the project is to be implemented. Both of these attributes take values that vary continuously and they could even be combined with project attributes which take discrete or binary values. If one is considering a regulation then the stringency of the regulation and the timing of its implementation are both subject to infinite variation.

One strategy for locating the optimal policy is to make the task of identifying the best possible project part of an optimisation problem. Whether this is feasible depends on whether the relationships between project attributes and the benefit cost ratio of the project can be described in mathematical terms which make it amenable to solution via an IAM. Obviously the search for the optimal strategy is hampered by discontinuities in the mathematical functions.

A well-known example of the a policy optimising IAM model is the DICE model of climate change in which the optimal amount of GHG abatement over time is calculated along with the optimal amount of land scheduled for reforestation. Calculating the optimal cutback in GHG emissions in every time periods along with the optimal amount of reforestation would clearly be impossible without a computer model. In this IAM moreover the value of an additional tonne of GHGs emerges from the model as part of the solution. These values for GHG emissions have been widely used in cost benefit analysis of environmental projects which result in a change in the quantity of GHG emissions.

10.9 Recommended changes to guidance

- Guidance should explain the difference between partial and general equilibrium analysis.
- Guidance should provide brief descriptions of the key methods of general equilibrium analysis, particularly CGE models and ESMs indicating their strengths and weaknesses, their areas of application and provide advice on the circumstances under which each might be required in project appraisal.
- Guidance should briefly describe IAMs explaining the range of application of such models, their capabilities and under what circumstances such tools should and should not be considered for use in policy appraisal.

11 The distributional impacts of environmental projects

If aggregate willingness to pay for a project exceeds the costs then that project is deemed profitable under cost benefit analysis. Strictly speaking however, this does not mean that the project is welfare enhancing; cost benefit analysis fails to take into account the distribution of the costs and benefits of the project. Accordingly it is frequently argued that cost benefit analysis should be supplemented by distributional analysis.

For environmental projects this distributional analysis might take several different forms. One form of distributional analysis is concerned with the fact that costs and benefits are measured in monetary terms. The same monetary change might have different welfare impacts because the marginal utility of money varies between rich and poor. The standard way of addressing this concern is through the use of distributional weights. The proper use of distributional weights is already described in Annex 5 of core guidance. Views nevertheless differ on the appropriateness distributional weights and some economists believe that distributional concerns are better handled through other means.

Whilst there is no conceptual difficulty in employing distributional weights in cost benefit of environmental projects the same practical challenges remain: only infrequently is it the case that the incomes of those affected by the project can be known with sufficient accuracy as to allow meaningful adjustments using distributional weights. And in any case, not every environmental project raises significant distributional concerns from the outset. Furthermore, because the basis for distributional weights is anyway contested cost benefit analyses of environmental projects including distributional weights should only ever accompany rather than replace comparison of aggregate costs and benefits.

We do not comment further on this sort of distributional analysis because we see little prospect for its widespread incorporation into the cost benefit analysis of environmental projects. In addition there is ample guidance on this matter.

The second form of distributional analysis relevant to environmental projects focuses on the distribution of environmental outcomes as opposed to the distributional outcomes of the project. We see much better prospects for implementing this type of analysis. Even here two different sorts of analyses can be undertaken.

In the first sort of distributional analysis the issue is whether environmental outcomes are improved such that for any particular outcome at least as many households enjoy an outcome at least as good as they did prior to the implementation of the environmental project. The second type of distributional analysis focuses not on whether environmental outcomes have unambiguously improved if evaluated at any particular environmental outcome but whether outcomes are more equal than previously. This type of analysis derives from the environmental justice literature (see e.g. Bowen 2002 for a review). It must be borne in mind that a project can result in improved environmental outcomes in the first sort of analysis and yet result in greater inequality. And it must be understood that both of these analyses are limited in the sense that they consider only the environmental outcome.

Any analysis of the distributional impacts of an environmental project requires information on both the baseline distribution of environmental amenities as well as the distribution if the project is implemented. This of course presupposes the ability to model the distributional outcomes. But predicting the geographical dispersion of air pollution for example is difficult and requires significant time and resources. Even establishing the baseline may in some instances be difficult if there is currently only limited monitoring of particular environmental pollutants.

If they are mentioned at all distributional concerns are typically addressed using purely descriptive techniques and visual methods. For example, an analysis might merely tabulate the changes in environmental outcomes arising from the implementation of a project experienced in particular geographical areas. This information might nevertheless be difficult for the policy maker to digest especially if there are many geographical areas. Perhaps the most obvious tool to illustrate the geographical pattern of changes in environmental outcomes is a map indicating the changes in particular locations. But here too such displays become less helpful as the number of geographical areas grows and if a mixed picture emerges.

11.1 The empirical cumulative distribution of environmental outcomes

The single most informative distributional analysis involves constructing the empirical cumulative distribution function for the environmental outcome of interest. The empirical cumulative distribution obviously contains much more information than either the first or second moments of the distribution. It is easiest to explain the technique using the level of pollution as an example of an environmental outcome.

Constructing the empirical distribution function involves ranking all households according to the level of pollution to which they are subjected. The next step is to plot the proportion of individuals who enjoy a level of pollution better than each level of pollution. For example, the least polluted 10 percent of the population enjoy a level of pollution that is less than or equal to 5 micrograms per cubic metre whereas the least polluted 50 percent of the population might enjoy a level of pollution which is less than or equal to 10 micrograms per cubic metre.

Although the empirical cumulative distribution function has been presented in terms of pollution the idea could be extended to other environmental outcomes, including good and bad outcomes. Natural England for example, provides an analysis of the proportion of individuals having access to green space of a certain dimensions within a particular distance of where they live.

Continuing with the example of pollution now assume that the same analysis is undertaken using data corresponding to the counterfactual and that the resulting empirical cumulative distribution function is plotted on the same diagram. Suppose too that the empirical cumulative distribution from the counterfactual lies entirely below and to the right of the distribution describing the baseline. The implication is that, whatever level of pollution one cares to mention, a greater proportion of the population would, under the counterfactual, enjoy a level of pollution at least as good as under the baseline. Note carefully however that this does not imply that everyone experiences an improvement in pollution following implementation of the project – some people might lose.

Consider now a situation in which the empirical cumulative distribution functions corresponding to the baseline and the counterfactual cross. What this implies is that whether there has been an improvement depends on the level of pollution chosen as the basis for comparison. Overall it is difficult to say whether pollution has improved especially if there is no threshold beneath which concentrations are considered harmless. For an example of the application of the technique of stochastic dominance to environmental quality see Millimet and List (2003).

11.2 Analysis of inequality

The preceding section described a technique predominantly used to rank distributions of income and known as stochastic dominance. This technique suffers from two limitations. First, it cannot be used to rank distributions of environmental outcomes that cross. Second, it does not meet the concerns of policymakers whose interest goes beyond the question of whether more people might enjoy a better environmental outcome than before. Some policymakers are rather concerned that environmental outcomes should be more equal as a consequence of the implementation of the project.

Concern about changes in the equality of environmental outcomes associated with implementation of environmental projects parallels concerns about changes in the equality of outcomes associated with implementation of other sorts of projects. There is for example interest in changes in the equality of health outcomes associated with health projects to the extent that, if a health project were to generate improved health outcomes for everyone but simultaneously worsen the equality of those outcomes, it would almost certainly be viewed as contentious.

There exists a body of research which examines the distribution of environmental outcomes. This research sometimes uncovers marked differences in the geographical distribution of environmental outcomes and in the distribution of environmental outcomes according to income. Environmental projects may exacerbate or ameliorate such inequalities and even give rise to new inequalities where none previously existed. Despite this current guidance has little to say on providing to policymakers information on changes in the equality of outcomes associated with environmental projects.

In order to determine whether the implementation of an environmental project improves or worsens equality of outcome the analyst must rank distributions of environmental outcomes in terms of equality. Popular means of ranking distributions in terms of equality include the Lorenz curve and the concentration curve. It is once more easiest to describe the different techniques in the context of the level of pollution.

In the Lorenz curve the horizontal axis indicates percentiles of the population ranked by current pollution levels to which they are subjected. The vertical axis represents the cumulative percentage of pollution. On this graph a diagonal line would indicate perfect equality i.e. the lowest 10 percent of the population experience 10 percent of the total pollution whereas the lowest 50 percent of the population experience 50 percent of the total pollution and so on. The Lorenz curve however, typically lies below the diagonal indicating that the lowest 10 percent of the population will experience less that 10 percent of the pollution. The further away is the Lorenz curve from the diagonal the less equal the distribution of pollution.

If the Lorenz curve for the baseline and the Lorenz curve corresponding to the implementation of the project are superimposed onto the same diagram it may be observed that one curve is everywhere closer to the diagonal than the other implying a more equal distribution of pollution. A more common occurrence however, is that the two curves cross meaning that it is impossible to say whether one distribution is more equal than the other. A further limitation of the analysis is that it provides only an ordinal ranking: although it is possible to say that one distribution is more equal it is not possible to say by how much.

The main shortcoming of the Lorenz curve however, is that it is not possible to analyse distributional outcomes across groups. In particular, it is not possible to determine whether distributional outcomes are more equally distributed across households with different incomes. For this one requires concentration curves.

For concentration curves the vertical axis is once more the cumulative percentage of pollution but the horizontal axis is now the cumulative percentage of households ranked by household income. A perfectly equal distribution of pollution across household income would once again be represented by the diagonal line. Unlike with Lorenz curves however, the concentration curve can now cross the diagonal and even lie above it. Such would indeed be the case if poorer households experienced a greater percentage of pollution.

Concentration curves suffer from the same deficiencies as Lorenz curves. They cannot unambiguously rank the distribution of outcomes if the curves cross and any ranking is ordinal in nature. The technique is also unable to rank changes in the distribution of pollution between groups that have no inherent ordering.

It is because neither the Lorenz curve nor the concentration curve can provide a complete ranking of distributions that there is interest in the use of inequality indices. These indices provide a complete ranking of distributions by converting the distribution of pollution into a single number.

The most widely used index of inequality is the Gini coefficient. The Gini coefficient represents that fraction of the area that lies below the diagonal but above the Lorenz curve. A Gini coefficient equal to unity therefore represents perfect inequality whereas a Gini coefficient equal to zero represents perfect equality. One of the first uses of the Gini coefficient to measure health outcomes was the evolution over time in the distribution of age at the time of death in Great Britain.

The concentration index is similar to the Gini coefficient in that it represents the fraction of the area between the concentration curve and the diagonal line. The concentration index however will range from minus one to plus one. When the concentration index takes the value minus one it means that all the pollution is borne by the poorest household and when the value is plus one all the pollution is borne by the richest household.

DEFRA (2006) provides an example of the use of Lorenz and concentration curves applied to the distribution of pollution.

11.3 Recommended changes to guidance

- Either cost benefit analysis of environmental projects should be supplemented by distributional analysis or there should be some explanation of why this has not been done.

- Although it will commonly be very difficult to attach distributional weights to net benefits where appropriate supplementary analysis should involve analysing the empirical cumulative distribution of environmental outcomes for both baseline and counterfactual.
- Analysis should also consider the equality of environmental outcomes.

12 Conclusions

This report reviews current guidance on the cost benefit analysis of environmental projects. Guidance is presently divided between core and supplementary guidance with the latter written long after the former. Important developments regarding the way that people conceptualise the economy and the environment have now created a tension between these two documents particularly in terms of the terminology they use.

Any refresh of current guidance should resolve the different roles played by core and supplementary guidance. Revisions to guidance should provide a conceptual framework for understanding the way in which the economy and the environment are connected. Guidance must provide clear definitions of important concepts rather than refer the reader elsewhere.

Our report has paid particular attention to the twin concepts of natural capital and ecosystem services, though we argue that the term of environmental goods and services should be used in preference to the latter; in particular, it is a more inclusive term encompassing not only ecosystem services but also abiotic environmental goods and services and a range of other nonmarket flows arising from human production processes. Guidance should not only embrace these terms but render precise the meaning of each of these terms in a way that makes sense from an economic perspective.

Considerable work remains to be done in developing methods for valuing changes in the stock of natural capital. We have described the key elements that must be calculated in order to determine the net present value to society of holding more natural capital stock but warned that endeavours to calculate such a value are complex and an inherently multi-disciplinary undertaking. We have also illustrated that in some relatively simple cases, the marginal value of natural capital can be calculated with comparative ease provided that stock is being exploited in a way that conforms to assumptions of dynamic optimising behaviour.

It would not be an exaggeration to say that the organising concepts of core and supplementary guidance are respectively the notion of TEV and the classification of ecosystem services into PRCS. Although popular these approaches have limitations and can in some situations result in confusion. Guidance needs to address itself to the known limitations of these techniques.

While current guidance provides some insights into the methods of non-market valuation of environmental goods and services, there is much scope to improve and extend the presentation. For each method, the explanation should be pitched at an appropriate level and the description of each technique must be correct. No important technique should be omitted and if a particular technique has important shortcomings these should be noted. Currently, guidance focuses on the use of valuation techniques to value flows of environmental goods and services that enter household utility functions, but should also address a number of equally important techniques for valuing changes in the flow of environmental goods or services benefits that enter production functions.

Apart from closing the gap that has opened up between the contents of the Green Book and current thinking our analysis has also identified a number of long-standing issues where current Green Book guidance falters. These issues are often related to the existence of uncertainty. There is for example vagueness about the meaning of option values and when expected damage underestimates the benefits of projects. Guidance would also benefit from illustrating better the processes involved in decision-making under uncertainty.

Making decisions about environmental projects frequently involves computer models generally known as integrated assessment models (IAMs). We have categorised the different sorts of models and described their capabilities. We have also described the various situations where such models might be helpful. Three modelling capabilities seem to be of special relevance to the cost benefit analysis of environmental projects and should therefore be mentioned in guidance: the ability of IAMs to model interactions in a consistent manner, the ability of IAMs to optimise policy and to generate shadow prices, and the use of computable general equilibrium models to predict behavioural response.

Many environmental projects present spatial and temporal aspects. Unfortunately current practice surrounding discounting future environmental impacts leaves a lot to be desired and we sense that for some environmental projects this might make a large difference. Furthermore although current guidance acknowledges the importance of geographical location it does not fully alert the reader to the kinds of things made possible through the use of geographical information systems e.g. the calculation of value surfaces driven by the distribution of people across space and the spatial distribution of substitutes and complements. Time and space is an area where guidance needs to catch up with current practice and distinguish good practice from bad.

Time and again concern is expressed over the distributional impacts of environmental projects. Current guidance nonetheless refers to distributional impacts only in the context of non-environmental projects. It is however now possible to examine the distributional impacts of environmental policies and their effect on equality in a way that was hitherto regarded as disproportionately time-consuming.

It is likely that the future holds new challenges to the application of cost benefit analysis to environmental projects. It is to be hoped that these will result in further timely updates to guidance.

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